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Fast Reactor Database 2006 Update

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FOREWORD

Liquid metal cooled fast reactors (LMFRs) have been under development for about 50 years. Ten experimental fast reactors and six prototype and commercial size fast reactor plants have been constructed and operated.

In many cases, the overall experience with LMFRs has been rather good, with the reactors themselves and also the various components showing remarkable performances, well in accordance with the design expectations. The fast reactor system has also been shown to have very attractive safety characteristics, resulting to a large extent from the fact that the fast reactor is a low pressure system with large thermal inertia and negative power and temperature coefficients.

In addition to the LMFRs that have been constructed and operated, more than ten advanced LMFR projects have been developed, and the latest designs are now close to achieving economic competitivity with other reactor types.

In the current world economic climate, the introduction of a new nuclear energy system based on the LMFR may not be considered by utilities as a near future option when compared to other potential power plants. However, there is a strong agreement between experts in the nuclear energy field that, for sustainability reasons, long term development of nuclear power as a part of the world's future energy mix will require the fast reactor technology, and that, given the decline in fast reactor development projects, data retrieval and knowledge preservation efforts in this area are of particular importance.

This publication contains detailed design data and main operational data on experimental, prototype, demonstration, and commercial size LMFRs. Each LMFR plant is characterized by about 500 parameters: physics, thermohydraulics, thermomechanics, by design and technical data, and by relevant sketches. The focus is on practical issues that are useful to engineers, scientists, managers, university students and professors with complete technical information of a total of 37 LMFR plants.

The recurring themes are the selection and summary of the data associated with the choice of coolant, fuel and structural materials, reduction of the steel weight, simplification of the plant design/layout, other important fast reactor design issues, and how to solve these problems.

In the field of fast reactor design and operational data, the last reference document published by the IAEA was the 1996 Fast Reactor Database (IAEA-TECDOC-866). Since its publication, quite a lot has happened: the construction of two new reactors has been launched, and conceptual/design studies were initiated for various fast reactors, e.g. the Japanese JSFR-1500 and the Russian BN-1800 (both cooled by sodium), as well as for a wholly new line of LMFR concepts — modular reactors cooled by sodium and by lead-bismuth alloy, and prototype and demonstration commercial size fast reactors cooled by lead.

The data were produced by the IAEA's Technical Working Group on Fast Reactors (TWG-FR). For many of the TWG-FR Member States there is a significant history of fast reactor development, often extending over a period of 40+ years. The new and updated information on LMFR, which are in operation, under construction or development, has been prepared with contributions from China, India, Japan, Republic of Korea and the Russian Federation. The information contained in IAEA-TECDOC-866, produced by France, Germany, Italy, the UK and the USA, was included in the present report with some modification taking into account last events. The IAEA expresses its appreciation to all those who have participated in the preparation of the data for publication.

The IAEA officers responsible for this publication were A. Rineiskii, A. Stanculescu and Y. Yanev of the Department of Nuclear Energy.

CONTENTS

INTRODUCTION AND OVERVIEW

For almost 40 years, the IAEA has been serving interested Member States as a major fulcrum for fast reactor information exchange and collaborative research and technology development. Since 1967, the keystone of the Agency's activities in this field is the Technical Working Group on Fast Reactors (TWG-FR, previously International Working Group on Fast Reactors, IWG-FR).

Thanks to the TWG-FR activities and to the support of the Agency's INIS and Nuclear Knowledge Management Section, and based on the contributions of the TWG-FR Member States, it was possible to collect and assemble fast reactor design and operational data, as well as various other parameters, boundary conditions, and data related to operational experience, thus establishing a comprehensive overview of fast reactor technology. In particular, it is hoped that this reference document would permit reproducing, to a full or at least partial extent, the effective design approaches for fast reactor systems and components, and thus avoiding the repetition of unsuccessful design approaches.

The fast reactor database (FRDB) summarized in this report is very detailed[1]. It includes operational parameters, physical, hydraulic and thermomechanical characteristics, technological requirements, methods and criteria to ensure safe operation; design data like dimensions, materials information and main design features and performance parameters of reactor cores, components, and various systems, along with sketches and drawings.

Specifically, scientific and technological sections of the FRDB include the following information:

— ***reactor core characteristics, fuel design, and performance and sketches:*** diameter/height; enrichment and fissile isotope content: ^{235}U, ^{239}Pu, total Pu (all isotopes) of inner and outer core zones; volume fractions: fuel, coolant, void (fission gas); intrinsic and smeared density of fuel and blanket pellet; breeding gain: both total, and core regions only; average, maximum linear power and power density (at the beginning and at the end of fuel cycle), neutron flux; residence time for subassemblies: inner core, outer core, radial blanket; coolant velocity (maximum, average) and pressure drop in the core; reactivity coefficients: isothermal temperature, total power, maximum coolant void effect; Doppler for voided and unvoided core; numbers and dimensions of fuel subassemblies and fuel elements (outer diameter, cladding thickness and overall length); cladding and wrapper material, temperature of core and blanket fuel pins; pressure of fission products in fuel and blanket pins; restraint system: free-standing core, passive restraint using contact pads, etc.;

— ***control rods and drive mechanisms*****:** number of rods or devices, their configurations and dimensions: safety (shutdown), regulating, contributing to rapid shutdown, additional, diverse; absorber pins per each system; material of neutron absorber (groups 1 and 2); worth of safety and control rods; total reactivity worth of all rods moving over the whole range; vertical travel and rod-drop time; features of drive mechanism: safety, coarse, fine etc., with relevant sketches;

— ***heat transport system:*** thermal and electric power, coolant temperatures, steam conditions and thermal cycle option, primary circuit configuration: loop, pool; coolant inventory, flow rate in reactor and secondary circuit; number of coolant loops; primary, secondary and steam/water piping: material, diameter/thickness, provision of leak jacket; valving: stop, check, steam generator (SG) isolation etc.;

— ***main components of heat transport system:*** sketches and performance, materials of: reactor vessel, pumps, intermediate heat exchangers (IHX), SG; SG: operating principle and position of leak detection system and its capability of locating a leak, main features of system for

[1] Each LMFR power plant is characterized by about 500 items.

discharge of coolant/water reaction products; coolant purification system: permissible impurity concentration, plugging temperature in the primary circuit, cold traps: design and characteristics; cover gas system for coolant inertisation: method of gas sampling and analysis, clean-up; decay heat removal system: type, capacity, delay before operation in an emergency situation; preheating system: design and characteristics; turbine generators: type, power, speed, minimum condenser pressure etc.;

— ***shielding, containment and safety features:*** neutron and other limits at important locations: reactor vessel, core above and support structures, activity of secondary sodium, shielding materials; secondary containment building: volume, maximum design pressure, seismic acceleration; additional safety measures: double walls, guard vessel, collecting and cooling core debris etc.;

— ***safety and control:*** design, criteria for initiating automatic shutdown, principal shutdown systems, method and parameter of controlling reactor power, plant response designed to cope with seizure or stopping of a primary pump, methods of detection of coolant leaks and locating failed fuel pins;

— ***refueling:*** method and design: used within primary vessel, to store spent fuel, to handle fuel outside primary vessel; cooling method and maximum allowable fuel pin cladding temperature during handling of fuel subassembly: in vessel, outside the primary vessel, method of identifying subassemblies and core components during handling operations;

— ***in-service inspection provisions*****:** ISI of: inner and outer surface of the primary vessel and internal structures, primary and secondary piping, IHX and SG units.

The FRDB is structured according to three reactor categories:

(i) experimental reactors, typically of up to 100 MW(th) built to demonstrate the technology, but often including a steam plant and turbine-generators to allow operation as a small power station;

(ii) demonstration or prototype reactors, in which much of the scaling up required for a commercial station in terms of both overall size and individual components has been incorporated;

(iii) commercial-sized reactors developed as prototypes to demonstrate the system's capability to operate in a utility environment.

The FRDB is arranged in units: records of parameters, characteristics and design features are arranged in columns on paired pages as follows: data on experimental, demonstration or prototype reactors (two units for 24 reactors) and on commercial size fast reactors (one unit for 13 reactors) on the first and the second page, respectively. This database setup makes it possible not only to easily find the required parameter of a certain reactor, but also to compare it with that of the other reactors.

The FRDB includes data on 37 fast reactor plants, their thermal power ranging from 10 to 4000 MW. Thirty-one reactors out of 37 are connected to steam turbine-generators of 12 to 1 800 MW electric power. These reactor designs have been developed during a 50-year period using a variety of design approaches, such as:

— UO_2, PuO_2-UO_2, U-Pu-Zr, U-TRU-Zr, UN, PuN-UN, PuN-UN-MA, UC as a fuel;

— titanium-stabilized cold worked austenitic alloys, low nickel austenitic steel, martensitic and ferritic-martensitic alloys, high-nickel nimonic PE16 alloy as a fuel pin structure material;

— loop and pool principal design concepts of the primary circuit;

— sodium, sodium-potassium, lead and lead-bismuth as coolants;

— electromagnetic, mechanical pumps;

— once-through, forced recirculation, modular design and high self power SG.

The FRDB includes also system related information, e.g., type and sensitivity of systems for SG leak detection, which is required for ensuring safe operation of the main components and of the power plant as a whole:

— safety measures: to limit effect of vessel and piping rupture; to ensure natural convection cooling; collecting and cooling core debris following core full or partial meltdown; sodium leak detection, cover gas system for coolant inertisation;

— main criteria for initiating automatic shutdown and principal shutdown systems;

— methods and main parameters used for controlling reactor power;

— reactor refueling methods and equipment: within the PV; spent fuel storage; fuel handling outside PV; cooling during refueling, removing coolant from subassemblies and core components; identifying subassemblies and core components during handling operations;

— provision for ISI: inner and outer surface of the PV and in-vessel structures, primary and secondary circuit piping and equipment;

— decay heat removal: by natural convection; through the main coolant loops; through special heat removal loops to air (forced flow) and the main coolant loops with coolant flow provided by pony motors; through thermal siphon loops to air (natural convection only); through reactor vessel wall by radiation and convection; data on capacity and delay before operation in an emergency situation;

The FRDB reflects stages that have led to the physical and technological substantiation of fast reactor designs (from the first multi-purpose demonstration plant BN-350 to the EFR commercial power plant project). It comprises the numerous R&D findings that form the basis of fast reactor technology and design, of which the corner stones are:

— liquid metal coolant: technology, thermohydraulics, and sodium compatible materials;

— system of heat removal from reactor to SG and its conversion to electric energy;

— structure materials facilitating high fuel burnup;

— prefabricated thin-walled vessels of pool type reactors of 20 m and larger diameter delivered to the site;

— detectors of water/steam ingress into SG sodium having sensitivity of about 0.1g/s;

— high self power, simple design, single-vessel light SG with effective systems of tube bundle diagnostics and protection against water/steam leaks into sodium;

— plutonium recycling and nuclear waste incineration;

— passive reactor safety systems.

The causes and conditions of general achievements and setbacks in reactor and liquid metal coolant technologies are presented in the FRDB, e.g. those determining breeding characteristics (core geometry, fuel enrichment and fissile isotope content, volume fractions, intrinsic limits and smeared density of fuel and blanket pellet, etc), and the fuel burnup limits (chemical composition, fuel fabrication technology, neutron flux, dimensions, cladding and wrapper material, etc.)

The FRDB summarizes ongoing activities by documenting operational parameters and designs aiming at simplification, increase of reliability and improved economics of SGs (as one of the most important components of the heat transport system). The SG design development is reflected in the FRDB from the prototype fast reactors for which a section and module design approach was adopted, with each SG section consisting of evaporator (ev), superheater (sh), and reheater (rh) modules. Accordingly, the three Phénix SGs include 36 sections and 108 modules, while the three BN-600 SGs have 24 sections and 72 modules. This concept assured minimum operating loss caused by leak incidents. As a rule, repair and maintenance procedures were required for only one module at a time. For instance, in order to restore a failed SG module of the BN-600 reactor, it was not necessary to shut-down the reactor but only to slightly decrease its power and isolate the failed SG section by valves. However, SG modular design is complicated, metal-intensive and in some cases less reliable. The design of sodium-heated SG has been largely changed during the development of fast reactor technology. Studies were aimed at the creation of a reliable, low-cost design, which is easily inspected (diagnosed) during operation (after a SG unit switch-off). Experience gained during development and operation has shown that neither micro modular (BOR-60, Phénix), nor macro modular (BN-600), nor double wall (EBR-II) SG met completely these criteria. Upon experimental confirmation of the long-term resistance of steels (such as mono-metallic modified 9Cr-lMo steel) in sodium, water and steam (including wet steam), a possibility of assurance of once-through process in the tube (water heating, boiling, evaporation, and steam superheating) has appeared. This result, along with sodium replacement with steam in the reheater, has made it possible to use a single-vessel SG, which was first applied to the Super-Phénix reactor, namely: 750 MW power unit having welded coil tubes (10 000 welds) operated reliably. A high self power steam generator of 600 MW with straight long tubes was then designed for the EFR power plant.

It should be emphasized, that although designs and parameters of the early experimental fast reactors showed a wide variability, those of the commercial-sized plants are rather similar. Even with the initiation of a wholly new line of development, such as Pb and Pb-Bi cooled reactor designs, it is interesting to observe that their parameters are close to those of traditional reactors being advocated elsewhere. It is a further proof that the laws of physics and the principles of good engineering inevitably lead to similar optimal solution.

Summing up, the FRDB attempts to document the knowledge in fast reactor design and technology, as well as to preserve and to disseminate it until sustainability and economics criteria will create the necessary condition for large-scale deployment of fast reactors.

1. GENERAL INFORMATION

1.1. Reactors

Experimental Fast Reactors

Plant	Reactors
Rapsodie (France)	-
KNK-II (Germany)	Kompakte Natriumgekuhlte Kernreaktoranlage
FBTR (India)	Fast Breeder Test Reactor
PEC (Italy)	Prova Elementi di Combustibile
JOYO (Japan)	-
DFR (UK)	Dounreay Fast Reactor
BOR-60 (Russian Federation)	Bystrij Opytnyj Reactor (Fast Experimental Reactor)
EBR-II (USA)	Experimental Breeder Reactor II
Fermi (USA)	-
FFTF (USA)	Fast Flux Test Facility
BR-10 (Russian Federation)	Bystrij Reactor (Fast Reactor)
CEFR (China)	China Experimental Fast Reactor

Demonstration or Prototype Fast Reactors

Phénix (France)	-
SNR-300 (Germany)	Schneller Natriumgekühlte Reaktor
PFBR (India)	Prototype Fast Breeder Reactor
MONJU (Japan)	-
PFR (UK)	Prototype Fast Reactor
CRBRP (USA)	Clinch River Breeder Reactor Plant
BN-350 (Kazakhstan)	Bystrie neytrony (Fast neutrons)
BN-600 (Russian Federation)	Bystrie neytrony (Fast neutrons)
ALMR (USA)	Advanced Liquid Metal Reactor
KALIMER-150 (Republic of Korea)	Korean Advanced Liquid MEtal Reactor
SVBR-75/100 (Russian Federation)	Svinetc-Vismuth Bystriy Reactor (Lead-Bismuth Fast Reactor)
BREST-OD-300 (Russian Federation)	Bystriy Reactor Estestvennoy Bezopasnosti (Fast Reactor Natural Safety)

Commercial Size Reactors

Super-Phénix 1 (France)	-
Super-Phénix 2 (France)	-
SNR 2 (Germany)	Schneller Natriumgekuhlte Reaktor
DFBR (Japan)	Demonstration Fast Breeder Reactor
CDFR (UK)	Commercial Demonstration Fast Reactor
BN-1600 (Russian Federation)	Bystrie neytrony (Fast neutrons)
BN-800 (Russian Federation)	Bystrie neytrony (Fast neutrons)
EFR	European Fast Reactor
ALMR (USA)*	Advanced Liquid Metal Reactor
SVBR-75/100 (Russian Federation)**	Svinetc-Vismuth Bystriy Reactor (Lead-Bismuth Fast Reactor)
BN-1800 (Russian Federation)	Bystrie neytrony (Fast neutrons)
BREST-1200 (Russian Federation)	Bystrij Reactor Estestvennoy Bezopasnosti (Fast Reactor Natural Safety)
JSFR-1500 (Japan)	JNC Sodium-cooled Fast Reactor

* the commercial plant consists of 6 units, and have a breeding mission using a heterogeneous core with internal blanket

** the commercial plant consists of 16 units

1. GENERAL INFORMATION (cont.)

1.2. Location, postal address of station

Experimental Fast Reactors

Plant	Location, postal address of station
Rapsodie (France)	CEN Cadarache 13115 St. Paul les Durance
KNK-II (Germany)	KfK, Post Box 3640, D-76021 Karlsruhe
FBTR (India)	Kalpakkam, 603 102
PEC (Italy)	Brasimone
JOYO (Japan)	Oarai, JNC; 4002, Narita, Higashi-Ibaraki; Ibaraki 311-1393
DFR (UK)	Dounreay, Caithness, Scotland KW 14 7TZ
BOR-60 (Russian Federation)	Dimitrovgrad, U1'yanovsk region
EBR-II (USA)	Idaho, ANL; P.O. Box 2528; Idaho Falls, ID 83401
Fermi (USA)	Lagoona Beach, Michigan
FFTF (USA)	Westinghouse Hanford, P.O. Box 1970 Richland, WA 99352
BR-10 (Russian Federation)	Obninsk, Kaluga Region
CEFR (China)	China Institute of Atomic Energy (CIAE), Beijing

Demonstration or Prototype Fast Reactors

Phénix (France)	CEA Centre de Marcoule BP 171 30200 Bagnols sur Ceze
SNR-300 (Germany)	KKW Kalkar, Postfach 1220, D-4192 Kalkar
PFBR (India)	Kalpakkam
MONJU (Japan)	1, 2-chome, Shiraki, Tsuruga-city, Fukui-Prefecture
PFR (UK)	Dounreay, Caithness, Scotland KW14 7TZ
CRBRP (USA)	P.O. U, Oak Ridge Turnpike, Oak Ridge, TN 37830
BN-350 (Kazakhstan)	Mangyshlak Power Plant, Aktau
BN-600 (Russian Federation)	Beloyarsk Power Plant, Zarechny; Sverdlovsk region
ALMR (USA)	not determined
KALIMER-150 (Republic of Korea)	not determined
SVBR-75/100 (Russian Federation)	not determined
BREST-OD-300 (Russian Federation)	not determined

Commercial Size Reactors

Super-Phénix 1 (France)	CNPE de Creys Malville BP63, 38510 Morestel
Super-Phénix 2 (France)	project subsumed into EFR
SNR 2 (Germany)	project subsumed into EFR
DFBR (Japan)	to be determined
CDFR (UK)	Project subsumed into EFR
BN-1600 (Russian Federation)	Project subsumed into BN-1800
BN-800 (Russian Federation)	neloyarsk Power Plant, Zarechny, Sverdlovsk Region
EFR	not determined
ALMR (USA)	not determined
SVBR-75/100 (Russian Federation)	not determined
BN-1800 (Russian Federation)	not determined
BREST-1200 (Russian Federation)	not determined
JSFR–1500 (Japan)	not determined

1. GENERAL INFORMATION (cont.)

1.3. Administrative and responsible authority

Experimental Fast Reactors

	Administrative and responsible authority
Plant	Owner
Rapsodie (France)	Commissariat à l'Energie Atomique (CEA)
KNK-II (Germany)	Kernforschungszentrum Karlsruhe
FBTR (India)	Department of Atomic Energy, India
PEC (Italy)	ENEA
JOYO (Japan)	JNC
DFR (UK)	UK Atomic Energy Authority
BOR-60 (Russian Federation)	Agency for Atomic Energy
EBR-II (USA)	U.S. Department of Energy (USDOE)
Fermi (USA)	Power Reactor Development Co., Detroit Edison Co.
FFTF (USA)	U.S. Department of Energy
BR-10 (Russian Federation)	Agency for Atomic Energy
CEFR (China)	CIAE

Demonstration or Prototype Fast Reactors

Phénix (France)	CEA and Electricité de France (EdF)
SNR-300 (Germany)	Schnellbrüter - Kernkraftswerkgesellschaft (SBK)
PFBR (India)	Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)
MONJU (Japan)	JNC
PFR (UK)	UK Atomic Energy Authority
CRBRP (USA)	U.S. Department of Energy (USDOE)
BN-350 (Kazakhstan)	Atomic Energy Agency
BN-600 (Russian Federation)	Agency for Atomic Energy
ALMR (USA)	not determined
KALIMER-150 (Republic of Korea)	to be determined
SVBR-75/100 (Russian Federation)	Agency for Atomic Energy
BREST-OD-300 (Russian Federation)	Agency for Atomic Energy

Commercial Size Reactors

Super-Phénix 1 (France)	NERSA
Super-Phénix 2 (France)	Project subsumed into EFR
SNR 2 (Germany)	Project subsumed into EFR
DFBR (Japan)	not determined
CDFR (UK)	project subsumed into EFR
BN-1600 (Russian Federation)	project subsumed into BN-1800
BN-800 (Russian Federation)	Ministry for Atomic Energy
EFR	to be determined
ALMR (USA)	to be determined
SVBR-75/100 (Russian Federation)	Agency for Atomic Energy
BN-1800 (Russian Federation)	Agency for Atomic Energy
BREST-1200 (Russian Federation)	to be determined
JSFR-1500 (Japan)	to be determined

1.3. Administrative and responsible authority

Experimental Fast Reactors

	Administrative and responsible authority
Plant	Operator
Rapsodie (France)	CEA
KNK-II (Germany)	Kernkraftwerk Betriebsgesellschaft
FBTR (India)	Department of Atomic Energy, India
PEC (Italy)	ENEA
JOYO (Japan)	JNC
DFR (UK)	UK Atomic Energy Authority
BOR-60 (Russian Federation)	Agency for Atomic Energy
EBR-II (USA)	Argonne National Laboratory
Fermi (USA)	Power Reactor Development Co., Detroit Edison Co.
FFTF (USA)	Westinghouse Hanford
BR-10 (Russian Federation)	Agency for Atomic Energy
CEFR (China)	CIAE

Demonstration or Prototype Fast Reactors

Phénix (France)	CEA + EdF
SNR-300 (Germany)	SBK
PFBR (India)	BHAVINI
MONJU (Japan)	JNC
PFR (UK)	UK Atomic Energy Authority
CRBRP (USA)	Tennessee Valley Authority
BN-350 (Kazakhstan)	Atomic Energy Agency
BN-600 (Russian Federation)	Agency for Atomic Energy
ALMR (USA)	not determined
KALIMER-150 (Republic of Korea)	to be determined
SVBR-75/100 (Russian Federation)	Agency for Atomic Energy
BREST-OD-300 (Russian Federation)	Agency for Atomic Energy

Commercial Size Reactors

Super-Phénix 1 (France)	NERSA
Super-Phénix 2 (France)	project subsumed into EFR
SNR 2 (Germany)	project subsumed into EFR
DFBR (Japan)	not determined
CDFR (UK)	project subsumed into EFR
BN-1600 (Russian Federation)	Agency for Atomic Energy
BN-800 (Russian Federation)	Agency for Atomic Energy
EFR	not determined
ALMR (USA)	not determined
SVBR-75/100 (Russian Federation)	Agency for Atomic Energy
BN-1800 (Russian Federation)	Agency for Atomic Energy
BREST-1200 (Russian Federation)	not determined
JSFR-1500 (Japan)	not determined

1. GENERAL INFORMATION (cont.)

1.3. Administrative and responsible authority

Experimental Fast Reactors

	Administrative and responsible authority
Plant	Designer
Rapsodie (France)	Groupement Atomique Alsacienne Atlantique (GAAA)
KNK-II (Germany)	Interatom
FBTR (India)	Department of Atomic Energy
PEC (Italy)	ANSALDO/NIRA and ENEA
JOYO (Japan)	JNC/Toshiba/Hitachi/Mitsubishi/Fuji
DFR (UK)	UK Atomic Energy Authority
BOR-60 (Russian Federation)	Hydropress Design Bureau, Podolsk
EBR-II (USA)	Argonne National Laboratory
Fermi (USA)	Atomic Power Development Associates
FFTF (USA)	Westinghouse Advanced Reactors Division
BR-10 (Russian Federation)	Ministry for Atomic Energy
CEFR (China)	CIAE, Beijing Institute of Nuclear Energy (BINE)

Demonstration or Prototype Fast Reactors

Phénix (France)	CEA + EdF + GAAA
SNR-300 (Germany)	Internationale Natrium - Brutreaktor - Bau GmbH (INB)
PFBR (India)	Indira Gandhi Centre for Atomic Research
MONJU (Japan)	PNC/Mitsubishi/Hitachi/Toshiba/Fuji
PFR (UK)	NNC (National Nuclear Corporation)
CRBRP (USA)	Westinghouse Electric Corporation (lead)
BN-350 (Kazakhstan)	Machine Building Design Bureau, Nizhny Novgorod
BN-600 (Russian Federation)	Machine Building Design Bureau, Nizhny Novgorod
ALMR(USA)	General Electric Company (lead)
KALIMER-150 (Russian Federation)	to be determined
SVBR-75/100 (Russian Federation)	EDO GIDROPRESS
BREST-OD-300 (Russian Federation)	RDIPE, Moscow

Commercial Size Reactors

Super-Phénix 1 (France)	Novatome + EdF
Super-Phénix 2 (France)	Novatome + EdF
SNR 2 (Germany)	Interatom, Novatome, Ansaldo
DFBR (Japan)	The Japan Atomic Power Company
CDFR (UK)	National Nuclear Corporation
BN-1600 (Russian Federation)	Machine Building Design Bureau, Nizhny Novgorod
BN-800 (Russian Federation)	Machine Building Design Bureau, Nizhny Novgorod
EFR	Novatome, Siemens, NNC, EFR Associates
ALMR (USA)	General Electric Company (lead)
SVBR-75/100 (Russian Federation)	EDO GIDROPRESS
BN-1800 (Russian Federation)	Machine Building Design Bureau, Nizhny Novgorod
BREST-1200 (Russian Federation)	RDIPE, Moscow

1. GENERAL INFORMATION (cont.)

1.3. Administrative and responsible authority

Experimental Fast Reactors

	Administrative and responsible authority
Plant	Manufacturer or chief contractor
Rapsodie (France)	GAAA
KNK-II (Germany)	Interatom
FBTR (India)	Department of Atomic Energy, India
PEC (Italy)	ANSALDO/NIRA
JOYO (Japan	Toshiba/Hitachi/Mitsubishi/Fuji
DFR (UK)	UK Atomic Energy Authority
BOR-60 (Russian Federation)	Podol'sk Manufacturing Plant
EBR-II (USA)	H.K. Ferguson Co; constructor-Diversified Builders, Inc.
Fermi (USA)	United Engineers and Constructors
FFTF (USA)	Bechtel Power Corporation
BR-10 (Russian Federation)	Ministry for Atomic Energy
CEFR (China)	First Heavy Machine Building Company

Demonstration or Prototype Fast Reactors

Phénix (France)	CEA + EdF + GAAA
SNR-300 (Germany)	Interatom
PFBR (India)	BHAVINI
MONJU (Japan)	Mitsubishi/Hitachi/Toshiba/Fuji
PFR (UK)	TNPG/NNC (National Nuclear Corporation)
CRBRP (USA)	Stone and Webster Engineering Corporation
BN-350 (Kazakhstan)	Podol'sk Manufacturing Plant
BN-600 (Russian Federation)	Ministry of Energetics and MINATOM (USSR)
ALMR (USA)	not determined
KALIMER-150 (Republic of Korea)	to be determined
SVBR-75/100 (Russian Federation)	to be determined
BREST-OD-300 (Russian Federation)	Agency for Atomic Energy

Commercial Size Reactors

Super-Phénix 1 (France)	Novatome + NIRA
Super-Phénix 2 (France)	not determined
SNR 2 (Germany)	not determined
DFBR (Japan)	not determined
CDFR (UK)	National Nuclear Corporation
BN-1600 (Russian Federation)	not determined
BN-800 (Russian Federation)	Agency for Atomic Energy
EFR	not determined
ALMR (USA)	not determined
SVBR-75/100 (Russian Federation)	not determined
BN-1800 (Russian Federation)	not determined
BREST-1200 (Russian Federation)	not determined
JSFR-1500 (Japan)	JNC/JAPC/ Mitsubishi (Hitachi/Toshiba/Fuji/Kawasaki)

1. GENERAL INFORMATION (cont.)

1.3. Administrative and responsible authority

Experimental Fast Reactors

	Administrative and responsible authority
Plant	Licensing authority
Rapsodie (France)	CEA
KNK-II (Germany)	Wirtschaftsministerium Baden - Württemberg
FBTR (India)	Atomic Energy Regulatory Board
PEC (Italy)	ENEA Nuclear Safety Direction
JOYO (Japan)	Ministry of Educ., Cult., Sport, Sc. and Techn. (MEXT)
DFR (UK)	UK Atomic Energy Authority
BOR-60 (Russian Federation)	Gosatomnadzor
EBR-II (USA)	US Atomic Energy Commission (now USDOE)
Fermi (USA)	US Atomic Energy Commission (now USDOE)
FFTF (USA)	U.S. Department of Energy
BR-10 (Russian Federation)	Gosatomnadzor
CEFR (China)	China National Nuclear Safety Administration

Demonstration or Prototype Fast Reactors

Phénix (France)	French Administration
SNR-300 (Germany)	Wirtschaftsministerium Nordrhein - Westfalen
PFBR (India)	Atomic Energy Regulatory Board
MONJU (Japan)	STA, and Ministry of International Trade and Industry
PFR (UK)	UK Nuclear Installation Inspectorate
CRBRP (USA)	U.S. Nuclear Regulatory Commission
BN-350 (Kazakhstan)	Atomic Energy Agency
BN-600 (Russian Federation)	Gosatomnadzor
ALMR (USA)	U.S. Nuclear Regulatory Commission
KALIMER-150 (Republic of Korea)	Korea Ministry Science and Technology
SVBR-75/100 (Russian Federation)	Gosatomnadzor
BREST-OD-300 (Russian Federation)	Gosatomnadzor

Commercial Size Reactors

Super-Phénix 1 (France)	French Administration
Super-Phénix 2 (France)	French Administration
SNR 2 (Germany)	Wirtschaftsministerium Nordrhein - Westfalen
DFBR (Japan)	not determined
CDFR (UK)	Nuclear Installations Inspectorate
BN-1600 (Russian Federation)	Gosatomnadzor
BN-800 (Russian Federation)	Gosatomnadzor
EFR	not determined
ALMR (USA)	U.S. Nuclear Regulatory Commission
SVBR-75/100 (Russian Federation)	Gosatomnadzor
BN-1800 (Russian Federation)	Gosatomnadzor
BREST-1200 (Russian Federation)	Gosatomnadzor
JSFR-1500 (Japan)	to be determined

1. GENERAL INFORMATION (cont.)

1.4. Dates of major events

Experimental Fast Reactors

Plant	Dates of major events				
	Start of construction	First criticality	First electricity generation	First full power operation	Final shutdown
Rapsodie (France)	1962	Jan. 1967		Mar. 1967	Apr. 1983
KNK-II (Germany)		Oct. 1972	Apr. 1978	1978	Oct. 1991
FBTR (India)	1972	Oct. 1985	1994	1996	
PEC (Italy)	Jan. 1974	project cancelled			
JOYO (Japan)	Feb. 1970	Jul. 2003*		Oct. 2003*	
DFR (UK)	1954	1959	1962	1963	1977
BOR-60 (Russian Federation)	1964	1968	1969	1970	
EBR-II (USA)	June 1958	**	Aug. 1964	1965	1998
Fermi (USA)	Aug. 1956	Aug. 1963	Aug. 1966	Oct. 1970	1975
FFTF (USA)	June 1970	Feb. 1980		Dec. 1980	1996
BR-10 (Russian Federation)	1956	1958		1959***	Dec. 2003
CEFR (China)	May 2000	To be determined			

Demonstration or Prototype Fast Reactors

Phénix (France)	1968	1973	1973	Mar. 1974	****
SNR-300 (Germ.)	1973, finished in 1985; in 1991 the Government announced that SNR-300 should not proceed to commence operation				
PFBR (India)	2003	To be determined			
MONJU (Japan)	1985	1994	1995		
PFR (UK)	1966	1974	1975	1977	Mar. 1994
CRBRP (USA)	project cancelled				
BN-350 (Kazakhstan)	1964	Nov. 1972	1973	mid 1973	Apr. 1999
BN-600 (Russian Federation)	1967	Feb. 1980	Apr. 1980	Dec. 1981	not determined
ALMR (USA)	not determined				
KALIMER-150 (Republic of Korea)	not determined				
SVBR-75/100 (Russian Federation)	not determined				
BREST-OD-300 (Russian Federation)	not determined				

* MK-III; MK-I: Apr. 1977 and July 1978; Nov. 1982 - MK-II

** dry criticality: Sept. 30, 1961, Wet criticality: Nov. 11, 1963

*** at 5 MW(th) as BR-5

**** since 1993 as an irradiatian facility in support of the CEA R&D programme on long-lived radioactive waste management

1.4. Dates of major events

Commercial Size Reactors

Plant	Dates of major events				
	Start of construction	First criticality	First electricity generation	First full power operation	Final shutdown
Super-Phénix 1 (France)	1976	1985	1986	1986	1998
Super-Phénix 2 (France)	project subsumed into EFR				
SNR 2 (Germany)	project subsumed into EFR				
DFBR (Japan)	not determined				
CDFR (UK)	project subsumed into EFR				
BN-1600 (Russian Federation)	project subsumed into BN-1800				
BN-800 (Russian Federation)	2002*	2012	to be determined		
EFR	not determined				
ALMR (USA)	not determined				
SVBR-75/100 (Russian Federation)	not determined				
BN-1800 (Russian Federation)	not determined				
BREST-1200 (Russian Federation)	not determined				
JSFR-1500 (Japan)	not determined				

* In 1997 the license for reneval of the BN-800 construction was issued

1. GENERAL INFORMATION (cont.)

1.5. Nominal full power
1.6. Coolant

Experimental Fast Reactors

Plant	Nominal full power		Coolant	
	Thermal (MWth)	Electric, Gross (MWe)	Primary circuit	Secondary circuit
Rapsodie (France)	40	0	sodium	sodium
KNK-II (Germany)	58	20	sodium	sodium
FBTR (India)	40	13	sodium	sodium
PEC (Italy)	120	0	sodium	sodium
JOYO (Japan)	140*	0	sodium	sodium
DFR (UK)	60	15	sodium-potassium	
BOR-60 (Russian Federation)	55	12	sodium	sodium
EBR-II (USA)	62.5	20	sodium	sodium
Fermi (USA)	200	61	sodium	sodium
FFTF (USA)	400	0	sodium	sodium
BR-10 (Russian Federation)	8	0	sodium	Sodium
CEFR (China)	65	23.4	sodium	sodium

Demonstration or Prototype Fast Reactors

Phénix (France)	563**	255	sodium	sodium
SNR-300 (Germany)	762	327	sodium	sodium
PFBR (India)	1250	500	sodium	sodium
MONJU (Japan)	714	280	sodium	sodium
PFR (UK)	650	250	sodium	sodium
CRBRP (USA)	975	380	sodium	sodium
BN-350 (Kazakhstan)	750	130***	sodium	sodium
BN-600 (Russian Federation)	1470	600	sodium	sodium
ALMR (USA)	840	303	sodium	sodium
KALIMER-150 (Republic of Korea)	392.2	162.2	sodium	sodium
SVBR-75/100 (Russian Federation)	265	80	lead-bismuth	none
BREST-OD-300 (Russian Federation)	700	300	lead	none

* MK-III; 50 and 75 MWth for MK-I.; 100 MWth for MK-II

** since 1993, the reactor power has been limited to 350 MW(th), 145 MW(e) on two secondary loop operations: the role of Phénix as an irradiatian facility has been emphasized, particularly in support of the CEA R&D programme in the context of line 1 of the 30 December 1991, law on long-lived radioactive waste management

*** 150 MWth used for desalination

1. GENERAL INFORMATION (cont.)

1.5. Nominal full power
1.6. Coolant

Commercial Size Reactors

Plant	Nominal full power		Coolant	
	Thermal (MWth)	Electric, Gross (MWe)	Primary circuit	Secondary circuit
Super-Phénix 1 (France)	2990	1242	sodium	sodium
Super-Phenix 2 (France)	3600	1440	sodium	sodium
SNR 2 (Germany)	3420	1497	sodium	sodium
DFBR (Japan)	1600	660	sodium	sodium
CDFR (UK)	3800	1500	sodium	sodium
BN-1600 (Russian Federation)	4200	1600	sodium	sodium
BN-800 (Russian Federation)	2100	870	sodium	sodium
EFR	3600	1580	sodium	sodium
ALMR (USA)	840*	303*	sodium	Sodium
SVBR-75/100 (Russian Federation)	280*	101.6*	lead-bismuth	none
BN-1800 (Russian Federation)	4000	1800	sodium	sodium
BREST-1200 (Russian Federation)	2800	1200	lead	none
JSFR-1500 (Japan)	3530	1500	sodium	sodium

* one module

1. GENERAL INFORMATION (cont.)

1.7. Coolant temperature
1.8. Steam conditions

Experimental Fast Reactors

Plant	Coolant temperature (°C)		Steam conditions (at turbine inlet, full power)	
	Mixed coolant temperature in primary circuit at inlet to IHX	Mixed coolant temperature in secondary circuit at inlet to steam generator (SG)	Temperature (°C)	Pressure (MPa)
Rapsodie (France)	510	498	no SG, dump heat exchanger	
KNK-II (Germany)	525	504	485	7.85
FBTR (India)	544	525	490	16.7
PEC (Italy)	550	495	no SG, dump heat exchanger	
JOYO (Japan)	500*	470**	no SG, dump heat exchanger	
DFR (UK)	350	330	270	1
BOR-60 (Russian Federation)	545	480	430	8
EBR-II (USA)	473	467	433	8.79
Fermi (USA)	427	408	407	4.1
FFTF (USA)	565	538	no SG, dump heat exchanger	
BR-10 (Russian Federation)	470	380	no SG, dump heat exchanger	
CEFR (China)	516	495	470	13.0

Demonstration or Prototype Fast Reactors

Phénix (France)	560***	550	510	16.8
SNR-300 (Germany)	546	520	495	16.7
PFBR (India)	544	525	490	16.7
MONJU (Japan)	529	505	483	12.5
PFR (UK)	550	540	513	12.8
CRBRP (USA)	535	494	482	9.81
BN-350 (Kazakhstan)	430	415	410	4.5
BN-600 (Russian Federation)	550	520	500	13.2
ALMR (USA	499	477	429	15.2
KALIMER-150 (Republic of Korea)	530	511	483	15.5
SVBR-75/100 (Russian Federation)	435****	no secondary circuit	250	4.7
BREST-OD-300 (Russian Federation)	540****	no secondary circuit	525	27

* MK-III; (470 in MK-I, 75 MWth)
** 450 in MK-1, 75 MWth
*** the NPP Phénix has been operated for ~100000 hours at a temperature of 560°C of the reactor hot structures with thermal efficiency of 45.3%, that is the highest value in the nuclear power practice
**** mixed primary coolant temperature at inlet to Steam Generator (SG)

1.7. Coolant temperature
1.8. Steam conditions

Commercial Size Reactors

Plant	Coolant temperature (°C)		Steam conditions (at turbine inlet, full power)	
	Mixed coolant temperature in primary circuit at inlet to IHX	Mixed coolant temperature in secondary circuit at inlet to steam generator (SG)	Temperature (°C)	Pressure (MPa)
Super-Phénix 1 (France)	542	525	487	17.7
Super-Phénix 2 (France)	544	525	495	17.7
SNR 2 (Germany)	540	510	495	17.2
DFBR (Japan)	550	520	495	16.6
CDFR (UK)	540	510	490	17.4
BN-1600 (Russian Federation)	550	515	495	13.7
BN-800 (Russian Federation)	544	505	490	13.7
EFR	545	525	490	18.5
ALMR (USA)	499	477	429	15.2
SVBR-75/100 (Russian Federation)	482***	no secondary circuit	307	9.5
BN-1800 (Russian Federation)	575	540	525	26.0
BREST-1200 (Russian Federation)	540***	no secondary circuit	525	27.0
JSFR-1500 (Japan)	550	520	495	18.0

*** mixed primary coolant temperature at inlet to SG

1.9. Primary circuit configuration
1.10. Drive fuel charge

Experimental Fast Reactors

Plant	Primary circuit configuration	Drive fuel charge
Rapsodie (France)	loop	PuO_2-UO_2
KNK-II (Germany)	loop	PuO_2-UO_2
FBTR (India)	loop	PuC-UC
PEC (Italy)	loop	PuO_2-UO_2
JOYO (Japan)	loop	PuO_2-UO_2
DFR (UK)	loop	U-% Mo metal alloy
BOR-60 (Russian Federation)	loop	PuO_2-UO_2
EBR-II (USA)	pool	U-Zr metal alloys*
Fermi (USA)	loop	U metal with 10 wt % Mo
FFTF (USA)	loop	PuO_2-UO_2
BR-10 (Russian Federation)	loop	UN (early PuO_2, UC)
CEFR (China)	pool	UO_2

Demonstration or Prototype Fast Reactors

Phénix (France)	pool	PuO_2-UO_2
SNR-300 (Germany)	loop	PuO_2-UO_2
PFBR (India)	pool	PuO_2-UO_2
MONJU (Japan)	loop	PuO_2-UO_2
PFR (UK)	pool	PuO_2-UO_2
CRBRP (USA)	loop	PuO_2-UO_2
BN-350 (Kazakhstan)	loop	UO_2
BN-600 (Russian Federation)	pool	UO_2 first, Partly PuO_2-UO_2 later
ALMR (USA)	pool	U-Pu-Zr Metal (PuO_2-UO_2 backup)
KALIMER-150 (Republic of Korea)	pool	U-TRU-Zr
SVBR-75/100 (Russian Federation)	pool	UO_2 first, PuO_2-UN later
BREST-OD-300 (Russian Federation)	pool	PuN-UN-MA**

* including some recycled fission products from the pyrometallurgical fuel cycle

** minor actinides

1. GENERAL INFORMATION (cont.)

1.9. Primary circuit configuration
1.10. Drive fuel charge

Commercial Size Reactors

Plant	Primary circuit configuration	Drive fuel charge
Super-Phénix 1 (France)	pool	PuO_2-UO_2
Super-Phénix 2 (France)	pool	PuO_2-UO_2
SNR 2 (Germany)	pool	PuO_2-UO_2
DFBR (Japan)	loop	PuO_2-UO_2
CDFR (UK)	pool	PuO_2-UO_2
BN-1600 (Russian Federation)	pool	PuO_2-UO_2
BN-800 (Russian Federation)	pool	PuO_2-UO_2
EFR	pool	PuO_2-UO_2
ALMR (USA)	pool	U-Pu-Zr metal (PuO_2-UO_2 backup)
SVBR-75/100 (Russian Federation)	pool	UO_2 first; PuO_2, UN later
BN-1800 (Russian Federation)	pool	PuN-UN
BREST-1200 (Russian Federation)	pool	PuN-UN-MA*
JSFR-1500 (Japan)	loop	PuO_2-UO_2

* minor actinides

2. CORE AND BLANKET LAYOUT OR GEOMETRY

2.1. General core and blanket configurations

Experimental Fast Reactors

Plant	General core and blanket configurations				
	Core geometry		Blanket geometry		Core restraint system +
Rapsodie (France)	H	R	-	AB	F
KNK-II (Germany)	H	R*	AA**	AB**	-
FBTR (India)	Q	R	AA	AB	P
PEC (Italy)	Q	-	AA	AB	-
JOYO (Japan)	H	***	***	***	P
DFR (UK)	H	-	AA	AB	F
BOR-60 (Russian Federation)	H	R	AA	AB	P
EBR-II (USA)	H	R****	-	-	-
Fermi (USA)	S	R	AA	AB	-
FFTF (USA)	H	-	-	-	-
BR-10 (Russian Federation)	H	-	-	-	F
CEFR (China)	Q	R	AA	AB	P

Demonstration or Prototype Fast Reactors

Phénix (France)	H	R	AA	AB	F
SNR-300 (Germany)	Q	R	AA	AB	-
PFBR (India)	H	R	AA	AB	P
MONJU (Japan)	H	R	AA	AB	F
PFR (UK)	H	R	AA	AB	P
CRBRP (USA)	H, Het	R	AA	AB	P
BN-350 (Kazakhstan)	Q	R	AA	AB	P
BN-600 (Russian Federation)	Q	R	AA	AB	P
ALMR (USA)	H	-	-	-	F
KALIMER-150 (Republic of Korea)	Het	R	-	-	P
SVBR-75/100 (Russian Federation)	Q	-	-	-	P
BREST-OD-300 (Russian Federation)	Q	no radial and axial blankets			P

* only 5 blanket-elements
** only inner core
*** MK-III; (R, AA, AB, respectively, in MK-I)
**** beyond the radial stainless steel reflector, + See IAEA Technical Report Series No. 246, "Status of Liquid Metal Fast Reactors"(1985), p. 273 (Fig. V-7) - core restraints

S - Square prism
Q - Approximately circular/cylindrical
Het - Heterogeneous core
AA - Axial blanket of fertile above core
AB - Axial blanket of fertile material below core
F - Free-standing core
P - Passive restraint using contact pads

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.1. General core and blanket configurations

Commercial Size Reactors

Plant	General core and blanket configurations				
	Core geometry		Blanket geometry		Core restraint system +
Super-Phénix 1 (France)	H	R	AA	AB	F
Super-Phénix 2 (France)	H	R	-	AB	-
SNR 2 (Germany)	Q	R	AA	AB	-
DFBR (Japan)	H	R	AA	AB	P
CDFR (UK)	Q	R	AA	AB	P
BN-1600 (Russian Federation)	Q	R	AA	AB	P
BN-800 (Russian Federation)	Q	R	-	AB	P
EFR	Q	R	AA	AB	F
ALMR (USA)	H, Het	R	-	-	P
SVBR-75/100 (Russian Federation)	Q	-	-	-	-
BN-1800 (Russian Federation)	Q	-	-	-	P
BREST-1200 (Russian Federation)	Q	-	no radial and axial blankets		P
JSFR-1500 (Japan)	-	-	-	-	-
Breeding core	Q	R	AA	AB	P
Break even core	Q	no radial blanket	AA	AB	P

+ See IAEA Technical Report Series No. 246, "Status of Liquid Metal Fast Reactors" (1985), p. 273 (Fig. V-7) for illustrations of core restraints

S - Square prism
Q - Approximately circular/cylindrical
Het - Heterogeneous core
AA - Axial blanket of fertile above core
AB - Axial blanket of fertile material below core
F - Free-standing core
P - Passive restraint using contact pads

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.2. Numbers of subassemblies in equilibrium core (excluding control rods)

Experimental Fast Reactors

Plant	Numbers of subassemblies in equilibrium core (excluding control rods)			
	Inner core	Outer core	Radial blanket	Reflector or other zone outside radial blanket including shielding and storage positions
Rapsodie (France)	64-73	-	276	211 (nickel)
KNK-II (Germany)	7	22	5	49
FBTR (India)	76	0	342	294
PEC (Italy)	78 (and 1 test channel)	0	0	199* and 262**
JOYO (Japan)	19 (max. 25)***	58 (max. 60)	none	223
DFR (UK)*****	153	189	300	1572
BOR-60 (Russian Federation)	80-114	0	138	
EBR-II (US)	127 (total in core)	0	366****	144****
Fermi (USA)	105	0	531	222
FFTF (USA)	28	45	0	93
BR-10 (Russian Federation)	86-90	0	-	34-30
CEFR (China)	81	-	none	622

Demonstration or Prototype Fast Reactors

Phénix (France)	55	48	90	1317
SNR-300 (Germany)	109	90	96	186
PFBR (India)	85	96	120	419
MONJU (Japan)	108	90	172	324
PFR (UK)	28	44	41	94
CRBRP (USA)	156/82 (internal blanket)	0	126	312
BN-350 (Kazakhstan)	61/48******	113	350	107
BN-600 (Russian Federation)	136/94******	139	362	190
ALMR (USA)	84	108	0	180
KALIMER-150 (Republic of Korea)	54	-	72	241
SVBR-75/100 (Russian Federation)	55	none		
BREST-OD-300 (Russian Federation)	45	64/36*******		148

* reflector
** radial shield
*** none in MK-I and MK-II
**** blanket is beyond the reflector in radial direction
***** pins, not subassemblies
****** inner zone/intermediate zone of the inner core
******* inner zone/outer zone of the outer zone

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.2. Numbers of subassemblies in equilibrium core (excluding control rods)

Commercial Size Reactors

Plant	Numbers of subassemblies in equilibrium core (excluding control rods)			
	Inner core	Outer core	Radial blanket	Reflector or other zone outside radial blanket including shielding and storage positions
Super-Phénix 1 (France)	193	171	234	1288
Super-Phénix 2 (France)	208	180	78	270*
SNR 2 (Germany)	252	162	120	450
DFBR (Japan)	199	96	138	1237
CDFR (UK)	193	156	234	-
BN-1600 (Russian Federation)	258	216	84	1087
BN-800 (Russian Federation)	211/156*****	198	90	546
EFR	207/108*****	72	78	873
ALMR (USA)	84	08	0	180
SVBR-75/100 (Russian Federation)	55	none		
BN-1800 (Russian Federation)	642		-	1001
BREST-1200 (Russian Federation)	148	108/76*******		208
JSFR-1500 (Japan)	-	-	-	-
Breeding core	288	274	96	210
Break even core	288	274	no radial blanket	306

***** inner zone/intermediate zone of the inner core
******* inner zone/outer zone of the outer zone

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.3. Core dimensions

Experimental Fast Reactors

Plant	Core dimensions (mm) at 20°C		
	Equivalent diameter of inner core zone (mm)*	Equivalent diameter of outer core zone (mm)*	Height of fissile zone (mm)
Rapsodie (France)	-	446	320
KNK-II (Germany)	358	824	600
FBTR (India)	-	492	320
PEC (Italy)	-	833	650
JOYO (Japan)	-	800	500 (550 in MK I, II)
DFR (UK)	-	530	530
BOR-60 (Russian Federation)	-	460	450
EBR-II (USA)	-	697	343
Fermi (USA)	-	831	775
FFTF (USA)	767	1202	914
BR-10 (Russian Federation)	-	206	400
CEFR (China)	-	600	450

Demonstration or Prototype Fast Reactors

Phénix (France)	960	1390	850
SNR-300 (Germany)	1353	1780	950
PFBR (India)	1353	1970	1000
MONJU (Japan)	1368	1800	930
PFR (UK)	933	1470	910
CRBRP (USA)	-	2020	914
BN-350 (Kazakhstan)	880/1100**	1580	1000
BN-600 (Russian Federation)	1270/1650**	2050	1030
ALMR (USA)	-	2427	660
KALIMER-150 (Republic of Korea)	1559	-	1000
SVBR-75/100 (Russian Federation)	1645	-	900
BREST-OD-300 (Russian Federation)	1280	1990/2296***	1100

* equivalent diameter means the diameter of a cylindrical zone with the same cross-sectional area as the actual zone

** inner zone/intermediate zone of the inner core

*** inner zone/outer zone of the outer zone

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.3. Core dimensions

Commercial Size Reactors

Plant	Core dimensions (mm) at 20°C		
	Equivalent diameter of inner core zone (mm)*	Equivalent diameter of outer core zone (mm)*	Height of fissile zone (mm)
Super-Phénix 1 (France)	2600	3700	1000
Super-Phénix 2 (France)	2900	3970	1200
SNR 2 (Germany)	-	4130	1000
DFBR (Japan)	2450	2990	1000
CDFR (UK)	2250	3000	1150
BN-1600 (Russian Federation)	3160	4450	780
BN-800 (Russian Federation)	1630/2092**	2561	880
EFR	2948/3688**	4051	1000
ALMR (USA)	-	2164	1070
SVBR-75/100 (Russian Federation)	1645	-	900
BN-1800 (Russian Federation)	-	5167	800
BREST-1200 (Russian Federation)	3350	4150/4750***	1100
JSFR-1500 (Japan)	-	-	-
Breeding core	3890	5380	1000
Break even core	3890	5380	1000

* equivalent diameter means the diameter of a cylindrical zone with the same cross-sectional area as the actual zone

** inner zone/intermediate zone of the inner core

*** inner zone/outer zone of the outer zone

2.4. Radial blanket dimensions
2.5. Axial blanket dimensions

Experimental Fast Reactors

Plant	Radial blanket dimensions (mm) at 20°C		Axial blanket dimensions (mm) at 20°C		
	Outer diameter or equivalent diameter of zone	Height of fertile column	Thickness of upper axial blanket within fuel pin	Thickness of upper axial blanket above top of fuel pin	Thickness of lower axial blanket within fuel pin
Rapsodie (France)	1270	1077	0	0	0
KNK-II (Germany)	-	980	200	-	200
FBTR (India)	1260	1000	0	235	0
PEC (Italy)	1551*	2419*	180	-	225
JOYO (Japan)	**	**	**	-	**
DFR (UK)	1980	2490	142	-	0
BOR-60 (Russian Federation)	770	900	100	-	150
EBR-II (USA)	1562***	1397***	0	-	0
Fermi (USA)	2030	1650	356	-	356
FFTF (USA)	1778*	1198*	144*	-	144*
BR-10 (Russian Federation)	-	-	0	-	0
CEFR (China)	-	-	100	0	250

Demonstration or Prototype Fast Reactors

Phénix (France)	1880	1668	0	260	300
SNR-300 (Germany)	2130	1750	400	-	400
PFBR (India)	2508	1600	300	0	300
MONJU (Japan)	2400	1600	300	-	350
PFR (UK)	1840	1460	102	460****	450
CRBRP (USA)	2850	1625	356	-	356
BN-350 (Kazakhstan)	2490	1580	300	-	400350
BN-600 (Russian Federation)	3000	1580	300	-	-
ALMR (USA)	no radial blanket	-	-	no radial blanket	-
KALIMER-150 (Republic of Korea)	1931	1000	-	no radial blanket	-
SVBR-75/100 (Russian Federation)	2090	-	-	300	-
BREST-OD-300 (Russian Federation)	no radial blanket	-	-	no radial blanket	-

* reflector dimensions
** none in MK-III; (1400, 1400, 400, 400, respectively, in MK- II, MK-I)
*** reflector outer diameter-1019 mm, reflector height-1583 mm
**** not fitted in all fuel types

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.4. Radial blanket dimensions
2.5. Axial blanket dimensions

Commercial Size Reactors

Plant	Radial blanket dimensions (mm) at 20°C		Axial blanket dimensions (mm) at 20°C		
	Outer diameter or equivalent diameter of zone	Height of fertile column	Thickness of upper axial blanket within fuel pin	Thickness of upper axial blanket above top of fuel pin	Thickness of lower axial blanket within fuel pin
Super-Phénix 1 (France)	4700	1600	300	0	300
Super-Phénix 2 (France)	4325	1510	0	-	300
SNR 2 (Germany)	5080	1600	500	-	500
DFBR (Japan)	3570	1700	350	-	350
CDFR (UK)	3800	1800	300	-	300
BN-1600 (Russian Federation)	4800	1150	0	-	350
BN-800 (Russian Federation)	2750	1580	0	-	350
EFR	4383	1000	150	-	250
ALMR (USA)	2427	1473	0	203	0
SVBR-75/100(Russian Federation)	2090	-	-	300	-
BN-1800 (Russian Federation)	to be determined				
BREST-1200 (Russian Federation)	no radial blanket		no axial blanket		
JSFR-1500 (Japan)	-	-	-	-	-
Breeding core	5780	1400	200	-	200
Break even core	no radial blanket		150	-	200

2.6. Lattice pitch of components on centre plane of core
2.7. Fuel subassembly dimensions
2.8. Fuel enrichment

Experimental Fast Reactors

Plant	Lattice pitch of components on centre plane of core (mm)		Fuel subassembly Dimensions (mm)		Fuel enrichment
	At 20°C	At operating temperature	Width across flats	Subassembly length	Number of fuel enrichment zones
Rapsodie (France)	50.8	-	49.8	1661.5	1
KNK-II (Germany)	129	-	108	2250	2
BTR (India)	50.8	51.1	49.8	1661.5	1
PEC (Italy)	81.5	82	85.5	3000	1
JOYO (Japan)	81.5	82.0	78.5	2970	2*
DFR (UK)	23.4	23.5	-	-	1
BOR-60 (Russian Federation)	45	-	44	1575	1
EBR-II (USA)	58.93	59.34	58.17	2340	1
Fermi (USA)	68.4	-	67.2	2450	1
FFTF (USA)	120.0	120.6	118	3658	2
BR-10 (Russian Federation)	27	-	26.1	833	1
CEFR (China)	61	61.37	59	2592	1

Demonstration or Prototype Fast Reactors

Phénix (France)	127	-	124	4300	2
SNR-300 (Germany)	115	-	110	3700	2
PFBR (India)	135	135.9	131.3	4500	2
MONJU (Japan)	116	116.5	105	4200	2
PFR (UK)	145.3	146.2	142.0	3800	2
CRBRP (USA)	121	122	116	4270	1
BN-350 (Kazakhstan)	98	98.5	96	3500	3
BN-600 (Russian Federation)	98.4	99.0	96	3500	3
ALMR (USA)	161.4	162	157.1	4775	2
KALIMER-150 (Republic of Korea)	161	161.8	157	4755.7	1
SVBR-75/100 (Russian Federation)	223.88	-	225.45	1845	4
BREST-OD-300 (Russian Federation)	167.7	169	166.5	3850	1

* MK – III, one in MK - I and MK - II

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.6. Lattice pitch of components on centre plane of core
2.7. Fuel subassembly dimensions
2.8. Fuel enrichment

Commercial Size Reactors

Plant	Lattice pitch of components on centre plane of core (mm)		Fuel subassembly Dimensions (mm)		Fuel enrichment
	At 20°C	At operating temperature	Width across flats	Subassembly length	Number of fuel enrichment zones
Super-Phénix 1 (France)	179	180	173	5400	2
Super-Phénix 2 (France)	-	-	-	4850	2
SNR 2 (Germany)	185	-	180	-	-
DFBR (Japan)	158	-	145	4600	2
CDFR (UK)	147.0	147.9	141.2	4000	2
BN-1600 (Russian Federation)	188	189	184	4500	2
BN-800 (Russian Federation)	100	100.6	94.5	3500	3
EFR	188	189.3	183	4800	3
ALMR (USA)	161.4	162	157.1	4775	1
SVBR-75/100(Russian Federation)	223.88	-	225.45	1845	4
BN-1800 (Russian Federation)	188	-	189.3	4500	1
BREST-1200 (Russian Federation)	231.2	233	230	3850	1
JSFR-1500 (Japan)	-	-	-	-	-
Breeding core	206	207	192	4570	2
Break even core	206	207	192	4570	2

2.9. Fuel enrichment zones*

Experimental Fast Reactors

Plant	Fuel enrichment zones*		
	Inner core enrichment (%)	Outer core enrichment (%)	Intermediate core enrichment (if applicable)
Rapsodie (France)	30% PuO_2 + 70% UO_2	-	-
KNK-II (Germany)	88.1-95.1	37 (^{235}U)	-
FBTR (India)	55**	-	-
PEC (Italy)	28.5	-	-
JOYO (Japan)	30***	34****	-
DFR (UK)	75	-	-
BOR-60 (Russian Federation)	56-90	-	-
EBR-II (USA)	67	-	-
Fermi (USA)	25.6	-	-
FFTF (USA)	20.3*****	24.6******	-
BR-10 (Russian Federation)	90	-	-
CEFR (China)	-	64.4	-

Demonstration or Prototype Fast Reactors

Phénix (France)	18	23	-
SNR-300 (Germany)	25 Pu_{tot}	36 Pu_{tot}	-
PFBR (India)	20.7	27.7	-
MONJU (Japan)	16	21	-
PFR (UK)	22.0	28.5	-
CRBRP (USA)	-	32.8	-
BN-350 (Kazakhstan)	17 (UO_2)	26 (UO_2)	21 (UO_2)
BN-600 (Russian Federation)	17 (UO_2)	26 (UO_2)	21 (UO_2)
ALMR (USA)	21.0	25.2	-
KALIMER-150 (Republic of Korea)	21.1	-	-
SVBR-75/100 (Russian Federation)	16.1	-	-
BREST-OD-300 (Russian Federation)	14.6 (Pu+MA)	-	-

* Enrichment = mass of fissile atoms/mass of fissile and fertile atoms (i. e. ^{235}U in U-based fuels; ^{235}U + all Pu isotopes in U/Pu-based fuels)

** 70 in the initial core

*** none in MK-I, -II

**** 30 and 33 in MK- I,- II, respectively

***** 0.2243 w/o Pu/(U+Pu) (Pu-88% fissile)

****** 0.2737 w/o Pu/(U+Pu) (Pu-88% fissile)

2. CORE AND BLANKET LAYOUT OR GEOMETRY (cont.)

2.9. Fuel enrichment zones*

Commercial Size Reactors

Plant	Fuel enrichment zones*		
	Inner core enrichment (%)	Outer core enrichment (%)	Intermediate core enrichment (if applicable)
Super-Phénix 1 (France)	16	19.7	-
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	18 Pu_{tot}	23 Pu_{tot}	-
DFBR (Japan)	11	16	-
CDFR (UK)	15.0	20.5	-
BN-1600 (Russian Federation)	18.2	21.1	-
BN-800 (Russian Federation)	19.5	24.7	22.1
EFR	18.3	26.9	22.4
ALMR (USA)	23.2	-	-
SVBR-75/100 (Russian Federation)	-	16.1	-
BN-1800 (Russian Federation)	-	14.8	-
BREST-1200 (Russian Federation)	-	13.8 (Pu+MA)	-
JSFR-1500 (Japan)	-	-	-
Breeding core	11.5**	13.0**	-
Break even core	11.5**	13.1**	-

* Enrichment = mass of fissile atoms/mass of fissile and fertile atoms (i.e. ^{235}U in U-based fuels; ^{235}U + all Pu isotopes in U/Pu-based fuels)

** ^{235}U and Pu fissile/ fissile and fertile

3. CORE CHARACTERISTICS

3.1. Reference number of core
3.2. Fissile material content of a core

Experimental Fast Reactors

Plant	Reference number of core	Fissile material content of a core (kg)		
		^{235}U	^{239}Pu	Total plutonium (all isotopes)
Rapsodie (France)	-	79.5	31.5	-
KNK-II (Germany)	-	312	28	39
FBTR (India)	MK II	0.7	85.6	124.4
PEC (Italy)	-	79	175	310
JOYO (Japan)	MK III	110*	-	160*
DFR (UK)	-	247	3	3.5
BOR-60 (Russian Federation)	-	95	53**	58
EBR-II (USA)	Run 128	229	4.5	5.0
Fermi (USA)	-	484	0	0
FFTF (USA)	-	14	516	587
BR-10 (Russian Federation)	-	113	-	-
CEFR (China)	equilibrium	235.4	0.41	0.414

Demonstration or Prototype Fast Reactors

Phénix (France)	-	35	717	931
SNR-300 (Germany)	-	57	1058	1536
PFBR (India)	-	17.3	1361	1978
MONJU (Japan)	-	13.5	870	1400
PFR (UK)	equilibrium	50	760	950
CRBRP (USA)	equilibrium	7.6	1468	1705
BN-350 (Kazakhstan)	-	1220***	75	77
BN-600 (Russian Federation)	equilibrium	2020***	110	112
ALMR (USA)	-	14	-	2283
KALIMER-150 (Republic of Korea)	-	20.48	1090	1519.78
SVBR-75/100 (Russian Federation)	-	1470	-	-
BREST-OD-300 (Russian Federation)	equilibrium	-	-	2260

* MK- III; (175 and 100 in MK-I, -II). MK III; (^{239}Pu + $Pu^{241}Pu$): 160 and 150 in MK-I, II)
** ^{239}Pu and ^{241}Pu
*** for cores with UO_2 fuel

3. CORE CHARACTERISTICS (cont.)

3.1. Reference number of core
3.2. Fissile material content of a core

Commercial Size Reactors

Plant	Reference number of core	Fissile material content of a core (kg)		
		^{235}U	^{239}Pu	Total plutonium (all isotopes)
Super-Phénix 1 (France) 1st core	-	142	4054	5780
Super-Phénix 2 (France)	-	-	-	-
SNR 2 (Germany)	-	210	4800	8000
DFBR (Japan)	-	40	2430	4130
CDFR (UK)	reference	60	3000	3400
BN-1600 (Russian Federation)	equilibrium	80	5400**	7900
BN-800 (Russian Federation)	equilibrium	30	1870**	2710
EFR	-	81	-	8808
ALMR (USA)	-	30	-	2800
SVBR-75/100 (Russian Federation)	-	1470	-	-
BN-1800 (Russian Federation)	equilibrium	-	-	12070
BREST-1200 (Russian Federation)	equilibrium	-	6060	8560
JSFR-1500 (Japan)	-	-	-	-
Breeding core	equilibrium	110	7560	13630
Break even core	equilibrium	110	7570	13680

** ^{239}Pu and ^{241}Pu

3. CORE CHARACTERISTICS (cont.)

3.3. Core volume fractions averaged over whole core (excluding experiments)

Experimental Fast Reactors

Plant	Core volume fractions averaged over whole core (excluding experiments)			
	Fuel	Coolant	Steel	Void or fission gas space
Rapsodie (France)	0.425	0.396	0.136	0.023
KNK-II (Germany)	0.32	0.43	0.21	0.04**
FBTR (India)	0.374	0.354	0.238	0.034
PEC (Italy)	0.346	0.376	0.248	0.030
JOYO (Japan)	0.37*	0.37*	0.23*	0.03
DFR (UK)	0.40	0.40	0.20	0
BOR-60 (Russian Federation)	0.48	0.29	0.23	0
EBR-II (USA)	0.318	0.487	0.195	0
Fermi (USA)	0.279	0.472	0.249	0
FFTF (USA)	0.31	0.39	0.26	0.04
BR-10 (Russian Federation)	0.445	0.287	0.218	0.05
CEFR (China)	0.374	0.376	0.190	0.06

Demonstration or Prototype Fast Reactors

Phénix (France)	0.37	0.35	0.25	0.03
SNR-300 (Germany)	0.295	0.50	0.19	0.015
PFBR (India)	0.297	0.410	0.239	0.054
MONJU (Japan)	0.335	0.400	0.245	0.020
PFR (UK)	0.35	0.41	0.21	0.03
CRBRP (USA)	0.325	0.419	0.234	0.022
BN-350 (Kazakhstan)	0.380	0.33	0.22	0.07
BN-600 (Russian Federation)	0.375	0.34	0.215	0.07
ALMR (USA)	0.378	0.366	0.257	0
KALIMER-150 (Republic of Korea)	0.376	0.3747	0.249	0
SVBR-75/100 (Russian Federation)	0.55	0.285	0.14	0.025
BREST-OD-300 (Russian Federation)	0.30	0.60	0.10	0

* 0.36, 0.40, 0.21 in MK- I, respectively
** volume fraction of moderating material

3. CORE CHARACTERISTICS (cont.)

3.3. Core volume fractions averaged over whole core (excluding experiments)

Commercial Size Reactors

Plant	Core volume fractions averaged over whole core (excluding experiments)			
	Fuel	Coolant	Steel	Void or fission gas space
Super-Phénix 1 (France)	0.37	0.34	0.24	0.05
Super-Phénix 2 (France)	0.37	0.37	0.24	0.02
SNR 2 (Germany)	0.364	0.39	0.22	0.026
DFBR (Japan)	0.39	0.33	0.23	0.05
CDFR (UK)	0.25	0.51	0.18	0.06
BN-1600 (Russian Federation)	0.415	0.306	0.229	0.05
BN-800 (Russian Federation)	0.340	0.390	0.220	0.05
EFR	0.361	0.329	0.235	0.075
ALMR (USA)	0.378	0.366	0.257	0
SVBR-75/100 (Russian Federation)	0.55	0.285	0.14	0.025
BN-1800 (Russian Federation)	0.446	0.294	0.228	0.032
BREST-1200 (Russian Federation)	0.26	0.635	0.105	0
JSFR-1500 (Japan)	-	-	-	-
Breeding core	0.36	0.30	0.26	0.08
Break even core	0.36	0.30	0.26	0.08

3. CORE CHARACTERISTICS (cont.)

3.4. Power density
3.5. Mean length of reactor run
3.6. Mean length of routine shutdown for refuelling (excluding long maintenance periods)

Experimental Fast Reactors

Plant	Power density (kW/litre of fuel) [fuel volume defined by space within cladding]		Mean length of reactor run (days)	Mean length of routine shutdown for refuelling (excluding long maintenance periods) (days)
	Maximum	Average over core		
Rapsodie (France)	3060	2210	80	10
KNK-II (Germany)*	1280/886	985/599	-	-
FBTR (India)	2344	1806	45-60	7
PEC (Italy)	1384	930	60	15
JOYO (Japan)	2500 (2350)	1600 (1225 MK-II)	60**	16
DFR (UK)	1250	900	55	-
BOR-60 (Russian Federation)	2300	1900	100	45
EBR-II (USA)	2704	1610	49	7
Fermi (USA)	2774	1642	14	-
FFTF (USA)	1857	1114	107	***
BR-10 (Russian Federation)	2182	1588	100	12
CEFR (China)	1867	1132	73	14

Demonstration or Prototype Fast Reactors

Phénix (France)	1950	1200	90	7
SNR-300 (Germany)	1613	1016	588****	-
PFBR (India)	1763	1247	240	22
MONJU (Japan)	-	-	148	30
PFR (UK)	1720	1160	90	21
CRBRP (USA)	1983	1023	275	90
BN-350 (Kazakhstan)	1995	1155	105	10
BN-600 (Russian Federation)	1587	940	160	15
ALMR (USA)	1070	708	310	55
KALIMER-150 (Republica of Korea)	342.9	240.4	547	to be determined
SVBR-75/100 (Russian Federation)	382	140	2200	60
BREST-OD-300 (Russian Federation)	835	510	300	25

* test subassembly/driver subassembly
** (45 in MK-I, 70 in MK-II)
*** 1 at 46 days and 2 at 25 days
**** 588 days or 441 equivalent full power days

3. CORE CHARACTERISTICS (cont.)

3.4. Power density
3.5. Mean length of reactor run
3.6. Mean length of routine shutdown for refuelling (excluding long maintenance periods)

Commercial Size Reactors

Plant	Power density (kW/litre of fuel) [fuel volume defined by space within cladding]		Mean length of reactor run (days)	Mean length of routine shutdown for refuelling (excluding long maintenance periods) (days)
	Maximum	Average over core		
Super-Phénix 1 (France)	1250	785	640	120*****
Super-Phénix 2 (France)	1200	755	270	15 or 45
SNR 2 (Germany)	800	500	365	30
DFBR (Japan)	-	-	456	60
CDFR (UK)	2400	1750	270	28
BN-1600 (Russian Federation)	1130	670	330	35
BN-800 (Russian Federation)	1796	1152	140	13.7-17
EFR	1100	670	425	20
ALMR (USA)	950	610	595	105
SVBR-75/100 (Russian Federation)	382	140	2200	60
BN-1800 (Russian Federation)	925	536	500	to be determined
BREST-1200 (Russian Federation)	690	550	300	to be determined
JSFR-1500 (Japan)	-	-	-	-
Breeding core	630	390	800	45
Break even core	650	400	800	45

***** whole core refuelling

3. CORE CHARACTERISTICS (cont.)

3.7. Mean residence time for subassemblies

Experimental Fast Reactors

Plant	Mean residence time for subassemblies (full power days)					
	Internal blanket	Inner core	Outer core	Row 1 radial blanket	Row 2 radial blanket	Row 3 radial blanket
Rapsodie (France)	-	400	-	720	1350	1690
KNK-II (Germany)	-	455	455	1700	-	-
FBTR (India)	-	225	-	-	-	-
PEC (Italy)	-	330	-	-	-	-
JOYO (Japan)	-	358	439*	none**	none	none
DFR (UK)	-	110	110	-	-	-
BOR-60 (Russian Federation)	-	730	900	1450	1800	2200
EBR-II (USA)	-	395	480	-	-	-
Fermi (USA)	-	75	-	-	-	-
FFTF (USA)	-	720	600	-	-	-
BR-10 (Russian Federation)	-	880	-	-	-	-
CEFR (China)	-	240	320	-	-	-

Demonstration or Prototype Fast Reactors

Phénix (France)	-	600	800	600	900	1400
SNR-300 (Germany)	-	441	441	613	1728	-
PFBR (India)	-	567	641	780	-	1825
MONJU (Japan)	-	740	740	740	740	740
PFR (UK)	-	300	400	800	1200	1200
CRBRP (USA)	-	328	328	328	878	1153
BN-350 (Kazakhstan)	-	525	525-735	630	1050	1470
BN-600 (Russian Federation)	-	480	480	640	960	1280
ALMR (USA)	-	1241	1241	-	-	-
KALIMER-150 (Republic Korea)	1395	-	2790	-	-	-
SVBR-75/100 (Russian Federation)	-	2200	-	-	-	-
BREST-OD-300 (Russian Federation)	-	-	-	no radial blanket		

* MK-III; (250 and 270 in MK-I, II, respectively)

** MK- III; (300 for row 1-4 in MK-I)

3. CORE CHARACTERISTICS (cont.)

3.7. Mean residence time for subassemblies

Commercial Size Reactors

Plant	Mean residence time for subassemblies (full power days)					
	Internal blanket	Inner core	Outer core	Row 1 radial blanket	Row 2 radial blanket	Row 3 radial blanket
Super-Phénix 1 (France)	-	640	640	320***	640***	640***
Super-Phénix 2 (France)	-	1350	1350	1620	-	-
SNR 2 (Germany)	-	1100	1100	2200	-	-
DFBR (Japan)	-	1370	1370	1370	1610	-
CDFR (UK)	-	550	550	1000	1500	1500
BN-1600 (Russian Federation)	-	1320	1320	1320	-	-
BN-800 (Russian Federation)	-	420	420	420	-	-
EFR	-	1700	1700	2720	-	-
ALMR (USA)	-	1189	1784	-	2379****	-
SVBR-75/100 (Russian Federation)	-	2200	-	-	-	-
BN-1800 (Russian Federation)	-	1500	2000	-	-	-
BREST-1200 (Russian Federation)	-	no radial blanket				
JSFR-1500 (Japan)	-	-	-	-	-	-
Breeding core	-	3200	3200	3200	-	-
Break even core	-	3200	3200	no radial blanket		

*** anticipated radial blanket unloading

**** cumulative, including residence time in internal blanket before shuffling to radial blanket

3. CORE CHARACTERISTICS (cont.)

3.8. Burnup

Experimental Fast Reactors

Plant	Burnup (MWd/t of heavy metal)			
	Maximum achieved	Average achieved	Maximum target	Average target
Rapsodie (France)	102000	-	-	-
KNK-II (Germany)	172000	75000	-	
FBTR (India)	-	-	50000	38000
PEC (Italy)	-	-	65000	57000
JOYO (Japan)	86900*	68500**	200000***	90000
DFR (UK)	3000	2500	-	-
BOR-60 (Russian Federation)	176000	73000	260000	140000
EBR-II (USA)	80000	66000	-	-
Fermi (USA)	4000	3000	10000	8000
FFTF (USA)	155000	70000	-	-
BR-10 (Russian Federation)	62300	45500	-	-
CEFR (China)	-	-	100000	75000

Demonstration or Prototype Fast Reactors

Phénix (France)	150000****	100000	170000	125000
SNR-300 (Germany)	-	-	86000	57000
PFBR (India)	-	-	113000	77000
MONJU (Japan)	-	-	940000	80000
PFR (UK)	200000	150000	250000	-
CRBRP (USA)	-	-	74200	50000
BN-350 (Kazakhstan)	97000	58000	120000	70000
BN-600 (Russian Federation)	97000	60000	120000	72000
ALMR (USA)	-	-	125000	90000
KALIMER-150 (Republic of Korea)	-	-	120670	87610
SVBR-75/100 (Russian Federation)	-	-	106700	71500
BREST-OD-300 (Russian Federation)	-	-	91700	61450

* MK-III, pellet peak; (143 900 in an irradiation test assembly)
** MK-III, average core discharge burnup, (118 500 in an irradiation test assembly)
*** MK-III, limit average burnup for fuel pin, in irradiation test assembly)
**** these levels were reached with 8 cores of fuel which was 166 000 fuel pins

3. CORE CHARACTERISTICS (cont.)

3.8. Burnup

Commercial Size Reactors

Plant	Burnup (MWd/t of heavy metal)			
	Maximum achieved	Average achieved	Maximum target	Average target
Super-Phénix 1 (France)	90000	60000	113000	70000
Super-Phénix 2 (France)	-	-	136000	85000
SNR 2 (Germany)	-	-	150000	120000
DFBR (Japan)	-	-	110000	90000
CDFR (UK)	-	-	170000	115000
BN-1600 (Russian Federation)	-	-	170000	115000
BN-800 (Russian Federation)	-	-	98000	66000
EFR	-	-	190000	134000****
ALMR (USA)	-	-	150000	100000
SVBR-75/100 (Russian Federation)	-	-	106700	71500
BN-1800 (Russian Federation)	-	-	118000	66000
BREST-1200 (Russian Federation)	to be determined			
JSFR-1500 (Japan)	-	-	-	-
Breeding core	-	-	220000	150000
Break even core	-	-	220000	150000

**** average core discharge burnup

3. CORE CHARACTERISTICS (cont.)

3.9. Neutron flux

Experimental Fast Reactors

Plant	Neutron flux ($\times 10^{15}$n/cm^2 s)	
	Maximum	Average
Rapsodie (France)	3.2	2.3
KNK-II (Germany)	1.9	1.3
FBTR (India)	3.4	2.5
PEC (Italy)	4.0	2.6
JOYO (Japan)	5.7*	3.5**
DFR (UK)	2.5	1.9
BOR-60 (Russian Federation)	3.7	3.0
EBR-II (USA)	2.7	1.6
Fermi (USA)	4.5	2.6
FFTF (USA)	7.0	4.2
BR-10 (Russian Federation)	0.86	0.63
CEFR (China)	3.1	2.1

Demonstration or Prototype Fast Reactors

Phénix (France)	6.8	
SNR-300 (Germany)	6.7	4.9
PFBR (India)	8.1	4.5
MONJU (Japan)	6.0	3.6
PFR (UK)	7.6	5.0
CRBRP (USA)	5.5	3.6
BN-350 (Kazakhstan)	5.4	3.5
BN-600 (Russian Federation)	6.5	4.3
ALMR (USA)	4.5	2.9
KALIMER-150 (Republic of Korea)	3.01	2.2
SVBR-75/100 (Russian Federation)	1.7	1.15
BREST-OD-300 (Russian Federation)	3.8	2.35

* MK I-II; (4.9 in MK-II)

** MK-III, (2.7 in MK-II)

3.9. Neutron flux

Commercial Size Reactors		
	Neutron flux ($\times 10^{15}$n/cm^2 s)	
Plant	Maximum	Average
Super-Phénix 1 (France)	6.1	3.6
Super-Phénix 2 (France)	5.0	-
SNR 2 (Germany)	5.4	-
DFBR (Japan)	to be determined	
CDFR (UK)	10	5.9
BN-1600 (Russian Federation)	5.5	-
BN-800 (Russian Federation)	8.8	5.6
EFR	5.3	3.5
ALMR (USA)	3.3	2.3
SVBR-75/100 (Russian Federation)	1.7	1.15
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	3.8	2.4
JSFR-1500 (Japan)	-	-
Breeding core	3.2	2.0
Break even core	3.2	2.0

3. CORE CHARACTERISTICS (cont.)

3.10. Percentage of subassemblies changed at each shutdown

Experimental Fast Reactors

Plant	Percentage of subassemblies changed at each shutdown (refuelling plan at equilibrium condition)			
	Inner core fuel	Outer core fuel	Control rods	Radial blanket, innermost row
Rapsodie (France)	20		20	-
KNK-II (Germany)	100	100	100	-
FBTR (India)	selective removal of subassemblies			
PEC (Italy)	20	-	16.7	-
JOYO (Japan)	17.6	13.8*	-	-
DFR (UK)	50	50	33	0
BOR-60 (Russian Federation)	12-16	-	-	5-7
EBR-II (USA)	remove fuel at 8% burnup			
Fermi (USA)	change 1-2 subassemblies every 14 days			
FFTF (USA)	15	18	20	-
BR-10 (Russian Federation)	1-3	-	-	-
CEFR (China)	33	-	25	-

Demonstration or Prototype Fast Reactors

Phénix (France)	15	13	25	10
SNR-300 (Germany)	25	25	100	6
PFBR (India)	33	28	4	25
MONJU (Japan)	20	20	100	20
PFR (UK)	30	25	20	6
CRBRP (USA)	all fuel and inner blanket assemblies replaced every two cycles (2 years)			
BN-350 (Kazakhstan)	20	15	25	15
BN-600 (Russian Federation)	33.3	33.3	50	25
ALMR (USA)	25	25	33	-
KALIMER-150 (Republic of Korea)	33.3	-	-	-
SVBR-75/100 (Russian Federation)	100	-	-	-
BREST-OD-300 (Russian Federation)	20	-	20	none

* MK-III; (16.7 in MK-I, 75 MWth)

3.10. Percentage of subassemblies changed at each shutdown

Commercial Size Reactors

Plant	Percentage of subassemblies changed at each shutdown (refuelling plan at equilibrium condition)			
	Inner core fuel	Outer core fuel	Control rods	Radial blanket, innermost row
Super-Phénix 1 (France)	**	-	-	-
Super-Phénix 2 (France)	20	20	-	17
SNR 2 (Germany)	33.3	33.3	50	16.7
DFBR (Japan)	33.3	33.3	100	33.3
CDFR (UK)	33	30	20	12
BN-1600 (Russian Federation)	25	25	-	25
BN-800 (Russian Federation)	33.3	33.3	50	25
EFR	20	20	33.3/20***	12.5
ALMR(USA)	33	33	33	25
SVBR-75/100 (Russian Federation)	100	-	-	-
BN-1800 (Russian Federation)	31.2	-	-	-
BREST-1200 (Russian Federation)	20	to be determined		none
JSFR-1500 (Japan)	-	-	-	-
Breeding core	25.0	25.0	100	25.0
Break even core	25.0	25.0	100	no radial blanket

** not completely defined

**** control and shutdown rods / diverse shutdown rods

3. CORE CHARACTERISTICS (cont.)

3.11. Total breeding gain*
3.12. Breeding gain (core regions only)

Experimental Fast Reactors

Plant	Total breeding gain*	Breeding gain (core regions only)
Rapsodie (France)	configuration not for breeding	
KNK-II (Germany)	configuration not for breeding	
FBTR (India)	configuration not for breeding	
PEC (Italy)	configuration not for breeding	
JOYO (Japan)	0.03 (MK-I)	-
DFR (UK)	configuration not for breeding	
BOR-60 (Russian Federation)	configuration not for breeding	
EBR-II (USA)	configuration not for breeding	
Fermi (USA)	0.16	-
FFTF (USA)	configurtion not for breeding	
BR-10 (Russian Federation)	configuration not for breeding	
CEFR (China)	configuration not for breeding	

Demonstration or Prototype Fast Reactors

Phénix (France)	0.16**	-
SNR-300 (Germany)	0.10 (MK II)	-
PFBR (India)	0.05	negative
MONJU (Japan)	0.2	-
PFR (UK)	-0.05	-
CRBRP (USA)	0.24 (0.29 for initial core)	-
BN-350 (Kazakhstan)	0	-
BN-600 (Russian Federation)	-0.15	-
ALMR (USA)	configuration not for breeding	
KALIMER-150 (Republic of Korea)	0.05	-
SVBR-75/100 (Russian Federation)	-0.13 (UO_2)	0.04 (MOX)
BREST-OD-300 (Russian Federation)	0.05	-

* Breeding gain is defined as: BG = Wi(Ci-Di)/Fi
Ci and Di - respectively rates of creation and destruction of atoms of i
Wi - the worth of atoms of i, relative to ^{239}Pu atoms
Fi - the total fission rate

** A total breeding gain 1.16 was experimentally defined at the time of reprocessing of the fuel evacuated from the plant. The fuel cycle, based on mixed oxide fuel and PUREX reprocessing, has been closed and the first fuel subassembly made with reprocessed plutonium was loaded in the reactor in January 1980

3.11. Total breeding gain*
3.12. Breeding gain (core regions only)

Commercial Size Reactors		
Plant	Total breeding gain*	Breeding gain (core regions only)
Super-Phénix 1 (France)	0.18	-
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	0.12	-
DFBR (Japan)	0.2	-
CDFR (UK)	0.15	-
BN-1600 (Russian Federation)	0.1	-
BN-800 (Russian Federation)	-0.02	-
EFR	0.02	-0.2
ALMR (USA)	0.23	
SVBR-75/100 (Russian Federation)	-0.13 (UO_2)	0.04 (MOX)
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	0.05	-
JSFR-1500 (Japan)	-	-
Breeding core	0.10	-0.16
Break even core	0.03	-0.15

* Breeding gain is defined as: $BG = \frac{Wi(Ci-Di)}{Fi}$

Ci and Di - respectively rates of creation and destruction of atoms of i
Wi - the worth of atoms of i, relative to ^{239}Pu atoms
Fi - the total fission rate

3. CORE CHARACTERISTICS (cont.)

3.13. Reactivity coefficients

Experimental Fast Reactors

Plant	Reactivity coefficients		
	Isothermal temperature coefficient at full power (pcm/°C)	Total power coefficient of reactivity (pcm/MWth) at full power, constant inlet temperature	Maximum coolant void effect (dollars), including only regions with a positive coolant reactivity worth
Rapsodie (France)	-4.5	-6.0 (equilibrium)	-
KNK-II (Germany)	-5 (-4.7*)	-8 (-7.9*)	-2.4 (-3.2*)
FBTR (India)	-4.8 (-4.5*)	-19 (-35*)	-20.57
PEC (Italy)	-3.5 (-3.3*)	-2.5 (-4.3*)	+0.022
JOYO (Japan)	-3.1**	-4.2***	-4.1
DFR (UK)	-5.4	-6.7	0
BOR-60 (Russian Federation)	-4.0	-6.5	-8.0
EBR-II (USA)	-3.6	-4.2	-
Fermi (USA)	-0.39	-0.20	-
FFTF (USA)	-1.08	-0.4	-13
BR-10 (Russian Federation)	-2.2	-8.2	-6.1
CEFR (China)	-4.57	-6.54	-4.99

Demonstration or Prototype Fast Reactors

Phénix (France)	-2.7	-0.5	-
SNR-300 (Germany)	-2.3	-0.3	+2.9
PFBR (India)	-1.8/-1.2 (fresh/equil.)	-0.64/-0.57 (fresh/equil.)	+4.3
MONJU (Japan)	-2.0	-09.4 to1.1	-
PFR (UK)	-3.3	-1.7	+2.6
CRBRP (USA)	-0.63	-0.2	+2.29 (end of cycle 4)
BN-350 (Kazakhstan)	-1.9	-0.7	-0.6****
BN-600 (Russian Federation)	-1.7	-0.6	-0.3****
ALMR (USA)	-	-	4.0
KALIMER-150 (Republic of Korea)	-	-	2.6
SVBR-75/100 (Russian Federation)	-2.2	-3.1	-2.9 (+0.32 core drained)
BREST-OD-300 (Russian Federation)	-1.9	-0.3	-1.6

* for free fuel instead of bound fuel
** MK-III; (-3.8 in MK-I at 75 MWth, - 2.7 in MK-II)
*** MK-III; (-6.2 in MK-I at 75 MWth, - 6.3 in MK-II)

3.13. Reactivity coefficients

Commercial Size Reactors

Plant	Reactivity coefficients		
	Isothermal temperature coefficient at full power (pcm/°C)	Total power coefficient of reactivity (pcm/MWth) at full power, constant inlet temperature	Maximum coolant void effect (dollars), including only regions with a positive coolant reactivity worth
Super-Phénix 1 (France)	-2.75	-0.1	+5.9
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	-	-	-
DFBR (Japan)	-	-	+4.0
CDFR (UK)	-0.20	-0.16	+5.7
BN-1600 (Russian Federation)	-1.6	-0.1	~ 0****
BN-800 (Russian Federation)	-1.7	-0.36	~ 0****
EFR	-1.1	-0.12	+6.4
ALMR (USA)	-	-	+6.5
SVBR-75/100 (Russian Federation)	-2.2	-3.1	-2.9 (+0.32 core drained)
BN-1800 (Russian Federation)	-	-	~ 0
BREST-1200 (Russian Federation)	-1.9	-0.3	-1.6
JSFR-1500 (Japan)	-	-	-
Breeding core	-0.6	-0.15	+5.3
Break even core	-0.6	-0.15	+5.3

**** core and upper part of subassemblies

3.13. Reactivity coefficients

Experimental Fast Reactors

	Reactivity coefficients	
	Doppler coefficient (Tdk/dt)	
Plant	For voided core	For unvoided core
Rapsodie (France)	0	0
KNK-II (Germany)	-	-0.0030
FBTR (India)	0.0	0.0
PEC (Italy)	-0.002	-0.003
JOYO (Japan)	-0.00095	-0.0017
DFR (UK)	-	0.0002
BOR-60 (Russian Federation)	-	0.0015
EBR-II (USA)	value is very small, approximately -0.0003	sodium-in; therefore no sodium-out calculations have been made
Fermi (USA)	-	-0.00026
FFTF (USA)	-0.003	-0.005
BR-10 (Russian Federation)	0	0
CEFR (China)	-0.0021	-0.0025

Demonstration or Prototype Fast Reactors

Phénix (France)	-0.004	-0.006
SNR-300 (Germany)	-0.003	-0.004
PFBR (India)	-0.0045	-0.0066
MONJU (Japan)	-0.0040	-0.0057 to -0.0076
PFR (UK)	-	-0.0068
CRBRP (USA)	-0.0166	-0.00258
BN-350 (Kazakhstan)	-0.0049	-0.007
BN-600 (Russian Federation)	-0.0044	-0.007
ALMR (USA)	-0.0017	-0.0028
KALIMER-150 (Republic of Korea)	-	-0.0042
SVBR-75/100 (Russian Federation)	to be determined	
BREST-OD-300 (Russian Federation)	-	-0. 0066

3. CORE CHARACTERISTICS (cont.)

3.13. Reactivity coefficients

Commercial Size Reactors

	Reactivity coefficients	
	Doppler coefficient (Tdk/dt)	
Plant	For voided core	For unvoided core
Super-Phénix 1 (France)	-0.007	-0.009
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	-	-0.008
CDFR (UK)	-0.0056	-0.0080
BN-1600 (Russian Federation)		-0.007
BN-800 (Russian Federation)	-0.004	-0.007
EFR	-0.005	-0.0065
ALMR (USA)	-0.0026	-0.0044
SVBR-75/100 (Russian Federation)	to be determined	
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	-	-0.0066
DFBR (Japan)	-	-
Breeding core	-0.005	-0.006
Break even core	to be determined	-0.006

4. FUEL DESIGN AND PERFORMANCE

4.1. Number of fuel pins per subassembly

Experimental Fast Reactors

	Number of fuel pins per subassembly	
Plant	Core	Blanket
Rapsodie (France)	61	7
KNK-II (Germany)	169/211*	121
FBTR (India)	61	7
PEC (Italy)	91	-
JOYO (Japan)	127**	none (19 in MK-I)
DFR (UK)	1	1
BOR-60 (Russian Federation)	37	-
EBR-II (USA)	91	19
Fermi (USA)	140	25
FFTF (USA)	217	-
BR-10 (Russian Federation)	7	-
CEFR (China)	61	-

Demonstration or Prototype Fast Reactors

Phénix (France)	217	61
SNR-300 (Germany)	127	61
PFBR (India)	217	61
MONJU (Japan)	169	61
PFR (UK)	325/265/169***	85
CRBRP (USA)	217	61
BN-350 (Kazakhstan)	127	37
BN-600 (Russian Federation)	127	37
ALMR (USA)	271	-
KALIMER-150 (Republic of Korea)	271	127
SVBR-75/100 (Russian Federation)	12114 (55 subassemblies)	None
BREST-OD-300 (Russian Federation)	156/160	None

* test zone
** MK- III; (91 in MK-I)
*** dependent on pin diameter (see 4.2.1)

4. FUEL DESIGN AND PERFORMANCE (cont.)

4.1. Number of fuel pins per subassembly

Commercial Size Reactors

	Number of fuel pins per subassembly	
Plant	Core	Blanket
Super-Phénix 1 (France)	271	91
Super-Phénix 2 (France)	271	127
SNR 2 (Germany)	271	127
DFBR (Japan)	217	127
CDFR (UK)	325	85
BN-1600 (Russian Federation)	331	91
BN-800 (Russian Federation)	127	37
EFR	331	169
ALMR (USA)	271	127
SVBR-75/100 (Russian Federation)	12114 (55 subassemblies)	None
BN-1800 (Russian Federation)	331	-
BREST-1200 (Russian Federation)	272	None
JSFR-1500 (Japan)	-	-
Breeding core	255*	217
Break even core	255*	no radial blanket

* 16 fuel pins are eliminated to arrange the inner duct for re-criticality evasion

4. FUEL DESIGN AND PERFORMANCE (cont.)

4.2. Core fuel pin dimensions and fuel density

Experimental Fast Reactors

Plant	Core fuel pin dimensions (mm) and fuel density		
	Outer diameter	Thickness of cladding	Overall length of fuel pin
Rapsodie (France)	5.1	0.37	320
KNK-II (Germany)	6*/8.2**	0.38	1540
FBTR (India)	5.1	0.37	531.5
PEC (Italy)	6.7	0.45	1935
JOYO (Japan)	5.5***	0.35***	1533***
DFR (UK)	20	2.3	1228
BOR-60 (Russian Federation)	6	0.3	1100
EBR-II (USA)	4.42	0.305	343
Fermi (USA)	4.01	0.127	833
FFTF (USA)	5.84	0.38	2380
BR-10 (Russian Federation)	8.4	0.4	615
CEFR (China)	6.00	0.30	1622

Demonstration or Prototype Fast Reactors

Phénix (France)	6.6	0.45	850
SNR-300 (Germany)	7.6	0.38	2475
PFBR (India)	6.6	0.45	2580
MONJU (Japan)	6.5	0.47	2800
PFR (UK)	5.8/6.6/8.5	0.38	2250
CRBRP (USA)	5.84	0.38	2906
BN-350 (Kazakhstan)	6.9	0.4	2445
BN-600 (Russian Federation)	6.9	0.4	2445
ALMR (USA)	7.44	0.56	3842
KALIMER-150 (Republic of Korea)	7.4	0.55	3708.1
SVBR-75/100 (Russian Federation)	12	0.4	1638
BREST-OD-300 (Russian Federation)	9.4/9.8/10.5	0.5	2250

* test zone
** driver
*** MK-III; (6.3, 0.35, 1900, respectively, in MK-I)

4.2. Core fuel pin dimensions and fuel density

Commercial Size Reactors

Plant	Core fuel pin dimensions (mm) and fuel density		
	Outer diameter	Thickness of cladding	Overall length of fuel pin
Super-Phénix 1 (France)	8.5	0.56	2700
Super-Phénix 2 (France)	8.5	0.56	2690
SNR 2 (Germany)	8.5	0.565	2900
DFBR (Japan)	8.5	0.5	3100
CDFR (UK)	6.6	0.52	2500
BN-1600 (Russian Federation)	8.5	0.55	2410
BN-800 (Russian Federation)	6.6	0.4	2000
EFR	8.2	0.52	2645
ALMR (USA)	7.44	0.56	3842
SVBR-75/100 (Russian Federation)	12	0.4	1638
BN-1800 (Russian Federation)	8.6	0.55	2300
BREST-1200 (Russian Federation)	9.1/9.6/10.4	0.5	to be determined
JSFR-1500 (Japan)	-	-	-
Breeding core	10.4	0.71	2690
Break even core	10.4	0.71	2690

4. FUEL DESIGN AND PERFORMANCE (cont.)

4.2. Core fuel pin dimensions and fuel density

Experimental Fast Reactors

Plant	Core fuel pin dimensions (mm) and fuel density (% TD)	
	Intrinsic density of fuel pellet	Smeared density of fuel with fuel assumed to occupy whole space inside the cladding tube
Rapsodie (France)	92.0*	88.0*
KNK-II (Germany)	86.5	80.0
FBTR (India)	11.7 (86)	10.7 (78)
PEC (Italy)	95.0	87.6
JOYO (Japan)	94.0	87.0
DFR (UK)	19.0*	18.0*
BOR-60 (Russian Federation)	8.3-9.3*	-
EBR-II (USA)	17.7*	75.0
Fermi (USA)	100	100
FFTF (USA)	90.4	85.5
BR-10 (Russian Federation)	12.9*	11.7*
CEFR (China)	96.5	77.55

Demonstration or Prototype Fast Reactors

Phénix (France)	95.0	85.0
SNR-300 (Germany)	86.5	80.0
PFBR (India)	94.6	90.0
MONJU (Japan)	85.0	-
PFR (UK)	10.8*	8.6*
CRBRP (USA)	91.3	83.2
BN-350 (Kazakhstan)	10.4*	8.6*
BN-600 (Russian Federation)	10.4*	8.6*
ALMR (USA)	100	75.0
KALIMER-150 (Republic of Korea)	15.8	75.0
SVBR-75/100 (Russian Federation)	10.41*	9.65*
BREST-OD-300 (Russian Federation)	95.0	80.0

* g/cm^3

4.2. Core fuel pin dimensions and fuel density

Commercial Size Reactors

Plant	Core fuel pin dimensions (mm) and fuel density (% TD)	
	Intrinsic density of fuel pellet	Smeared density of fuel with fuel assumed to occupy whole space inside the cladding tube
Super-Phénix 1 (France)	95.5	82.6
Super-Phénix 2 (France)	95.5	-
SNR 2 (Germany)	93.0	87.0
DFBR (Japan)	95.0	83.7
CDFR (UK)	10.8*	8.6*
BN-1600 (Russian Federation)	10.4*	9.0*
BN-800 (Russian Federation)	10.4*	8.6*
EFR	96.0	82.7
ALMR (USA)	100	75.0
SVBR-75/100 (Russian Federation)	10.41*	9.65*
BN-1800 (Russian Federation)	-	11.59*
BREST-1200 (Russian Federation)	92.0	75.0
JSFR-1500 (Japan)	-	-
Breeding core	95.0	82.0
Break even core	95.0	82.0

* g/cm^3

4.3. Blanket fuel pin dimensions and density of fertile column

Experimental Fast Reactors

Plant	Blanket fuel pin dimensions (mm) and density (% TD) of fertile column				
	Outer diameter	Thickness of cladding	Length	Intrinsic density of pellets	Smeared density, with fuel assumed to occupy whole space inside the cladding tube
Rapsodie (France)	16.5	0.5	1079	10.5*	10.0*
KNK-II (Germany)	9.15	0.5	1363	94	89
FBTR (India)	16.5	0.5	1079	95	90
PEC (Italy)	-	-	-	-	-
JOYO (Japan)	**	**	**	-	-
DFR (UK)	34***	0.9***	2490***	-	-
BOR-60 (Russian Federation)	-	-	-	-	-
EBR-II (USA)	12.5	0.457	1397	17.7*	90
Fermi (USA)	11.3	0.25	1650	100	98
FFTF (USA)	-	-	-	-	-
BR-10 (Russian Federation)	-	-	-	-	-
CEFR (China)	-	-	-	-	-

Demonstration or Prototype Fast Reactors

Phénix (France)	13.4	0.45	1668	-	-
SNR-300 (Germany)	11.6	0.55	2475	95.0	91.0
PFBR (India)	14.33	0.6	2370	94	90.7
MONJU (Japan)	12.0	0.5	2800	93.0	90.0
PFR (UK)	13.5	1.0	1900	10.7*	10.0*
CRBRP (USA)	12.85	0.38	2959	95.6	93.2
BN-350 (Kazakhstan)	14.0	0.4	1980	93.0	90.0
BN-600 (Russian Federation)	14.0	0.4	1980	93.0	90.0
ALMR (USA)	-	-	-	-	-
KALIMER-150 (Republic of Korea)	12.0	0.55	3708	16.2*	85.0
SVBR-75/100 (Russian Federation)	none				
BREST-OD-300 (Russian Federation)	none				

** none in MK-III; (15, 0.6, 1900, respectively, in MK-I)
*** nickel reflector pins

4.3. Blanket fuel pin dimensions and density of fertile column

Commercial Size Reactors

	Blanket fuel pin dimensions (mm) and density (%TD) of fertile column				
Plant	Outer diameter	Thickness of cladding	Length	Intrinsic density of pellets	Smeared density, with fuel assumed to occupy whole space inside the cladding tube
Super-Phénix 1 (France)	15.8	0.57	1944	95.5	91.6
Super-Phénix 2 (France)	13.6	0.57	2480	-	-
SNR 2 (Germany)	15.8	0.6	2900	96.0	90.0
DFBR (Japan)	11.3	0.4	3100	95.0	-
CDFR (UK)	13.5	0.5	2000	10.8*	9.7*
BN-1600 (Russian Federation)	17.5	0.5	2000	10.6*	10.0*
BN-800 (Russian Federation)	14.0	0.4	1980	10.6*	9.7*
EFR	11.5	0.6	2645	96	89
ALMR (USA)	12.0	0.54	3842	15.7*	85
SVBR-75/100 (Russian Federation)	no radial blanket				
BN-1800 (Russian Federation)	to be determined				
BREST-1200 (Russian Federation)	no radial blanket				
JSFR-1500 (Japan)					
Breeding core	11.7	0.42	2690	95.0	90.0
Break even core	no radial blanket				

* g/cm^3

4.4. Cladding material
4.5. Wrapper material

Experimental Fast Reactors

	Cladding material		Wrapper material
Plant	Core	Blanket	
Rapsodie (France)	316	316	-
KNK-II (Germany)	1.4970	1.4981	-
FBTR (India)	316 (20% CW)	316	316 L (CW)
PEC (Italy)	316 (15%-20% CW)	-	-
JOYO (Japan)	316 (20% CW)	none**	316(20% CW) or Cr 15 Ni 20
DFR (UK)	niobium	18/8/1	-
BOR-60 (Russian Federation)	Cr16 Ni15		-
EBR-II (USA)	316	304 L	-
Fermi (USA)	Zr	304	-
FFTF (USA)	316 (20% CW)		-
BR-10 (Russian Federation)	Cr16 Ni15 Mo3 Nb	-	Cr16Ni 15 Mo3 Nb
CEFR (China)	06Cr16Ni15Mo2Mn2TiVB	-	08Cr16Ni11Mo3Ti

Demonstration or Prototype Fast Reactors

Phénix (France)	Cr 17 Ni 13 Mo 2.5 Mn 1.5 Ti Si		
SNR-300 (Germany)	X10 Cr Ni Mo Ti B1515	1.4970	
PFBR (India)	15Cr 15Ni MoTi (CW)	15Cr 15Ni MoTi (CW)	15Cr 15Ti MoTi (CW)
MONJU (Japan)	mod 316	mod 316	mod 316
PFR (UK)	*	316	PE16/FV448
CRBRP (USA)	316 (20% CW)	316 (20% CW)	
BN-350 (Kazakhstan)	Cr16 Ni15 Mo2+MnTiSi (CW)	Cr16 Ni15 Mo2+MnTiSi (CW)	Cr13Mn Nb
BN-600 (Russian Federation)	Cr16 Ni15 Mo2+MnTiSi (CW)	Cr16 Ni15 Mo2+MnTiSi (CW)	Cr13Mn Nb
ALMR (USA)	HT-9	-	HT-9
KALIMER-150 (Republic of Korea)	HT-9	HT-9	HT-9
SVBR-75/100 (Russian Federation)	EP-823 (12%Cr)	-	-
BREST-OD-300 (Russian Federation)	EP- 823 (12Cr)	-	Cr12 Ni06Mo0.9

* various materials including Nimonic PE16
** MK-III (316 (20% CW) in MK-I)

4.4. Cladding material
4.5. Wrapper material

Commercial Size Reactors

	Cladding material (type of steel)		Wrapper material
Plant	Core	Blanket	
Super-Phénix 1 (France)	Cr 17 Ni 13 Mo 2.5 Mn 1.5 Ti Si	-	-
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	1.4970	1.4970	-
DFBR (Japan)	advanced austentic	advanced austenitic	advanced austenitic
CDFR (UK)	PE16	PE10	
BN-1600 (Russian Federation)	Cr16Ni15Mo2MnTiSi(CW)	Cr16Ni15Mo2MnTiSi(CW)	Cr13MnNb
BN-800 (Russian Federation)	Cr16Ni15Mo2MnTiSi(CW)	Cr16Ni15Mo2MnTiSi(CW)	Cr13MnNb
EFR	AIM1 or PE16	AIM1 or PE16	EM10 or Euralloy
ALMR (USA)	HT-9	HT-9	HT-9
SVBR-75/100 (Russian Federation)	EP-823 (12%Cr)	-	-
BN-1800 (Russian Federation)	to be determined		
BREST-1200 (Russian Federation)	EP- 823 (12Cr)	-	Cr12Ni06Mo0.9
JSFR-1500 (Japan)	-	-	-
Breeding core	ODS	ODS	PNC-FMS
Break even core	ODS	ODS	PNC-FMS

4. FUEL DESIGN AND PERFORMANCE (cont.)

4.6. Mechanical separation of pins
4.7. Linear power

Experimental Fast Reactors

Plant	Mechanical separation of pins		Linear power (kW/m)		
	Core fuel	Blanket fuel	Maximum, fuel (at start of life)	Maximum, blanket (at end of life)	Average core
Rapsodie (France)	W	W	43	-	31
KNK-II (Germany)	G	W	45	5	24
FBTR (India)	W	W	35		27
PEC (Italy)	W	-	36.5	2.1	24.5
JOYO (Japan)	W	-	42* (driver)	-	-
DFR (UK)	F	F	370	-	250
BOR-60 (Russian Federation)	W	-	54	-	40
EBR-II (USA	-	-	34.8	4.9	23
Fermi (USA)	G	W	28	14	17
FFTF (USA)	W	-	41.3	-	23.4
BR-10 (Russian Federation)	W	-	44	-	32
CEFR (China)	W	W	40	-	26.1

Demonstration or Prototype Fast Reactors

Phénix (France)	W	W	45	41	27
SNR-300 (Germany)	G	W	36	23	23
PFBR (India)	W	W	45	35	28.7
MONJU (Japan)	W	W	36	27	21
PFR (UK)	G	G	48	50	27.0
CRBRP (USA)	W	W	40.3	54.1	26.7
BN-350 (Kazakhstan)	W	W	40	48	24
BN-600 (Russian Federation)	W	W	47	48	28
ALMR (USA)	W	-	34	-	22
KALIMER-150 (Republic of Korea)	W	W	28.7	28.49	20.12
SVBR-75/100 (Russian Federation)	G	-	36		24.3
BREST-OD-300 (Russian Federation)	G	no radial blanket	41.9/39.5/32.6	-	-

* MK III; (32 and 40, in MK-I at 75 MWt and MK-II, respectively)

W - wire wrapped
G - grids
F fins on pin cladding

4.6. Mechanical separation of pins
4.7. Linear power

Commercial Size Reactors

Plant	Mechanical separation of pins		Linear power (kW/m)		
	Core fuel	Blanket fuel	Maximum, fuel, (at start of life)	Maximum, blanket (at end of life)	Average core
Super-Phénix 1 (France)	W	W	48	48	30
Super-Phénix 2 (France)	W	W	48	48	30
SNR 2 (Germany)	G	W	45	-	-
DFBR (Japan)	W	W	41	-	25
CDFR (UK)	G	W	43	63	28
BN-1600 (Russian Federation)	W	W	48.7	39.6	30
BN-800 (Russian Federation)	W	W	48	48	31
EFR	W	W	52	41	26
ALMR (USA)	W	W	31	34	19
SVBR-75/100 (Russian Federation)	G	-	36	-	24.5
BN-1800 (Russian Federation)	W	-	41	-	24
BREST-1200 (Russian Federation)	-	-	41.9/39.5/32.6	-	-
JSFR-1500 (Japan)	-	-	-	-	-
Breeding core	W	W	40	to be determined	25
Break even core	W	no radial blanket	41	no radial blanket	25

W - wire wrapped
G - grids
F - fins on pin cladding

4.8. Maximum cladding surface temperature of core fuel pin
4.9. Fission product gas volume per pin

Experimental Fast Reactors

Plant	Maximum cladding surface temperature of core fuel pin (°C)	Fission product gas volume per pin (cm^3)	
		Core fuel pin	Blanket fuel pin
Rapsodie (France)	635**	2.5	2
KNK-II (Germany)	600**	16	16
FBTR (India)	600**	1.9	-
PEC (Italy)	700	15.6	-
JOYO (Japan)	675*	10 (15 in MK-1)	none, 60 (in MK-1)
DFR (UK)	400	0	0
BOR-60 (Russian Federation)	710	7.3	-
EBR-II (USA)	580	2.4	12.8
Fermi (USA)	566	0	-
FFTF (USA)	680	19.0	-
BR-10 (Russian Federation)	565	4.8	-
CEFR (China)	670	10.3***	7

Demonstration or Prototype Fast Reactors

Phénix (France)	650**	13	12
SNR-300 (Germany)	600**	25	89
PFBR (India)	697	25.7	93.4
MONJU (Japan)	675****	-	-
PFR (UK)	670	14	34
CRBRP (USA)	732	21.1	133
BN-350 (Kazakhstan)	600	20.6	46
BN-600 (Russian Federation)	695	20.6	46
ALMR (USA)	609	31.6	-
KALIMER-150 (Republic of Korea)	35	to be determined	
SVBR-75/100 (Russian Federation)	600	44.3	-
BREST-OD-300 (Russian Federation)	644	47/51.7/60.3	-

* MK-III, midwall; (620 in MK-I, 650 in MK-II)
** best estimate; without hot-spot factors
*** not including the gas volume incorporated press spring
**** midwall

4.8. Maximum cladding surface temperature of core fuel pin
4.9. Fission product gas volume per pin

Commercial Size Reactors

Plant	Maximum cladding surface temperature of core fuel pin (°C)	Fission product gas volume per pin (cm^3)	
		Core fuel pin	Blanket fuel pin
Super-Phénix 1 (France)	620**	43	40
Super-Phénix 2 (France)	627**	-	-
SNR 2 (Germany)	570**	52	150
DFBR (Japan)	700***	-	-
CDFR (UK)	670	-	-
BN-1600 (Russian Federation)	675	50	-
BN-800 (Russian Federation)	700	18	46
EFR	635**	47	100
ALMR (USA)	609	31.6	-
SVBR-75/100(Russian Federation)	600	44.3	-
BN-1800 (Russian Federation)	to be determined		
BREST-1200 (Russsia)	650	to be determined	no radial blankets
JSFR-1500 (Japan)	-	-	-
Breeding core	700****	-	-
Break even core	700****	-	-

** best estimate; without hot-spot factors
*** midwall

4. FUEL DESIGN AND PERFORMANCE (cont.)

4.10. Pressure of fission products
4.11. Method of detecting failed pins

Experimental Fast Reactors

Plant	Pressure of fission products (gas in fuel pin at operating temperature and maximum burnup) (MPa)	Method of detecting failed pins			
Rapsodie (France)	12.8	-	DB	DS	-
KNK-II (Germany)	2.6	DM	-	-	CGM
FBTR (India)	6.0	DM	-	-	CGM
PEC (Italy)	5.0	DM*	DB	-	CGM
JOYO (Japan)	7.3	DM	-	-	CGM
DFR (UK)	-	-	DB	-	CGM
BOR-60 (Russian Federation)	10.0	DM	-	-	CGM
EBR-II (USA)	12.4	DM	-	-	CGM
Fermi (USA)	0.0	-	-	-	CGM
FFTF (USA)	4.28	-	-	-	CGM
BR-10 (Russian Federation)	5.0	DM	-	-	CGM
CEFR (China)	2.8	-	DB	-	CGM

Demonstration or Prototype Fast Reactors

Phénix (France)	-	DM	DB	DS	CGM
SNR-300 (Germany)	3.1	DM	-	-	CGM
PFBR (India)	5.8	DM	-	-	CGM
MONJU (Japan)	6.9	DM	-	-	CGM
PFR (UK)	5.6	-	DB	DS	CGM
CRBRP (USA)	4.93	DM	-	-	-
BN-350 (Kazakhstan)	4.4	DM	-	-	CGM
BN-600 (Russian Federation)	5.0	DM	DB	-	CGM
ALMR (USA)	6.7	-	-	-	
KALIMER-150 (Republic of Korea)	7.6	to be determined			CGM
SVBR-75/100 (Russian Federation)	3.0	-	-	-	CGM
BREST-OD-300 (Russian Federation)	3.0	DM	DB	-	CGM

* test channel

DM - Delayed neutron detection (main primary circuit pipes)
DB - Delayed neutron detection (bypass pipes
DS - Delayed neutron detection (special pipework)
CGM - Cover gas monitoring system

4. FUEL DESIGN AND PERFORMANCE (cont.)

4.10. Pressure of fission products
4.11. Method of detecting failed pins

Commercial Size Reactors

Plant	Pressure of fission products (gas in fuel pin at operating temperature and maximum burnup) (MPa)	Method of detecting failed pins			
Super-Phénix 1 (France)	4.0	-	-	DS	CGM
Super-Phénix 2 (France)	-	-	-	DS**	CGM
SNR 2 (Germany)	5.0	-	-	-	-
DFBR (Japan)	-	-	-	DS	CGM
CDFR (UK)	-	-	DB	DS	CGM
BN-1600 (Russian Federation)	-	DM	DB	-	CGM
BN-800 (Russian Federation)	5.0	DM	DB	-	CGM
EFR	6.2	DM	-	-	-
ALMR (USA)	6.7	-	-	-	CGM
SVBR-75/100 (Russian Federation)	7.6	to be determined			CGM
BN-1800 (Russian Federation)	-	DM	DB	to be determined	
BREST-1200 (Russian Federation)	to be determined	DM	DB	-	CGM
JSFR-1500 (Japan)	-	-	-	-	
Breeding core	10.7	-	-	DS	CGM
Break even core	10.7	-	-	DS	CGM

** in-vessel instrumentation

DM - Delayed neutron detection (main primary circuit pipes)
DB - Delayed neutron detection (bypass pipes
DS - Delayed neutron detection (special pipework)
CGM - Cover gas monitoring system

4.12. Methods of locating failed pins

Experimental Fast Reactors

Plant	Methods of locating failed pins			
Rapsodie (France)	SSm	GT	DSp	-
KNK-II (Germany)	SSm	-	DSp	WSp
FBTR (India)	-	-	-	-
PEC (Italy)	SSm (SSm*)	-	-	-
JOYO (Japan)	-	-	-	WSp
DFR (UK)	-	GT**	-	-
BOR-60 (Russian Federation)	-	-	DSp	WSp
EBR-II (USA)	-	GT	-	-
Fermi (USA)	-	GT (Kr, Xe)	-	-
FFTF (USA)	-	-	DSp	-
BR-10 (Russian Federation)	-	-	-	-
CEFR (China)	-	-	DSp	WSp

Demonstration or Prototype Fast Reactors

Phénix (France)	SSm	-	-	-
SNR-300 (Germany)	SSm	-	-	WSp
PFBR (India)	SSm	-	-	-
MONJU (Japan)	-	GT	-	-
PFR (UK)	SSm	GT	-	-
CRBRP (USA)	-	GT	DSp	-
BN-600 (Russian Federation)	-	-	DSp	-
ALMR (USA)	SSm	GT	-	-
KALIMER-150 (Republic of Korea)	-	GT	-	-
SVBR-75/100 (Russian Federation)	-	-	DSp	-
BREST-OD-300 (Russian Federation)	-	GT	DSp	WSp

* test channel
** a few experimental pins only

SSm - Sodium sampling to allow transfer and monitoring of delayed neutron precursors
GT - Gas tagging with selected isotopes in pin
DSp - Dry sipping method to induce release of fission products
WSp - Wet sipping method to induce release of fission products

4.12. Methods of locating failed pins

Commercial Size Reactors

Plant	Methods of locating failed pins			
Super-Phénix 1 (France)	SSm	-	-	-
Super-Phénix 2 (France)	SSm	-	-	-
SNR 2 (Germany)	-	-	-	-
DFBR (Japan)	SSm	-	DSp	-
CDFR (UK)	SSm			
BN-1600 (Russian Federation)	to be determined			
BN-800 (Russian Federation)	***	-	DSp	-
EFR	SSm	-	-	-
ALMR (USA)	SSm	GT	-	-
SVBR-75/100 (Russian Federation)	-		DSp	-
BN-1800 (Russian Federation)	-	-	DSp	-
BREST-1200 (Russian Federation)	to be determined			
JSFR-1500 (Japan)	-	-	-	-
Breeding core	SSm	-	-	-
Break even core	SSm	-	-	-

*** locating of section with failed pins

SSm - Sodium sampling to allow transfer and monitoring of delayed neutron precursors
GT - Gas tagging with selected isotopes in pin
DSp - Dry sipping method to induce release of fission products
WSp - Wet sipping method to induce release of fission products

5. CONTROL RODS AND DRIVE MECHANISMS

5.1. Safety (shutdown) rods[(a)]
5.2. Regulating rods[(b)]
5.3. Rapid shutdown rods[(c)]
5.4. Additional shutdown rods[(d)]

Experimental Fast Reactors

Plant	Safety (shutdown) rods[(a)]	Regulating rods[(b)]		Rapid shutdown rods[(c)]	Additional shutdown rods[(d)]
		No. of group 1 regulating rods, sometimes designated "fine rods"	No. of group 2 regulating rods, sometimes designated "coarse rods"		
Rapsodie (France)	6	6	5	6	-
KNK-II (Germany)	8	-	-	-	-
FBTR (India)	6	6	0	-	-
PEC (Italy)	-	11	-	11	-
JOYO (Japan)	none (4 in MK-1)	6 (2 in MK-1)	none	6 (4 in MK-1)	none
DFR (UK)	9	0	6	15	-
BOR-60 (Russian Federation)	3	2	2	-	-
EBR-II (USA)	2	-	-	-	-
Fermi (USA)	8	2	-	-	-
FFTF (USA)	9	3	6	-	-
BR-10 (Russian Federation)	2 MRR*	2 (Ni)	1 MRR	2	-
CEFR (China)	3	2	3	8	-

Demonstration or Prototype Fast Reactors

Phénix (France)	6 (safety and regulating)	-	-	-	-
SNR-300 (Germany)	12	1	8	-	-
PFBR (India)	3	9	-	-	-
MONJU (Japan)	6	3	10	-	-
PFR (UK)	5	0	5	10	-
CRBRP (USA)	15	9	6	-	-
BN-350 (Kazakhstan)	3	2	7	5	-
BN-600 (Russian Federation)	6	2	19	8	-
ALMR (USA)	-	9	-	-	6GEM**+ 3 USS***
KALIMER-150 (Republic of Korea)	1 USS	-	-	-	6 GEM
SVBR-75/100 (Russian Federation)	6	2	29	13	
BREST-OD-300 (Russian Federation)	8	12	8	-	45 HSR**** +12 GEM

* MRR movable ring reflector (Ni)
** GEM gas expansion module
*** The ultimate shutdown system (USS) injects B_4C balls (see 5.9.11)
**** HSR - hydraulically suspended rod

Safety (shutdown) rods[(a)] - No. of safety (shut down) rods
Regulating rods[(b)] - No. of regulating rods (or combined regulating and safety rods)
Rapid shutdown rods[(c)] - No. of rods contributing to rapid shutdown within the first and second shutdown systems
Additional shutdown rods[(d)] - No. of additional, diverse, shutdown rods or devices

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.1. Safety (shutdown) rods[(a)]
5.2. Regulating rods[(b)]
5.3. Rapid shutdown rods[(c)]
5.4. Additional shutdown rods[(d)]

Commercial Size Reactors

Plant	Safety (shutdown) rods[(a)]	Regulating rods[(b)]		Rapid shutdown rods[(c)]	Additional shutdown rods[(d)]
		No. of group1 regulating rods, sometimes designated "fine rods	No. of group 2 regulating rods, sometimes designated "coarse rods"		
Super-Phénix 1 (France)	24	21	-	21	3
Super-Phénix 2 (France)	27	-	-	-	-
SNR 2 (Germany)	25 + 12 (articulated)	-	-	-	-
DFBR (Japan)	30	-	-	-	-
CDFR (UK)	12	0	18	-	-
BN-1600 (Russian Federation)	12	2	23	37	-
BN-800 (Russian Federation)	12	2	16	12	3 HSRs****
EFR*****	33	5+12	4+12	33	-
ALMR (USA)	-	9	-	-	6 GEM** + 3 ultimate system injects ***
SVBR-75/100(Russian Federation)	6	2	29	13	-
BN-1800 (Russian Federation)	18	2	17	18	5 HSRs
BREST-1200 (Russian Federation)	to be determined				
JSFR-1500 (Japan)	-	-	-	-	-
Breeding core	17	-	40******	-	-
Break even core	17	-	40******	-	-

** GEM - gas expansion module
*** the ultimate system injects B_4C balls
**** HSR - hydraulically suspended rod
***** diverse shutdown rods + control and shutdown rods
****** group 1 and 2 rods

Safety (shutdown) rods[(a)] - No. of safety (shut down) rods
Regulating rods[(b)] - No. of regulating rods (or combined regulating and safety rods)
Rapid shutdown rods[(c)] - No. of rods contributing to rapid shutdown within the first and second shutdown systems
Additional shutdown rods[(d)] - No. of additional, diverse, shutdown rods or devices

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.5. Absorber pins

Experimental Fast Reactors

	Absorber pins		
	No. of absorber pins per control rod		
Plant	Safety rods	Group 1 rods	Group 2 rods
Rapsodie (France)	1	-	-
KNK-II (Germany)	55	-	55
FBTR (India)	1	-	-
PEC (Italy)	7	7	7
JOYO (Japan)	none (7 in MK-I)	7	none (17.6 in MK-I)
DFR (UK)	1		10*
BOR-60 (Russian Federation)	7	4	7
EBR-II (USA)	-	-	-
Fermi (USA)	6	19	-
FFTF (USA)	-	61	61
BR-10 (Russian Federation)	-	-	-
CEFR (China)	7	7	7

Demonstration or Prototype Fast Reactors

Phénix (France)	7	-	-
SNR-300 (Germany)	19	19	19
PFBR (India)	19	19	-
MONJU (Japan)	19	19	19
PFR (UK)	19	-	19
CRBRP (USA)	-	37	31
BN-350 (Kazakhstan)	7	7	85
BN-600 (Russian Federation)	7	31	8
ALMR (USA)	-	61	-
KALIMER-150 (Republic of Korea)	-	61	-
SVBR-75/100 (Russian Federation)	1	7	7
BREST-OD-300 (Russian Federation)	30	30	-

* fuel pins

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.5. Absorber pins

Commercial Size Reactors

	Absorber pins		
	No. of absorber pins per control rod		
Plant	Safety rods	Group 1 rods	Group 2 rods
Super-Phénix 1 (France)	31/16***	31	-
Super-Phénix 2 (France)	20 or 31	-	-
SNR 2 (Germany)	55 (articulated)	61	-
DFBR (Japan)	31	-	-
CDFR (UK)	19	-	19
BN-1600 (Russian Federation)	not determined		
BN-800 (Russian Federation)	7	7	7
EFR	37/55**	37/55**	37/55**
ALMR (USA)	-	61	
SVBR-75/100 (Russian Federation)	1	7	7
BN-1800 (Russian Federation)	19	19	19
BREST-1200 (Russian Federation)	to be determined		
JSFR-1500 (Japan)	-	-	-
Breeding core	19	19	19
Break even core	19	19	19

** control and shutdown rods/diverse shutdown rods
*** diverse shutdown rods

5.5. Absorber pins

Experimental Fast Reactors

Plant	Absorber pins		
	Outer diameter of absorber pin safety (mm)	Group 1	Group 2
Rapsodie (France)	45.0	-	-
KNK-II (Germany)	10.3	10.3	-
FBTR (India)	-	-	-
PEC (Italy)	17.7	17.7	17.7
JOYO (Japan)	none*	18.5**	none
DFR (UK)	23.0	-	20.0***
BOR-60 (Russian Federation)	12.0	12.0	12.0
EBR-II (USA)	-	-	-
Fermi (USA)	15.9	7.9	-
FFTF (USA)	12.0	12.0	-
BR-10 (Russian Federation)	-	-	-
CEFR (China)	14.9	14.9	14.9

Demonstration or Prototype Fast Reactors

Phénix (France)	28.0	-	-
SNR-300 (Germany)	15.5	15.5	15.5
PFBR (India)	21.4	22.4	-
MONJU (Japan)	17.0	17.0	17.0
PFR (UK)	22.0	-	22.0
CRBRP (USA)	-	15.3	14.0
BN-350 (Kazakhstan)	23.0	9.5	6.9
BN-600 (Russian Federation)	23.0	9.5	23.0
ALMR (USA)	-	16.7	-
KALIMER-150 (Republic of Korea)	to be determined		
SVBR-75/100 (Russian Federation)	40.0	12.0	12.0
BREST-OD-300 (Russian Federation)	20.5	20.5	-

* MK-III; (17.6 in MK-I)

** MK-III; (17.8 and 18.5 in MK-I and MK-II, respectively)

*** the reactor was controlled by movement of fuel pins in triangular clusters

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.5. Absorber pins

Commercial Size Reactors

Plant	Absorber pins		
	Outer diameter of absorber pin safety (mm)	Group 1	Group 2
Super-Phénix 1 (France)	21/53, 26.7****	21.0	-
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	-	17.6	-
DFBR (Japan)	20.0	-	-
CDFR (UK)	22.0	-	22.0
BN-1600 (Russian Federation)	not determined	-	-
BN-800 (Russian Federation)	23.0	23.0	23.0
EFR	22.78/16.35*****	22.78/16.35*****	22.78/16.35*****
ALMR (USA)	-	16.7	
SVBR-75/100 (Russian Federation)	40.0	12.0	12.0
BN-1800 (Russian Federation)	31.0	31.0	31.0
BREST-1200 (Russian Federation)	to be determined		
JSFR-1500 (Japan)	-	-	-
Breeding core	34.8	35.8	35.8
Break even core	34.8	35.8	35.8

**** diverse shutdown rods
*****control and shutdown rods / diverse shutdown rods

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.5. Absorber pins

Experimental Fast Reactors

Plant	Absorber pins		
	Material of neutron absorber (safety)	Group 1	Group 2
Rapsodie (France)	BC90	BC90	-
KNK-II (Germany)	-	BC93	-
FBTR (India)	BC90	BC90	-
PEC (Italy)	-	BC90	-
JOYO (Japan)	none (BC90 in MK-1)	BC90	none
DFR (UK)	B80	fuel	-
BOR-60 (Russian Federation)	BC80	BC80 or Eu_2O_3	BC80
EBR-II (USA)	fuel	fuel + BC followers	-
Fermi (USA)	BC	BC	-
FFTF (USA)	B20	B20	B20
BR-10 (Russian Federation)*	-	-	-
CEFR (China)	BC91	BC20	BC91

Demonstration or Prototype Fast Reactors

Phénix (France)	BC48	BC48	BC48
SNR-300 (Germany)	BC47	BC47	BC47
PFBR (India)	BC65	BC65	-
MONJU (Japan)	BC90	BC39	BC39
PFR (UK)	BC40	BC20	BC20
CRBRP (USA)	BC92	BC92	BC92
BN-350 (Kazakhstan)	BC80	BC60	UO_2enriched/UO_2 depleted
BN-600 (Russian Federation)	BC80	BC20	BC20
ALMR (USA)	-	BC92	-
KALIMER-150 (Republic of Korea)	BC	BC	-
SVBR-75/100 (Russian Federation)	BC50	BC50	BC50
BREST-OD-300 (Russian Federation)	BC20	Er_2O_3	-

* movable ring reflector (Ni)

[If B_4C is used it is abbreviated below as BCx, where x is the enrichment (%B^{10}) and if boron powder or sintered powder is used it is abbreviated as Bx]

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.5. Absorber pins

Commercial Size Reacotrs

Plant	Absorber pins		
	Material of neutron absorber (safety)	Group 1	Group 2
Super-Phénix 1 (France)	BC90	BC90	-
Super-Phénix 2 (France)	BC90	BC90	BC90
SNR 2 (Germnay)	-	B90	B90
DFBR (Japan)	BC92	-	-
CDFR (UK)	BC30	-	BC20
BN-1600 (Russian Federation)	BC80	BC80	BC80
BN-800 (Russian Federation)	BC92	BC20	BC60
EFR	BC30, 45, 90	BC30,45,90	BC30, 90**
ALMR (USA)	-	BC20	-
SVBR-75/100 (Russian Federation)	BC50	BC50	BC50
BN-1800 (Russian Federation)	BC92	-	-
BREST-1200 (Russian Federation)	to be determined		
JSFR-1500 (Japan)	-	-	-
Breeding core	BC80	BC80	BC80
Break even core	BC80	BC80	BC80

** control and shutdown rods/diverse shutdown rods

[If B_4C is used it is abbreviated below as BCx, where x is the enrichment (%B^{10}) and if boron powder or sintered powder is used it is abbreviated as Bx]

5.CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.6. Worth of control rod

Experimental Fast Reactors

Plant	Worth of control rod (% ΔK/K)				
	Safety (total)	Group 1 (total)	Group 1 (per rod)	Group 2 (total)	Total reactivity worth of all rods moving over whole range
Rapsodie (France)	10.0	-	-	15.0	-
KNK-II (Germany)	4.5	-	-	-	-
FBTR (India)	6.92	-	-	-	-
PEC (Italy)	6.8	-	-	-	6.8
JOYO (Japan)	none	10.1 (13 in MK-II)	1.9 in row 3, 0.7-r. 5	none	10.1 (13 in MK-II)
DFR (UK)	8.0	-	-	8.0	-
BOR-60 (Russian Federation)	4.15	0.8	0.4	3.2	-
EBR-II (USA)	1.0 B_{ef}	3.7 B_{ef}	0.8 B_{ef}*	-	-
Fermi (USA)	9.2 B_{ef}	0.92	-	-	-
FFTF (USA)	-	6.3	8.4	-	-
BR-10 (Russian Federation)	5.1	0.18	0.09	5.1	5.1
CEFR (China)	3.09	0.30	0.15	1.82	9.03

Demonstration or Prototype Fast Reactors

Phénix (France)	8.0	-	-	-	-
SNR-300 (Germany)	2.9	7.3	0.8	-	-
PFBR (India)	4.0	10.1	1.1	-	14.5
MONJU (Japan)	5.8	-	-	-	7.0**
PFR (UK)	2.0	-	-	7.0	-
CRBRP (USA)	-	22.2 B_{ef}	12.8 B_{ef}	-	-
BN-350 (Kazakhstan)	3.5	0.5	0.25	3.2	-
BN-600 (Russian Federation)	2.9	0.48	0.24	7.0	-
ALMR (USA)	9.3	-	-	-	-
KALIMER-150 (Republic of Korea)	2.1	8.2	-	-	-
SVBR-75/100 (Russian Federation)	1.37	0.48	0.27	6.0	6.48
BREST-OD-300 (Russian Federation)	0.72	0.70 (per rod)	0.15 (per GEM)	0.26 (per HSR)	3.6

* with boron follower (0.38 B_{ef} -without boron follower)

** group 1 and 2 with one rod stuck

5.6. Worth of control rod

Commercial Size Reactors

Plant	Worth of control rod (% ΔK/K)				
	Safety (total)	Group 1 (total)	Group 1 (per rod)	Group 2 (total)	Total reactivity worth of all rods moving over whole range
Super-Phénix 1 (France)	10.0	8.5	0.4	-	10.0
Super-Phénix 2 (France)	12.0	-	-	-	-
SNR 2 (Germany)	2.9	8.5	0.4	-	-
DFBR (Japan)	8.9 + 1.6	-	-	-	-
CDFR (UK)	4.0	-	-	5.0	-
BN-1600 (Russian Federation)	2.8	0.4	0.2	6.7	-
BN-800 (Russian Federation)	4.1	0.4	0.2	6.1	9.0
EFR***	10.3	8.1	0.34	-	10.3
ALMR (USA)	6.8	-	-	-	-
SVBR-75/100 (Russian Federation)	1.37	0.48	0.27	6.0	6.48
BN-1800 (Russian Federation)	to be determined				
BREST-1200 (Russian Federation)	to be determined				
JSFR-1500 (Japan)	-	-	-	-	-
Breeding core	2.3	-	-	-	6.8****
Break even core	to be determined				

*** diverse shutdown
**** group 1 and 2 with one rod stuck

5.7. Vertical travel of control rod

Experimental Fast Reactors

	Vertical travel of control rod (mm)		
Plant	Safety	Group 2	Group 1
Rapsodie (France)	450	-	-
KNK-II (Germany)	670	-	620
FBTR (India)	450	-	450
PEC (Italy)	750	750	750
JOYO (Japan)	none*	none*	650*
DFR (UK)	700	600	-
BOR-60 (Russian Federation)	450	450	400
EBR-II (USA)	361	361	361
Fermi (USA)	1370	-	508
FFTF (USA)	940	940	940
BR-10 (Russian Federation)	300-340	300-340	280
CEFR (China)	500±20	500±20	500±20

Demonstration or Prototype Fast Reactors

Phénix (France)	900	-	-
SNR-300 (Germany)	1050	-	830
PFBR (India)	1075	-	1085
MONJU (Japan)	1100	1000	1000
PFR (UK)	1320	1070	-
CRBRP (USA)	914-960	952	-
BN-350 (Kazakhstan)	1260	1060	750
BN-600 (Russian Federation)	900	900	750
ALMR (USA)	914	***	-
KALIMER-150 (Republic of Korea)	to be determined		
SVBR-75/100 (Russian Federation)	1200	1000	1000
BREST-OD-300 (Russian Federation)	870	870	1300

* MK-III; [900, 700 (fine and coarse) 5.7.1 and 5.7.3, respectively, MK-I]

*** by B_4C ball injection system

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.7. Vertical travel of control rod

Commercial Size Reactors

	Vertical travel of control rod (mm)		
Plant	Safety	Group 2	Group 1
Super-Phénix 1 (France)	1100	-	1100
Super-Phénix 2 (France)	1250	1250	1250
SNR-2 (Germany)	1200	1200	1200
DFBR (Japan)	1000	-	-
CDFR (UK)	1150	1000	-
BN-1600 (Russian Federation)	900	900	900
BN-800 (Russian Federation)	1030	870	870
EFR	1000/945**	1000/945**	1000/945**
ALMR (USA)	to be determined		
SVBR-75/100 (Russian Federation)	1200	1000	1000
BN-1800 (Russian Federation)	to be determined		
BREST-1200 (Russian Federation)	to be determined		
JSFR-1500 (Japan)	-	-	-
Breeding core	1000	1000	1000
Break even core	1000	1000	1000

** control and shutdown rods/diverse shutdown rods

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.8. Rod-drop time

Experimental Fast Reactors

	Rod-drop time, designed (seconds)		
Plant	Safety	Group 2	Group 1
Rapsodie (France)	0.4	-	-
KNK-II (Germany)	0.3	-	-
FBTR (India)	0.4	-	0.4
PEC (Italy)	0.5	0.5	0.5
JOYO (Japan)	none (0.8 in MK-1)	none	0.8
DFR (UK)	0.4	0.35	-
BOR-60 (Russian Federation)	0.5	200	-
EBR-II (USA)	1.0	0.450	-
Fermi (USA)	0.9	-	46
FFTF (USA)	0.935	0.935	-
BR-10 (Russian Federation)	0.4	0.4	-
CEFR (China)	0.7	2.5	2.5

Demonstration or Prototype Fast Reactors

Phénix (France)	0.7	-	-
SNR-300 (Germany)	0.55	0.56	0.56
PFBR (India)	1.0	-	1.0
MONJU (Japan)	less than 1.2	less than 1.2	less than 1.2
PFR (UK)	0.5	0.45	-
CRBRP (USA)	-	1.0	1.8
BN-350 (Kazakhstan)	0.7	220	5
BN-600 (Russian Federation)	1.0	160	11
ALMR (USA)	1.0	120	-
KALIMER-150 (Republic of Korea)	to be determined		
SVBR-75/100 (Russian Federation)	1.0	3.0	3.0
BREST-OD-300 (Russian Federation)	less than 2.5	less than 2.5	6.0 (per HSR*)

* HSR - hydraulically suspended rod

5.CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.8. Rod-drop time

Commercial Size Reactors

	Rod-drop time, designed (seconds)		
Plant	Safety	Group 2	Group 1
Super-Phénix 1 (France)	0.8	-	0.8
Super-Phénix 2 (France)	1.0	1.0	1.0
SNR 2 (Germany)	0.8	0.8	-
DFBR (Japan)	less than 1.2	-	-
CDFR (UK)	1.0	0.8	-
BN-1600 (Russian Federation)	to be determined		
BN-800 (Russian Federation)	1.0	174	13.0
EFR	0.7/0.7*	0.7/0.7*	0.7/0.7*
ALMR (USA)	1.0	120	-
SVBR-75/100 (Russian Federation)	1.0	3.0	3.0
BN-1800 (Russian Federation)	to be determined		
BREST-1200 (Russian Federation)	to be determined		
JSFR-1500 (Japan)	0.8	0.8	0.8

* control and shutdown rods/diverse shutdown rods

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.9. Features of drive mechanism

Experimental Fast Reactors

	Features of drive mechanism
Plant	Safety
Rapsodie (France)	screw drive with magnetic hold-up
KNK-II (Germany)	-
FBTR (India)	screw drive with magnetic hold-up
PEC (Italy)	electro-magnetic
JOYO (Japan)	none*
DFR (UK)	screw drive gear with magnetic hold-up
BOR-60 (Russian Federation)	gravity and spring assist
EBR-II (USA)	safety rods are pulled out of core by heavy yoke at bottom, uponmanual release
Fermi (USA)	-
FFTF (USA)	electro-mechanical linear actuating
BR-10 (Russian Federation)	gravity
CEFR (China)	ball-screw drive gear with magnetic hold-up, spring acceleration

Demonstration or Prototype Fast Reactors

Phénix (France)	mechanical + electro-mechanical
SNR-300 (Germany)	screw drive gear with magnetic hold-up (1st), springacceleration (2nd)
PFBR (India)	electro-mechanical in hot pool holds head of rod
MONJU (Japan)	motor drive/spring acceleration
PFR (UK)	screw drive gear with magnetic hold-up
CRBRP (USA)	primary: collapsible roller-nut drive; spring assisted gravity insertion
BN-350 (Kazakhstan)	rack drive gear with magnetic hold-up
BN-600 (Russian Federation)	rack drive gear with magnetic hold-up and accelerating spring
ALMR (USA)	B_4C balls released into open thimble at core center
KALIMER-150 (Republic of Korea)	SASS**, Curie point magnets
SVBR-75/100 (Russian Federation)	rack drive gear with electromagnetic hold-up, accelerating spring and visible lock
BREST-OD-300 (Russian Federation)	electro-mechanical

* motor drive/spring accleration in MK-1

** SASS – self-actuated shutdown system

5.9. Features of drive mechanism

Commercial Size Reactors

	Features of drive mechanism
Plant	Safety
Super-Phénix 1 (France)	rack drive gear with magnetic hold-up/electro magnet in sodium*
Super-Phénix 2 (France)	mechanical + electro-mechanical
SNR 2 (Germany)	1) electro-magnet in gas; 2) electro-magnet in sodium
DFBR (Japan)	screw drive gear with magnetic hold-up and SASS**
CDFR (UK)	screw drive gear with magnetic hold-up
BN-1600 (Russian Federation)	rack drive gear with magnetic hold-up and accelerating spring
BN-800 (Russian Federation)	rack drive gear with magnetic hold-up and accelerating spring
EFR	1) electro magnet in gas; 2) electro magnet in sodium
ALMR (USA)	B_4C balls released into open thimble at core centre
SVBR-75/100 (Russian Federation)	rack drive gear with electromagnetic hold-up, accelerating spring and visible lock
BN-1800 (Russian Federation)	to be determined
BREST-1200 (Russian Federation)	electro-mechanical
JSFR-1500 (Japan)	screw drive gear with magnetic hold-up and SASS**

* diverse shutdown rods

** SSAS - a passive shutdown system (Curie point magnets)

5. CONTROL RODS AND DRIVE MECHANISMS (cont.)

5.9. Features of drive mechanism

Experimental Fast Reactors

	Features of drive mechanism	
Plant	Coarse	Fine
Rapsodie (France)	-	-
KNK-II (Germany)	falling	-
FBTR (India)	-	-
PEC (Italy)	electro-magnetic	electro-magnetic
JOYO (Japan)	none*	motor drive / spring acceleration
DFR (UK)	screw drive gear with magnetic hold up	-
BOR-60 (Russian Federation)	screw drive gear with magnetic hold up	-
EBR-II (USA)	control rods actuated manually or automatically use air-assist and dashpot system to optimize velocity of stroke	-
Fermi (USA)	-	ball-nut-and-screw
FFTF (USA)	electro-mechanical linear actuating	electro-mechanical linear actuating
BR-10 (Russian Federation)	electro-mechanical	electro-mechanical
CEFR (China)	ball-screw and magnetic	ball-screw and magnetic

Demonstration or Prototype Fast Reactors

Phénix (France)	mechanical and electro-mechanical	-
SNR-300 (Germany)	screw drive gear with magnetic hold up	-
PFBR (India)	mechanical gripper holds head of rod; EM at inter seal argon atmosphere holds mobile assembly	-
MONJU (Japan)	motor drive/gas pressure acceleration (for both)	-
PFR (UK)	screw drive gear with magnetic hold up	-
CRBRP (USA)	secondary: ball-nut screw drive; hydraulic assisted insertion; coarse (fixed shim rods): none	-
BN-350 (Kazakhstan)	screw drive gear	screw drive gear
BN-600 (Russian Federation)	rack drive gear	rack drive gear
ALMR (USA)	ball-nut screw drive; motor-assisted drive in; fine motion control	-
KALIMER-150 (Republic of Korea)	ball-nut screw drive; motor-assisted drive in; fine motion control	-
SVBR-75/100 (Russian Federation)	rack drive gear with electro-magnetic hold-up, accelerating spring and visible lock	-
BREST-OD-300 (Russian Federation)	electro-mechanical	-

* MK-III. Motor drive / spring acceleration in MK-I

5.9. Features of drive mechanism

Commercial Size Reactors

	Features of drive mechanism	
Plant	Coarse	Fine
Super-Phénix 1 (France)	rack drive gear with magnetic hold up	-
Super-Phénix 2 (France)	mechanical and electro-mechanical	-
SNR 2 (Germany)	screw drive gear with magnetic hold up	-
DFBR (Japan)	-	-
CDFR (UK)	screw drive gear with magnetic hold up	-
BN-1600 (Russian Federation)	rack drive gear	rack drive gear
BN-800 (Russian Federation)	rack drive gear	rack drive gear
EFR	mechanical and electro-mechanical	mechanical and electro-mechanical
ALMR (USA)	ball-nut screw drive; motor assisted drive in, fine motion control	-
SVBR-75/100 (Russian Federation)	rack drive gear with electromagnetic hold-up, accelerating spring and visible lock	-
BN-1800 (Russian Federation)	to be determined	-
BREST-1200 (Russian Federation)	electro-mechanical	-
JSFR-1500 (Japan)	screw drive gear with magnetic hold up	-

6. HEAT TRANSPORT SYSTEM

6.1. Number of coolant loops
6.2. Coolant inventory

Experimental Fast Reactors

Plant	Number of coolant loops		Coolant inventory (t)	
	Primary (or for pool reactors, the number of primary pumps)	Secondary	Primary	Secondary
Rapsodie (France)	2	2	36.8	20
KNK-II (Germany)	2	2	27	50
FBTR (India)	2	2	26.7	44
PEC (Italy)	2 (1*)	2 (1*)	118 (14*)	67 (3.4*)
JOYO (Japan)	2	2	126	73
DFR (UK)	24	12	51	63
BOR-60 (Russian Federation)	2	2	22	20
EBR-II (USA)	2	1	286	41
Fermi (USA)	3	3	160	102
FFTF (USA)	3	3	406	199
BR-10 (Russian Federation)	2	2	1.7	5
CEFR (China)	2	2	260	48.2

Demonstration or Prototype Fast Reactors

Phénix (France)	3	3	800	381
SNR-300 (Germany)	3	3	550	402
PFBR (India)	2	2	1100	410
MONJU (Japan)	3	3	760	760
PFR (UK)	3	3	850	240
CRBRP (USA)	3	3	630	580
BN-350 (Kazakhstan)	6**	6**	470	450
BN-600 (Russian Federation)	3	3	770	830
ALMR (USA)	1	1	700	300
KALIMER-150 (Republic of Korea)	4	2	to be determined	
SVBR-75/100 (Russian Federation)	2	none	193	-
BREST-OD-300 (Russian Federation)	4	none	8600	-

* test channel
** one loop is a reserve loop
Note: all loops have one pump except the EBR-II primary and DFR secondary loops

6. HEAT TRANSPORT SYSTEM (cont.)

6.1. Number of coolant loops
6.2. Coolant inventory

Commercial Size Reactors

Plant	Number of coolant loops		Coolant inventory (t)	
	Primary (or for pool reactors, the number of primary pumps)	Secondary	Primary	Secondary
Super-Phénix 1 (France)	4	4	3200	1500
Super-Phénix 2 (France)	4	4	3300	800
SNR 2 (Germany)	4	8	3300	1250
DFBR (Japan)	3	3	1700	570
CDFR (UK)	4	4	3000	1600
BN-1600 (Russian Federation)	3	6	2600	2700
BN-800 (Russian Federation)	3	3	820	1100
EFR	3	6	2200	1300
ALMR (USA)	1	1	700	30
SVBR-75/100 (Russian Federation)	2	none	193x16	-
BN-1800 (Russian Federation)	3	6	2620	to be determined
BREST-1200 (Russian Federation)	4	none	to be determined	-
JSFR-1500 (Japan)	2	2	1333	862

6.3. Coolant flow rate

Experimental Fast Reactors

Plant	Coolant flow rate (kg/s)			
	Primary		Secondary	
	Total	Per loop	Total	Per loop
Rapsodie (France)	230	115	204	102
KNK-II (Germany)	280	140	260	130
FBTR (India)	230	115	138	69
PEC (Italy)	630 (15.8*)	315 (15.8*)	624 (15.8*)	312 (15.8*)
JOYO (Japan)	750**	380***	670****	330*****
DFR (UK)	450	19	450	38
BOR-60 (Russian Federation)	270	135	220	110
EBR-II (USA)	500	250	297	297
Fermi (USA)	1185	395	1200	400
FFTF (USA)	2180	727	2180	727
BR-10 (Russian Federation)	48	24	50	25
CEFR (China)	400	200	274	137

Demonstration or Prototype Fast Reactors

Phénix (France)	3000	1000	2319	773
SNR-300 (Germany)	3550	1180	3270	1090
PFBR (India)	7080	3540	5800	2900
MONJU (Japan)	4250	1420	3090	1030
PFR (UK)	3090	1030	2925	975
CRBRP (USA)	5240	1747	4836	1612
BN-350 (Kazakhstan)	3950	790	4400	880
BN-600	6600******	2200	6090	2030
ALMR (USA)	4762	4762	4409	4409
KALIMER-150 (Republic of Korea)	2143	536	1804	902
SVBR-75/100 (Russian Federation)	11760	5880	-	-
BREST-OD-300 (Russian Federation)	41600	10400	-	-

* test channel
** 600 in MK-I and MK-II
*** 300 in MK-I and MK-II
**** 600 in MK-I and MK-II
***** 300 in MK-I and MK-II
****** core excluding flowrate to the reactor vessel cooling system

6. HEAT TRANSPORT SYSTEM (cont.)

6.3. Coolant flow rate

Commercial Size Reactors

Plant	Coolant flow rate (kg/s)			
	Primary		Secondary	
	Total	Per loop	Total	Per loop
Super-Phénix 1 (France)	15700	-	13100	3270
Super-Phénix 2 (France)	19700	4925	15700	3920
SNR 2 (Germany)	18000	4500	-	4000
DFBR (Japan)	8160	2720	6780	2260
CDFR (UK)	15400	3860	15000	3747
BN-1600 (Russian Federation)	19500******	6500	17800	2970
BN-800 (Russian Federation)	8600******	2900	8400	2780
EFR	19300	6433	15300	2550
ALMR (USA)	4762	4762	4409	4409
SVBR-75/100 (Russian Federation)	11760	5880	-	-
BN-1800 (Russian Federation)	to be determined			
BREST-1200 (Russian Federation)	to be determined			
JSFR-1500 (Japan)	18005	9002	15022	7511

****** core excluding flowrate to the reactor vessel cooling system

6. HEAT TRANSPORT SYSTEM (cont.)

6.4. Coolant velocity in core
6.5. Pressure drop across core

Experimental Fast Reactors

Plant	Coolant velocity in core (m/s)		Pressure drop across core (MPa)
	Maximum	Average	
Rapsodie (France)	5.5	-	-
KNK-II (Germany)	-	-	-
FBTR (India)	6.2	5.4	0.3
PEC (Italy)	6.1	5.0	-
JOYO (Japan)	6.1 (6.6 in MK-I, II)	5.3	0.33
DFR (UK)	6.0	6.0	-
BOR-60 (Russian Federation)	11.0	8.0	0.35
EBR-II (USA)	8.0	~ 0.5	-
Fermi (USA)	-	4.8	-
FFTF (USA)	7.4	6.8	-
BR-10 (Russian Federation)	4.0	-	0.1
CEFR (China)	4.74	3.7	0.28

Demonstration or Prototype Fast Reactors

Phénix (France)	12.0	9.0	0.45
SNR-300 (Germany)	-	5.0	-
PFBR (India)	8.0	7.7	0.54
MONJU (Japan)	6.9	5.8	0.25
PFR (UK)	9	7.3	-
CRBRP (USA)	7.3	6.7	-
BN-350 (Kazakhstan)	7.4	6.5	0.69
BN-600 (Russian Federation)	8.0	7.5	0.70
ALMR (USA)	5.3	4.7	0.5
KALIMER-150 (Republic of Korea)	5.1	4.2	≤ 0.6
SVBR-75/100 (Russian Federation)	-	2.0	0.4
BREST-OD-300 (Russian Federation)	1.67	-	0.155

6.4. Coolant velocity in core
6.5. Pressure drop across core

Commercial Size Reactors

Plant	Coolant velocity in core (m/s)		Pressure drop across core (MPa)
	Maximum	Average	
Super-Phénix 1 (France)	7.7	6.1	0.47
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	-	-	-
DFBR (Japan)	-	-	0.5
CDFR (UK)	7.0	6.5	-
BN-1600 (Russian Federation)	5.7	5.3	0.45
BN-800 (Russian Federation)	7.3	6.7	0.68
EFR	7.8	6.7	0.5
ALMR (USA)	5.3	4.7	0.5
SVBR-75/100 (Russian Federation)	-	2.0	0.4
BN-1800 (Russian Federation)	to be determined		
BREST-1200 (Russian Federation)	≤ 2.0	to be determined	-
JSFR-1500 (Japan)	4.1*	2.9	0.3

* at sub-assembly outlet

6. HEAT TRANSPORT SYSTEM (cont.)

6.6. Coolant temperature

Experimental Fast Reactors

	Coolant temperature (°C)	
Plant	Primary (hot leg)	Primary (cold leg)
Rapsodie (France)	515	400
KNK-II (Germany)	525	360
FBTR (India)	515	380
PEC (Italy)	545 (600 Max.*)	400 (450 Max.*)
JOYO (Japan)	500**	350***
DFR (UK)	350	230
BOR-60 (Russian Federation)	530	330
EBR-II (USA)	473	371
Fermi (USA)	427	288
FFTF (USA)	503	360
BR-10 (Russian Federation)	470	350
CEFR (China)	530	360

Demonstration or Prototype Fast Reactors

Phénix (France)	560	395
SNR-300 (Germany)	546	377
PFBR (India)	547	397
MONJU (Japan)	529	397
PFR (UK)	560	399
CRBRP (USA)	535	388
BN-350 (Kazakhstan)	430	280
BN-600 (Russian Federation)	535	365
ALMR (USA)	498	358
KALIMER-150 (Republic of Korea)	530	386
SVBR-75/100 (Russian Federation)	435	286
BREST-OD-300 (Russian Federation)	540	420

* test channel
** 465 in MK-I, 75 MWth
*** 370 in MK-I, II

6. HEAT TRANSPORT SYSTEM (cont.)

6.6. Coolant temperature

Commercial Size Reactors

	Coolant temperature (°C)	
Plant	Primary (hot leg)	Primary (cold leg)
Super-Phénix 1 (France)	545	395
Super-Phénix 2 (France)	544	397
SNR 2 (Germany)	540	390
DFBR (Japan)	550	395
CDFR (UK)	540	370
BN-1600 (Russian Federation)	550	395
BN-800 (Russian Federation)	547	354
EFR	545	395
ALMR (USA)	498	358
SVBR-75/100 (Russian Federation)	482	320
BN-1800 (Russian Federation)	575	410
BREST-1200 (Russian Federation)	540	420
JSFR-1500 (Japan)	550	395

6. HEAT TRANSPORT SYSTEM (cont.)

6.6. Coolant temperature

Experimental Fast Reactors

	Coolant temperature (°C)	
Plant	Primary (hot leg)	Primary (cold leg)
Rapsodie (France)	485	360
KNK-II (Germany)	504	322
FBTR (India)	510	284
PEC (Italy)	495 (470-585*)	350 (320-435*)
JOYO (Japan)	470 (445 in MK-I)	300**
DFR (UK)	335	195
BOR-60 (Russian Federation)	480	210
EBR-II (USA)	467	270
Fermi (USA)	408	269
FFTF (USA)	459	316
BR-10 (Russian Federation)	380	270
CEFR (China)	495	310

Demonstration or Prototype Fast Reactors

Phénix (France)	550	343
SNR-300 (Germany)	520	335
PFBR (India)	525	355
MONJU (Japan)	505	325
PFR (UK)	540	370
CRBRP (USA)	502	344
BN-350 (Kazakhstan)	415	260
BN-600 (Russian Federation)	510	315
ALMR (USA)	477	325
KALIMER-150 (Republic of Korea)	511	340
SVBR-75/100 (Russian Federation)	none	
BREST-OD-300 (Russian Federation)	none	

* test channel
** 355 and 340 in in MK-I, II, respectively

6. HEAT TRANSPORT SYSTEM (cont.)

6.6. Coolant temperature

Commercial Size Reactors

Plant	Coolant temperature (°C)	
	Secondary (hot leg)	Secondary (cold leg)
Super-Phénix 1 (France)	525	345
Super-Phénix 2 (France)	525	345
SNR 2 (Germany)	510	340
DFBR (Japan)	520	335
CDFR (UK)	510	335
BN-1600 (Russian Federation)	515	345
BN-800 (Russian Federation)	505	309
EFR	525	340
ALMR (USA)	477	324
SVBR-75/100 (Russian Federation)	none	
BN-1800 (Russian Federation)	540	370
BREST-1200 (Russian Federation)	none	
JSFR-1500 (Japan)	520	335

6.6. Coolant temperature

Experimental Fast Reactors

Plant	Coolant temperature (°C)	
	Steam (water)	
	Steam generator (outlet)	Steam generator (inlet)
Rapsodie (France)	no SG, dump heat exchanger	
KNK-II (Germany)	485	200
FBTR (India)	480	200
PEC (Italy)	no SG, dump heat exchanger	
JOYO (Japan)	no SG, dump heat exchanger	
DFR (UK)	274	200
BOR-60 (Russian Federation)	430	200
EBR-II (USA)	433	301
Fermi (USA)	407	171
FFTF (USA)	no SG, dump heat exchanger	
BR-10 (Russian Federation)	no SG, dump heat exchanger	
CEFR (China)	480	190

Demonstration or Prototype Fast Reactors

Phénix (France)	512	246
SNR-300 (Germany)	495	230
PFBR (India)	493	235
MONJU (Japan)	487	240
PFR (UK)	515	342
CRBRP (USA)	482	242
BN-350 (Kazakhstan)	410	158
BN-600 (Russian Federation)	505	240
ALMR (USA)	454	215
KALIMER-150 (Republic of Korea)	483.2	230
SVBR-75/100 (Russian Federation)	260	225
BREST-OD-300 (Russian Federation)	525	355

6. HEAT TRANSPORT SYSTEM (cont.)

6.6. Coolant temperature

Commercial Size Reactors

Plant	Coolant temperature (°C) Steam (water)	
	Steam generator (outlet)	Steam generator (inlet)
Super-Phénix 1 (France)	490	237
Super-Phénix 2 (France)	490	237
SNR 2 (Germany)	490	240
DFBR (Japan)	495	240
CDFR (UK)	490	196
BN-1600 (Russian Federation)	495	240
BN-800 (Russian Federation)	490	190-210
EFR	490	240
ALMR (USA)	454	215
SVBR-75/100 (Russian Federation)	307	240
BN-1800 (Russian Federation)	525	270
BREST-1200 (Russian Federation)	525	355
JSFR-1500 (Japan)	497	240

6.7. Piping

Experimental Fast Reactors

Plant	Piping	
	Primary circuit material: hot leg (for pool reactors, there is no hot leg piping)	Primary circuit material: cold leg (for pool reactors, this is the piping connecting the primary pumps to the diagrid)
Rapsodie (France)	316	316
KNK-II (Germany)	1.6770	1.6770
FBTR (India)	316	316
PEC (Italy)	316 (316 B.F.*)	316 (316*)
JOYO (Japan)	304	304
DFR (UK)	18/8/1	18/8/1
BOR-60 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
EBR-II (USA)	304	304
Fermi (USA)	304	304
FFTF (USA)	316	304
BR-10 (Russian Federation)	Cr 18 Ni9	Cr 18 Ni9
CEFR (China)	-	304

Demonstration or Prototype Fast Reactors

Phénix (France)	316	316
SNR-300 (Germany)	1.4948	1.4948
PFBR (India)	316 LN	316 LN
MONJU (Japan)	304	304
PFR (UK)	321	321
CRBRP (USA)	316	304
BN-350 (Kazakhstan)	Cr 18 Ni 9	Cr 18 Ni 9
BN-600 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
ALMR (USA)	316	316
KALIMER-150 (Republic of Korea)	316	316
SVBR-75/100 (Russian Federation)	EP 302	Cr 18 Ni 9
BREST-OD-300 (Russian Federation)	none	none

* test channel

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Primary circuit material: hot leg (for pool reactors, there is no hot leg piping)	Primary circuit material: cold leg (for pool reactors, this is the piping connecting the primary pumps to the diagrid)
Super-Phénix 1 (France)	Cr18 Ni12 Mo2.5 Mn1.8 Si	Cr18 Ni10
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	304	304
DFBR (Japan)	316 FR	304
CDFR (UK)	316	304
BN-1600 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
BN-800 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
EFR	Cr 18 Ni13	Cr18 Ni13
ALMR	316	316
SVBR-75/100 (Russian Federation)	EP 302	Cr 18 Ni 9
BN-1800 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
BREST-1200 (Russian Federation)	none	none
JSFR-1500 (Japan)	12Cr-Steel	12Cr-Steel

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Experimental Fast Reactors

Plant	Piping	
	Secondary piping material	
	Hot leg	Cold leg
Rapsodie (France)	316	316
KNK-II (Germany)	1.6770	1.6770
FBTR (India)	316 LN	316 LN
PEC (Italy)	316	316
JOYO (Japan)	2 1/4 Cr-1 Mo	2 1/4 Cr-1 Mo
DFR (UK)	18/8/1	18/8/1
BOR-0 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
EBR-II (USA)	304*	304*
Fermi (USA)	2 1/4 Cr-1 Mo	2 1/4 Cr-1 Mo
FFTF (USA)	316	304
BR-10 (Russian Federation)	Cr 18 Ni9	Cr 18 Ni9
CEFR (China)	304 H	304 L

Demonstration or Prototype Fast Reactors

Phénix (France)	321	304
SNR-300 (Germany)	1.4948	-
PFBR (India)	316 LN	316 LN
MONJU (Japan)	304	304
PFR (UK)	321	321
CRBRP (USA)	316H	304H
BN-350 (Kazakhstan)	Cr 18 Ni 9	Cr 18 Ni 9
BN-600 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
ALMR (USA)	316	316
KALIMER-150 (Republic of Korea)	316	316
SVBR-75/100 (Russian Federation)	none	none
BREST-OD-300 (Russian Federation)	none	none

* 2 1/4 Cr-1 Mo used for connection to steam generator components

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Secondary piping material	
	Hot leg	Cold leg
Super-Phénix 1 (France)	Cr18 Ni12 Mo 2.5 Mn1.8 Si	Cr18 Ni12 Mo 2.5 Mn1.8 Si
Super-Phénix 2 (France)	316	316
SNR 2 (Germany)	304	304
DFBR (Japan)	304	304
CDFR (UK)	316	316
BN-1600 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
BN-800 (Russian Federation)	Cr 16 Ni 11 Mo 3	Cr 18 Ni 9
EFR	Cr 18 Ni 13	Cr 18 Ni 13
ALMR (USA)	316	316
SVBR-75/100 (Russian Federation)	none	none
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	none	none
JSFR-1500 (Japan)	12Cr-Steel	12Cr-Steel

6.7. Piping

Experimental Fast Reactors

Plant	Piping	
	Steam (water) piping material	
	Hot leg	Cold leg
Rapsodie (France)	no SG, dump heat exchanger	-
KNK-II (Germany)	no SG, dump heat exchanger	-
FBTR (India)	A335 Gr.P2	SA106 Gr.B
PEC (Italy)	no SG, dump heat exchanger	-
JOYO (Japan)	no SG, dump heat exchanger	-
DFR (UK)	18/8/1 in Cu Bond	mild steel
BOR-60 (Russian Federation)	12 Cr 1 Mo	12 Cr 1 Mo
EBR-II (USA)	2¼ Cr-1 Mo	2¼ Cr-1 Mo
Fermi (USA)	no SG, dump heat exchanger	-
FFTF (USA)	no SG, dump heat exchanger	-
BR-10 (Russian Federation)	no SG, dump heat exchanger	-
CEFR (China)	12 Cr Mo1 V	12 Cr Mo1 V

Demonstration or Prototype Fast Reactors

Phénix (France)	1 and 2% Cr	A42
SNR-300 (Germany)	X20 Cr Mo 12	15 Ni Cu Mo Nb 5
PFBR (India)	SA335 Gr P12	SA106 Gr.C
MONJU (Japan)	low alloy steel	carbon steel
PFR (UK)	2¼ Cr-1 Mo and 18/8/1	mild steel
CRBRP(USA)	2¼ Cr-1 Mo	SA106 Gr. B
BN-350 (Kazakhstan)	12 Cr 1Mo, V	carbon steel
BN-600 (Russian Federation)	12 Cr 1Mo, V	carbon steel Mn1
ALMR (USA)	2¼ Cr-1 Mo	2¼ Cr-1 Mo
KALIMER-150 (Republic of Korea)	carbon steel	carbon steel
SVBR-75/100 (Russian Federation)	to be determined	
BREST-OD-300 (Russian Federation)	Cr 18 Ni 10	Cr 18 Ni 10

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Steam (water) piping material	
	Hot leg	Cold leg
Super-Phénix 1 (France)	Cr 1 Mo Mn Si	Mn 1.2 Si
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	2¼ Cr-1 Mo	carbon steel
CDFR (UK)	9 Cr 1 Mo	mild steel
BN-1600 (Russian Federation)	not yet determined	-
BN-800 (Russian Federation)	12 Cr1 Mo,V	carbon steel, Mn1
EFR	20 Cr Mo 121	15 Ni Cu Mo Nb 5
ALMR (USA)	2¼ Cr 1 Mo	2¼ Cr 1 Mo
SVBR-75/100 (Russian Federation)	to be determined	-
BN-1800 (Russian Federation)	to be determined	-
BREST-1200 (Russian Federation)	Cr 18 Ni 10	Cr 18 Ni 10
JSFR-1500 (Japan)	carbon steel	carbon steel

6.7. Piping

Experimental Fast Reactors

Plant	Piping	
	Outer diameter of primary piping, hot leg (mm)	Thickness of primary piping, hot leg (mm)
Rapsodie (France)	302	4
KNK-II (Germany)	200	-
FBTR (India)	300	4
PEC (Italy)	609 (114*)	9.5 (6*)
JOYO (Japan)	510	9.5
DFR (UK)	101	3.5
BOR-60 (Russian Federation)	325	12
EBR-II (USA)	356	6.35
Fermi (USA)	760	9.5
FFTF (USA)	710	10
BR-10 (Russian Federation)	127	8
CEFR (China)**	-	-

Demonstration or Prototype Fast Reactors

Phénix (France)**	-	-
SNR-300 (Germany)	610	-
PFBR (India)**	-	-
MONJU (Japan)	810	11
PFR (UK)**	-	-
CRBRP (USA)	914	13
BN-350 (Kazakhstan)	630	13
BN-600 (Russian Federation) **	-	-
ALMR (USA)**	-	-
KALIMER-150 (Republic of Korea)**	-	-
SVBR-75/100 (Russian Federation)**	-	-
BREST-OD-300 (Russian Federation)**	-	-

* test channel
** pool type reactor

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Outer diameter of primary piping, hot leg (mm)	Thickness of primary piping, hot leg (mm)
Super-Phénix 1 (France)**	-	-
Super-Phénix 2 (France)**	-	-
SNR 2 (Germany)	900	-
DFBR (Japan)	965	15.9
CDFR (UK)**	-	-
BN-1600 (Russian Federation)**	-	-
BN-800 (Russian Federation)**	-	-
EFR**	-	-
ALMR (USA)**	-	-
SVBR-75/100 (Russian Federation)**	-	-
BN-1800 (Russian Federation)**	-	-
BREST-1200 (Russian Federation)**	-	-
JSFR-1500 (Japan)	1270	15.9

** pool type reactor

6.7. Piping

Experimental Fast Reactors

Plant	Piping	
	Outer diameter of secondary piping, hot leg (mm)	Thickness of secondary piping, hot leg (mm)
Rapsodie (France)	208	4
KNK-II (Germany)	200	-
FBTR (India)	200	8
PEC (Italy)	355.6 (114*)	8 (6*)
JOYO (Japan)	320	10.3
DFR (UK)	152	3.5
BOR-60 (Russian Federation)	325/219	12/10
EBR-II (USA)	305	6.35
Fermi (USA)	305	9.5
FFTF (USA)	405	10
BR-10 (Russian Federation)	127	8
CEFR (China)	219	10

Demonstration or Prototype Fast Reactors

Phénix (France)	510	6
SNR-300 (Germany)	610	-
PFBR (India)	558.8/406.4	8/10
MONJU (Japan)	560	9.5
PFR (UK)	360	10
CRBRP (USA)	610	13
BN-350 (Kazakhstan)	529/377	12/12
BN-600 (Russian Federation)	630	13
ALMR (USA)	711	13
KALIMER-150 (Republic of Korea)	356/508	7.9/9.5
SVBR-75/100 (Russian Federation)	none	
BREST-OD-300 (Russian Federation)	none	

* test channel

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Outer diameter of secondary piping, hot leg (mm)	Thickness of secondary piping, hot leg (mm)
Super-Phénix 1 (France)	700	11
Super-Phénix 2 (France)	760	-
SNR 2 (Germany)	800	-
DFBR (Japan)	711	12.7
CDFR (UK)	864	10
BN-1600 (Russian Federation)	820	13
BN-800 (Russian Federation)	630/820	12
EFR	711	11
ALMR (USA)	711	13
SVBR-75/100 (Russian Federation)	none	
BN-1800 (Russian Federation)	820	12
BREST-1200 (Russian Federation)	none	
JSFR-1500 (Japan)	1117.6	14.3

6.7. Piping

Experimental Fast Reacors

Plant	Piping	
	Outer diameter of steam (water) piping, hot leg (mm)	Thickness of steam (water) piping, hot leg (mm)
Rapsodie (France)	no SG, dump heat exchanger	
KNK-II (Germany)	no SG, dump heat exchanger	
FBTR (India)	100	13.5
PEC (Italy)	no SG, dump heat exchanger	
JOYO (Japan)	no SG, dump heat exchanger	
DFR (UK)	20	2
BOR-60 (Russian Federation)	100*	-
EBR-II (USA)	273	21.4
Fermi (USA)	305	-
FFTF (USA)	no SG, dump heat exchanger	
BR-10 (Russian Federation)	no SG, dump heat exchanger	
CEFR (China)	133	18.0

Demonstration or Prototype Fast Reactors

Phénix (France)	330	25
SNR-300 (Germany)	291	20.5
PFBR (India)	708.82	74.41
MONJU (Japan)	510	50
PFR (UK)	325	65
CRBRP (USA)	406	40.5
BN-350 (Kazakhstan)	350*	-
BN-600 (Russian Federation)	219	25
ALMR (USA)	508	38.1
KALIMER-150 (Republic of Korea)	to be determined	
SVBR-75/100 (Russian Federation)	250x2	20
BREST-OD-300 (Russian Federation)	273	36

* internal diameter

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Outer diameter of steam (water) piping, hot leg (mm)	Thickness of steam (water) piping, hot leg (mm)
Super-Phénix 1 (France)	458	42
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	508	72
CDFR (UK)	300	64
BN-1600 (Russian Federation)	500*	-
BN-800 (Russian Federation)	495	34
EFR	500*	-
ALMR (USA)	507	38.1
SVBR-75/100 (Russian Federation)	250x2	20
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	to be determined	
JSFR-1500 (Japan)	812.8	90

* internal diameter

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Experimental Fast Reactors

Plant	Piping		
	Outer diameter of primary piping, cold leg (mm)	Thickness of primary piping, cold leg (mm)	Outer diameter of secondary piping, cold leg (mm)
Rapsodie (France)	300	-	200
KNK-II (Germany)	200	-	200
FBTR (India)	300	4	200
PEC (Italy)	355.6 (114*)	8 (6*)	355.6 (114*)
JOYO (Japan)	450/300	7.9/6.5	300/250/200
DFR (UK)	101	-	152
BOR-60 (Russian Federation)	325/219	12/10	325/219/108
EBR-II (USA)	324*	10.3	324
Fermi (USA)	760	9.5	460/305
FFTF (USA)	405	10	405
BR-10 (Russian Federation)	127**	8**	127
CEFR (China)	127	8	325

Demonstration or Prototype Fast Reactors

Phénix (France)	-	-	510
SNR-300 (Germany)	560	-	560
PFBR (India)	620	10	812.8/558.8/406.4
MONJU (Japan)	610	9.5	560
PFR (UK)	-	-	610
CRBRP (USA)	610	13	457/610
BN-350 (Kazakhstan)	630/529	13/12	529/377
BN-600 (Russian Federation)	636***	16	820
ALMR (USA)	-	-	-
KALIMER-150 (Republic of Korea)	to be determined	-	356/508
SVBR-75/100 (Russian Federation)	none		
BREST-OD-300 (Russian Federation)	none		

* test channel
** for each of two primary pipes
*** two pipes per loop

6.7. Piping

Commercial Size Reactors

Plant	Piping		
	Outer diameter of primary piping, cold leg (mm)	Thickness of primary piping, cold leg (mm)	Outer diameter of secondary piping, cold leg (mm)
Super-Phénix 1 (France)	-	-	1000
Super-Phénix 2 (France)	-	-	1000
SNR 2 (Germany)	900		800
DFBR (Japan)	762	15.9	711
CDFR (UK)	-	-	864
BN-1 600 (Russian Federation)	1020****	20	920
BN-800 (Russian Federation)	820	12	630/820
EFR	885	14.5	711
ALMR (USA)	-	-	711
SVBR-75/100 (Russian Federation)	none		
BN-1800 (Russian Federation)	820	12	820
BREST-1200 (Russian Federation)	none		
JSFR-1500 (Japan)	863****	17.5	1117.6

**** two pipes per loop

6.7. Piping

Experimental Fast Reactors

Plant	Piping		
	Thickness of secondary piping, cold leg (mm)	Outer diameter of steam (water) piping, cold leg (mm)	Thickness of steam (water) piping, cold leg (mm)
Rapsodie (France)	-	-	-
KNK-II (Germany)	-	-	-
FBTR (India)	8	114.3	13.5
PEC (Italy)	8 (6*)	-	-
JOYO (Japan)	10.3/9.3/8.2	none	none
DFR (UK)	-	-	-
BOR-60 (Russian Federation)	8/6	100**	-
EBR-II (USA)	6.35	168	14.3
Fermi (USA)	9.5	200	-
FFTF (USA)	10	-	-
BR-10 (Russian Federation)	8	-	-
CEFR (China)	12	108	11.0

Demonstration or Prototype Fast Reactors

Phénix (France)	7	219	29
SNR-300 (Germany)	-	395	22.5
PFBR (India)	10/8/10	541.26	60.63
MONJU (Japan)	9.5	-	-
PFR (UK)	12	575	100
CRBRP (USA)	13	254	28.6
BN-350 (Kazakhstan)	12	250**	-
BN-600 (Russian Federation)	13	219	25
ALMR (USA)	13	406	36.5
KALIMER-150 (Republic of Korea)	7.9/9.5	to be determined	
SVBR-75/100 (Russian Federation)	none	150x2	15
BREST-OD-300 (Russian Federation)	none	194	30

* test channel
** internal diameter

6.7. Piping

Commercial Size Reactors

Plant	Piping		
	Thickness of secondary piping, cold leg (mm)	Outer diameter of steam (water) piping, cold leg (mm)	Thickness of steam (water) piping, cold leg (mm)
Super-Phénix 1 (France)	20	444	52
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	-	-	-
DFBR (Japan)	12.7	356	-
CDFR (UK)	-	-	-
BN-1600 (Russian Federation)	14	200	25
BN-800 (Russian Federation)	20	273	20
EFR	11	800**	-
ALMR (USA)	13	406	36.5
SVBR-75/100 (Russian Federation)	none	150x2	15
BN-1800 (Russian Federation)	to be determined		
BREST-1200 (Russian Federation)	none	to be determined	
JSFR-1500 (Japan)	14.3	609.6	50

** internal diameter

6.7. Piping

Experimental Fast Reactors

Plant	Piping	
	Provision of leak jacket	
	Primary	Secondary
Rapsodie (France)	yes	no
KNK-II (Germany)	yes*	no
FBTR (India)	yes	no
PEC (Italy)	yes (yes**)	no (no**)
JOYO (Japan)	yes	no
DFR (UK)	yes	no
BOR-60 (Russian Federation)	yes	no
EBR-II (USA)	yes	No
Fermi (USA)	no	no
FFTF (USA)	guard vessels	guard vessels
BR-10 (Russian Federation)	yes	no
CEFR (China)	not applicable	yes (partial)

Demonstration or Prototype Fast Reactors

Phénix (France)	not applicable	no
SNR-300 (Germany)	yes*	-
PFBR (India)	yes (for piping)	yes (for piping inside RCB)
MONJU (Japan)	guard vessels	no
PFR (UK)	not applicable	yes
CRBRP (USA)	guard vessels	guard vessels, catch pans
BN-350 (Kazakhstan)	yes	no
BN-600 (Russian Federation)	yes (for piping)	yes (for piping inside RCB)
ALMR (USA)	not applicable	yes
KALIMER-150 (Republic of Korea)	not applicable	yes
SVBR-75/100 (Russian Federation)	guard vessel	guard vessel
BREST-OD-300 (Russian Federation)	not applicable	not applicable

* below min. Na level
** test channel

6. HEAT TRANSPORT SYSTEM (cont.)

6.7. Piping

Commercial Size Reactors

Plant	Piping	
	Provision of leak jacket	
	Primary	Secondary
Super-Phénix 1 (France)	not applicable	no
Super-Phénix 2 (France)	not applicable	yes
SNR 2 (Germany)	not applicable	-
DFBR (Japan)	yes	yes
CDFR (UK)	not applicable	yes
BN-1600 (Russian Federation)	yes	no
BN-800 (Russian Federation)	yes	no
EFR	not applicable	yes
ALMR (USA)	not applicable	yes
SVBR-75/100 (Russian Federation)	guard vessel	guard vessel
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	not applicable	not applicable
JSFR-1500 (Japan)	yes	yes

6.8. Valving

Experimental Fast reactors

Plant	Valving			
	Primary			Secondary
	Hot leg stop	Cold leg stop	Check	Steam generator isolation
Rapsodie (France)	no	no	yes	-
KNK-II (Germany)	yes	yes	yes	no
FBTR (India)	no	no	yes	yes
PEC (Italy)	no (no)	no (no)	yes (yes)	-
JOYO (Japan)	no	no	yes	none
DFR (UK)	no	no	no	no (yes)
BOR-60 (Russian Federation)	yes	yes	yes	yes
EBR-II (USA)	no	-	no	no
Fermi (USA)	no	no	yes	no (yes)
FFTF (USA)	yes	yes	yes	-
BR-10 (Russian Federation)	yes	yes	yes	-
CEFR (China)	no	no	n/a	yes

Demonstration or Prototype Fast Reactors

Phénix (France)	no	no	yes	yes
SNR-300 (Germany)	no	no	yes	no
PFBR (India)	no	no	no	yes
MONJU (Japan)	no	no	yes	yes
PFR (UK)	yes	yes	no	yes
CRBRP (USA)	no	no	yes	yes
BN-350 (Kazakhstan)	yes	yes	yes	no
BN-600 (Russian Federation)	no	no	yes	yes
ALMR (USA)	no	no	no	yes
KALIMER-150 (Republic of Korea)	no	no	no	yes
SVBR-75/100 (Russian Federation)	no	no	no	no
BREST-OD-300 (Russian Federation)	no piping			yes

6.8. Valving

Commercial Size Reactors

Plant	Valving			
	Primary			Secondary
	Hot leg stop	Cold leg stop	Check	Steam generator isolation
Super-Phénix 1 (France)	no	no	no	no isolation valve on the sodium circuit
Super-Phénix 2 (France)	-	-	-	no
SNR 2 (Germany)	-	yes	-	-
DFBR (Japan)	no	no	no	no
CDFR (UK)	yes	yes	-	yes
BN-1600 (Russian Federation)	no	no	yes	yes
BN-800 (Russian Federation)	no	no	yes	yes
EFR	no	no	no	no isolation valve on the sodium circuit
ALMR (USA)	no	no	no	yes
SVBR-75/100 (Russian Federation)	no	no	no	no
BN-1800 (Russian Federation)	to be determined			
BREST-1200 (Russian Federation)	no piping			yes
JSFR-1500 (Japan)	no	no	no	no

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM

7.1. Reactor vessel (primary tank)

Experimental Fast Reactors

Plant	Reactor vessel (primary tank)			
	Dimension (mm)			Material
	Inside diameter	Thickness (minimum/ maximum)	Inside height	
Rapsodie (France)	2350	15		316
KNK-II (Germany)	1870	16	10150	1.6770
FBTR (India)	2350	15	-	316
PEC (Italy)	3080	30	10300	316
JOYO (Japan)	3600	25	10000	304
DFR (UK)	3200	12	6300	18/8/1
BOR-60 (Russian Federation)	1400	20	6200	Cr 18 Ni9
EBR-II (USA)	7920	19	3960	304
Fermi (USA)	4800(2800**)	50	11000	304
FFTF (USA)	6170	70	13130	304
BR-10 (Russian Federation)	338	7	4500	Cr 18 Ni 9
CEFR (China)	7960	25/50	12195	316

Demonstration or Prototype Fast Reactors

Phénix (France)	11820	15	12000	316
SNR-300 (Germany)	6700		15000	1.4948*
PFBR (India)	12850	25/40	12920	316LN
MONJU (Japan)	7100	50	17800	304
PFR (UK)	12200	25/50	15200	321
CRBRP (USA)	6170	60	17920	304
BN-350 (Kazakhstan)	6000	50	11900	Cr 18 Ni 9
BN-600 (Russian Federation)	12860	30	12600	Cr 18 Ni 9
ALMR (USA)	9118	51	19355	316
KALIMER-150 (Republic of Korea)	6920	50	18425	316
SVBR-75/100 (Russian Federation)	4130	35	7000	Cr 18 Ni 9
BREST-OD-300 (Russian Federation)	6800	40	14140	Cr 16 Ni 10

* 304 SS
** lower section

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.1. Reactor vessel (primary tank)

Commercial Size Reactors

Plant	Reactor vessel (primary tank)			
	Dimension (mm)			Material
	Inside diameter	Thickness (minimum/ maximum)	Inside height	
Super-Phénix 1 (France)	21000	25/60	17300	316
Super-Phénix 2 (France)	20000	20/35	16200	316
SNR 2 (Germany)	15000	-	-	304
DFBR (Japan)	10400	50	16000	316 FR
CDFR (UK)	19220	25	18100	316
BN-1600 (Russian Federation)	17000	25	14000	Cr 18 Ni 9
BN-800 (Russian Federation)	12900	30	14000	Cr 18 Ni 9
EFR	17200	35	15900	316
ALMR (USA)	9118	51	19355	316
SVBR-75/100 (Russian Federation)	4130	35	7000	Cr 18 Ni 9
BN-1800 (Russian Federation)	17000	25	19950	Cr 18 Ni 9
BREST-1200 (Russian Federation)	9000	50	~ 18600	Cr 16 Ni 10
JSFR-1500 (Japan)	10700	30	21200	316 FR

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps	
	Electrical (E) or Mechanical (M)	Main features
Rapsodie (France)	M	centrifugal
KNK-II (Germany)	M	centrifugal
FBTR (India)	M	centrifugal single section
PEC (Italy)	M	free surface centrifugal
JOYO (Japan)	M	single stage centrifugal
DFR (UK)	E	-
BOR-60 (Russian Federation)	M	centrifugal
EBR-II (USA)	-	centrifugal
Fermi (USA)	M	centrifugal
FFTF (USA)	M	free surface centrifugal
BR-10 (Russian Federation)	E	-
CEFR China)	M	centrifugal

Demonstration or Prototype Fast Reactors

Phénix (France)	-	single stage
SNR-300 (Germany)	-	centrifugal, single section
PFBR (India)	M	centrifugal, single stage, free surface, top suction
MONJU (Japan)	M	single stage centrifugal
PFR (UK)	M	centrifugal, double entry
CRBRP (USA)	M	free surface centrifugal
BN-350 (Kazakhstan)	M	centrifugal
BN-600 (Russian Federation)	M	centrifugal
ALMR (USA)	E	submersible, double statar, self cooled
KALIMER-150 (Republic of Korea)	E	submersible, double stator, self cooled
SVBR-75/100 (Russian Federation)	M	centrifugal, submersible
BREST-OD-300 (Russian Federation)	M	axial single section

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Commercial Size Fast Reactors

Plant	Main pumps	
	Electrical (E) or Mechanical (M)	Main features
Super-Phénix 1 (France)	M	single stage
Super-Phénix 2 (France)	M	single stage
SNR 2 (Germany)	-	centrifugal
DFBR (Japan)	M	single stage centrifugal
CDFR (UK)	M	centrifugal, multi-entry
BN-1600 (Russian Federation)	M	centrifugal
BN-800 (Russian Federation)	M	centrifugal
EFR	M	single stage centrifugal
ALMR (USA)	E	submersible, double stator, self cooled
SVBR-75/100 (Russian Federation)	M	centrifugal, submersible
BN-1800 (Russian Federation)	M	centrifugal
BREST-1200 (Russian Federation)	M	axial single section
JSFR-1500 (Japan)	M	single stage centrifugal

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps			
	Location		Pump capacity (m^3/min)	
	Primary	Secondary	Primary	Secondary
Rapsodie (France)	cold leg	hot leg	10.2	9.4
KNK-II (Germany)	hot leg	cold leg	10	8.6
FBTR (India)	cold leg	cold leg	11.0	6.2
PEC (Italy)	cold leg	cold leg	22.1(0.6*)	21.9 (1.1*)
JOYO (Japan)	cold leg	cold leg	26x2**	23x2***
DFR (UK)	cold leg	cold leg	1.3	1.3
BOR-60 (Russian Federation)	cold leg	cold leg	10	~ 14.0
EBR-II (USA)	cold leg	cold leg	34.1	22.3
Fermi (USA)	cold leg	cold leg	45	49
FFTF (USA)	hot leg	cold leg	56	56
BR-10 (Russian Federation)	cold leg	cold leg	3.3	3.3
CEFR (China)	cold leg	cold leg	14.25	9.5

Demonstration or Prototype Fast Reactors

Phénix (France)	cold leg	cold leg	63	52
SNR-300 (Germany)	hot leg	cold leg	86	76
PFBR (India)	cold leg	cold leg	247.8	200.4
MONJU (Japan)	cold leg	cold leg	100	71
PFR (UK)	cold leg	cold leg	84	75
CRBRP (USA)	hot leg	cold leg	130	115
BN-350 (Kazakhstan)	cold leg	cold leg	53.3	63.3
BN-600 (Russian Federation)	cold leg	cold leg	161.71	133.3
ALMR (USA)	cold leg	cold leg	82.5	151.7
KALIMER-150 (Republic of Korea)	cold leg	cold leg	35	62.14
SVBR-75/100 (Russian Federation)	cold leg	-	34.2	-
BREST-OD-300 (Russian Federation)	cold leg	-	72x4	-

* test channel
** 21x2 in MK-I, II
*** 21x2 in MK-I, II

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Commercial Size Fast Reactors

Plant	Main pumps			
	Location		Pump capacity (m^3/min)	
	Primary	Secondary	Primary	Secondary
Super-Phénix 1 (France)	cold leg	cold leg	290	230
Super-Phénix 2 (France)	cold leg	cold leg	350	270
SNR 2 (Germany)	hot leg	cold leg		
DFBR (Japan)	cold leg	cold leg	191	156
CDFR (UK)	cold leg	cold leg	310	300
BN-1600 (Russian Federation)	cold leg	cold leg	487	190
BN-800 (Russian Federation)	cold leg	cold leg	205	192
EFR	cold leg	cold leg	450	177
ALMR (USA)	cold leg	cold leg	82.5	151.7
SVBR-75/100 (Russian Federation)	cold leg	-	34.2	-
BN-1800 (Russian Federation)	cold leg	cold leg	-	-
BREST-1200 (Russian Federation)	cold leg	-	228.5x4	-
JSFR-1500 (Japan)	cold leg	cold leg	630x2	512x2

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps	
	Pump head (MPa)	
	Primary	Secondary
Rapsodie (France)	0.46	0.25
KNK-II (Germany)	-	-
FBTR (India)	0.46	0.3
PEC (Italy)	0.55 (1.24*)	0.2 (0.1*)
JOYO (Japan)	0.51**	0.35***
DFR (UK)	0.175	0.175
BOR-60 (Russian Federation)	0.85	0.6
EBR-II (USA)	0.386	-
Fermi (USA)	1.03	0.40
FFTF (USA)	1.01	0.81
BR-10 (Russian Federation)	0.3	0.3
CEFR (China)	0.38	0.35

Demonstration or Prototype Fast Reactors

Phénix (France)	0.5	0.4
SNR-300 (Germany)	0.685	0.833
PFBR (India)	0.63	0.55
MONJU (Japan)	0.8	0.5
PFR (UK)	0.8	0.4
CRBRP (USA)	1.12	0.86
BN-350 (Kazakhstan)	0.94	0.58
BN-600 (Russian Federation)	0.81	0.31
ALMR (USA)	0.76	0.34
KALIMER-150 (Republic of Korea)	0.8	0.4
SVBR-75/100 (Russian Federation)	0.55	-
BREST-OD-300 (Russian Federation)	0.225	-

* test channel
** 0.63 in MK-I, II
*** 0.37 in MK-I, II

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Commercial Size Fast Reactors

Plant	Main pumps	
	Pump head (MPa)	
	Primary	Secondary
Super-Phénix 1 (France)	0.53	0.25
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	0.8	0.48
CDFR (UK)	1.0	0.6
BN-1600 (Russian Federation)	0.5	0.331
BN-800 (Russian Federation)	0.82	0.42
EFR	0.6	0.457
ALMR (USA)	0.76	0.34
SVBR-75/100 (Russian Federation)	0.55	-
BN-1800 (Russian Federation)	~ 0.8	~ 0.4
BREST-1200 (Russian Federation)	0.2	-
JSFR-1500 (Japan)	0.639	0.335

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps			
	Speed (rev./min.)			
	Primary (nominal)	Secondary (nominal)	Primary (decay heat removal made using standby-supplies)	Secondary (decay heat removal made using standby-supplies)
Rapsodie (France)	1250	1000	-	-
KNK-II (Germany)	1430	1430	-	-
FBTR (India)	1500	1450	100	100
PEC (Italy)	681	1150	-	-
JOYO (Japan)	930	1060*	130 and EM pump	
DFR (UK)	-	-	-	-
BOR-60 (Russian Federation)	1200	1200	natural circulation	
EBR-II (USA)	880	-	-	-
Fermi (USA)	875	900	70	85
FFTF (USA)	1100	1110	110	110
BR-10 (Russian Federation)	-	-	-	-
CEFR (China)	990	900	150	150

Demonstration or Prototype Fast Reactors

Phénix (France)	820	800	100	100
SNR-300 (Germany)	960	960	-	-
PFBR (India)	590	900	89	-
MONJU (Japan)	850	1100	-	
PFR (UK)	950	950	96	0
CRBRP (USA)	1170	963	93	93
BN-350 (Kazakhstan)	1000	1000	250	250
BN-600 (Russian Federation)	1000	1000	250	250
ALMR (USA)	EM pumps		natural circulation	
KALIMER-150 (Republic of Korea)	EM pumps		natural circulation	
SVBR-75/100 (Russian Federation)	750	-	-	-
BREST-OD-300 (Russian Federation)	368	none	natural circulation	

* 975 in MK-I, II

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Commercial Size Fast Reactors

Plant	Main pumps: Speed (rev./min.) Primary (nominal)	Secondary (nominal)	Primary (decay heat removal made using standby-supplies)	Secondary (decay heat removal made using standby-supplies)
Super-Phénix 1 (France)	433	470	75	110
Super-Phénix 2 (France)	-	-	-	-
SNR 2 (Germany	-	-	-	-
DFBR (Japan)	855	875	128	114
CDFR (UK)	360	500	36	0
BN-1600 (Russian Federation)	600	1000	150	250
BN-800 (Russian Federation)	990	990	250	250
EFR	530	780	132.5	117
ALMR (USA)	EM pumps		natural circulation	
SVBR-75/100 (Russian Federation)	750	-	-	-
BN-1800 (Russian Federation)	600	-	natural circulation	
BREST-1200 (Russian Federation)	to be determined		natural circulation	
JSFR-1500 (Japan)	554	522	83	78

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps			
	Main pumps rating (kW)			
	Electrical power input			
	Primary (nominal)	Secondary (nominal)	Primary (under decay heat removal made using standby-supplies)	Secondary (under decay heat removal made using standby-supplies)
Rapsodie (France)	120	54	-	-
KNK-II (Germany)	-	-	-	-
FBTR (India)	150	55	2.5	-
PEC (Italy)	565 (73*)	155 (182*)	-	-
JOYO (Japan)	330	220	2.5	-
DFR (UK)	400	400	-	-
BOR-60 (Russian Federation)	285	-	-	-
EBR-II (USA)	260	-	-	-
Fermi (USA)	1000	350	-	-
FFTF (USA)	1520	1110	4.3	5.8
BR-10 (Russian Federation)	38	38	2.7	-
CEFR (China)	150	150	2	2

Demonstration or Prototype Fast Reactors

Phénix (France)	800	500	-	2
SNR-300 (Germany)	2400	1600	-	-
PFBR (India)	3600	2600	19	-
MONJU (Japan)	2000	800	22	22
PFR (UK)	4920	2010	18	0
CRBRP (USA)	3940	3940	18.6	18.6
BN-350 (Kazakhstan)	1700	1100	55	35
BN-600 (Russian Federation)	3150	1330	277	52
ALMR (USA)	1708	1448	-	-
KALIMER-150 (Republic of Korea)	850	850	to be determined	-
SVBR-75/100 (Russian Federation)	420	-	-	-
BREST-OD-300 (Russian Federation)	500	-	-	-

* test channel

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Commercial Size Reactors

Plant	Main pumps			
	Main pumps rating (kW)			
	Electrical power input			
	Primary (nominal)	Secondary (nominal)	Primary (under decay heat removal made using standby-supplies)	Secondary (under decay heat removal made using standby-supplies)
Super-Phénix 1 (France)	4170	1620	36	30
Super-Phénix 2 (France)	4500	2000	-	-
SNR 2 (Germany)	-	-	-	-
DFBR (Japan)	3400	900	to be determined	
CDFR (UK)	5500	4500	23	0
BN-1600 (Russian Federation)	6500	1500	150	75
BN-800 (Russian Federation)	4300	2000	250	-
EFR	to be determined	1660	to be determined	
ALMR (USA)	1708	1448	-	-
SVBR-75/100 (Russian Federation)	420	-	-	-
BN-1800 (Russian Federation)	7850	-	to be determined	
BREST-1200 (Russian Federation)	to be determined	-	-	-
JSFR-1500 (Japan)	9300	4000	to be determined	

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps	
	Principle of speed control	Operating range of speed control (% nominal flow)
Rapsodie (France)	Ward Leonard drive	-
KNK-II (Germany)	-	-
FBTR (India)	Ward Leonard drive	20-100
PEC (Italy)	-	15-100
JOYO (Japan)	static scherbius system	10-100*
DFR (UK)	voltage control	-
BOR-60 (Russian Federation)	Ward Leonard drive	20-100
EBR-II (USA)	variable frequency power supply	-
Fermi (USA)	constant speed	-
FFTF (USA)	-	50-100
BR-10 (Russian Federation)	variable voltage	0-100
CEFR (China)	variable frequency power supply	15-100

Demonstration or Prototype Fast Reactors

Phénix (France)	variable speed alternator	15-100
SNR-300 (Germany)	revolution regulated	-
PFBR (India)	variable frequency power supply	15-100
MONJU (Japan)	fluid coupled MG set	40-100
PFR (UK)	fluid coupling	20-100
CRBRP (USA)	variable frequency power supply	-
BN-350 (Kazakhstan)	two fixed speeds	25 and 100
BN-600 (Russian Federation)	variable frequency power supply	25-100
ALMR (USA)	variable frequency power supply	-
KALIMER-150 (Republic of Korea)	to be determined	-
SVBR-75/100 (Russian Federation)	one fixed speed	-
BREST-OD-300 (Russian Federation)	variable frequency power supply	30-100

* 30-100 in MK-I, II

7.2. Main pumps

Commercial Size Reactors

Plant	Main pumps	
	Principle of speed control	Operating range of speed control (% nominal flow)
Super-Phénix 1 (France)	variable speed alternator	15-100
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	variable frequency power supply	30-100
CDFR (UK)	fluid coupling	-
BN-1600 (Russian Federation)	to be determined	25-100
BN-800 (Russian Federation)	variable frequency power supply	25-100
EFR	variable frequency power supply	25-100
ALMR (USA)	variable frequency power supply	-
SVBR-75/100 (Russian Federation)	one fixed speed	-
BN-1800 (Russian Federation)	variable frequency power supply	25-100
BREST-1200 (Russian Federation)	variable frequency power supply	30-100
JSFR-1500 (Japan)	variable frequency power supply	15-100

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps	
	Materials of construction	
	Shaft	Hard facing alloy used in hydrostatic bearing
Rapsodie (France)	-	colmonoy
KNK-II (Germany)	-	-
FBTR (India)	921Cr/2Ni/2.7W	colmonoy
PEC (Italy)	Z15CNW22-12 (Norm. AFNOR)	stellite-12* (stellite-6**)
JOYO (Japan)	SCS13	stellite and 304
DFR (UK)	-	18/8/1
BOR-60 (Russian Federation)	SS	stellite
EBR-II (USA)	304	colmonoy
Fermi (USA)	304	colmonoy
FFTF (USA)	304	stellite-6
BR-10 (Russian Federation)	EM pumps	
CEFR (China)	304	stellite

Demonstration or Prototype Fast Reactors

Phénix (France)	-	colmonoy
SNR-300 (Germany)	-	-
PFBR (India)	304 LN	colmonoy
MONJU (Japan)	304	-
PFR (UK)	316	stellite
CRBRP (USA)	316	stellite
BN-350 (Kazakhstan)	SS	not applicable
BN-600 (Russian Federation)	SS	stellite
ALMR (USA)	EM pumps	
KALIMER-150 (Republic of Korea)	to be determined	
SVBR-75/100 (Russian Federation)	special steel	
BREST-OD-300 (Russian Federation)	Cr16Ni10	SiC

* rotating part
** fixed part

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Commercial Size Reactors

Plant	Main pumps	
	Materials of construction	
	Shaft	Hard facing alloy used in hydrostatic bearing
Super-Phénix 1 (France)	Cr 22 ni 12	colmonoy
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	-	-
CDFR (UK)	316	stellite
BN-1600 (Russian Federation)	SS	stellite
BN-800 (Russian Federation)	SS	stellite
EFR	-	stellite or colmonoy
ALMR (USA)	EM pumps	
SVBR-75/100 (Russian Federation)	special steel	
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	Cr16Ni10	to be determined
JSFR-1500 (Japan)	12Cr-Steel	12Cr-Steel

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.2. Main pumps

Experimental Fast Reactors

Plant	Main pumps	
	Materials of construction	
	Impeller	Diffuser
Rapsodie (France)	316	316
KNK-II (Germany)	-	-
FBTR (India)	316	316
PEC (Italy)	Z6CND 19-10 (CF 814) (Norm. AFNOR)	same as impeller
JOYO (Japan)	SCS13	SCS13
DFR (UK)	-	-
BOR-60 (Russian Federation)	SS	SS
EBR-II (USA)	304	304
Fermi (USA)	304	304
FFTF (USA)	304	304
BR-10 (Russian Federation)	-	-
CEFR (China)	316	316

Demonstration or Prototype Fast Reactors

Phénix (France)	316	316
SNR-300 (Germany)	-	-
PFBR (India)	CF 3	CF 3
MONJU (Japan)	304	304
PFR (UK)	316	316
CRBRP (USA)	316	316
BN-350 (Kazakhstan)	SS	SS
BN-600 (Russian Federation)	SS	SS
ALMR (USA)	-	
KALIMER-150 (Republic of Korea)	to be determined	
SVBR-75/100 (Russian Federation)	special steel	
BREST-OD-300 (Russian Federation)	Cr16Ni10	Cr16Ni10

7.2. Main pumps

Commercial Size Reactors

Plant	Main pumps	
	Materials of construction	
	Impeller	Diffuser
Super-Phénix 1 (France)	Cr 22 Ni 10 Mn Si	
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	304	304
CDFR (UK)	316	316
BN-1600 (Russian Federation)	SS	SS
BN-800 (Russian Federation)	SS	SS
EFR	-	-
ALMR (USA)	Cr 22 Ni 10 Mn Si	
SVBR-75/100 (Russian Federation)	special steel	
BN-1800 (Russian Federation)	to be determined	
BREST-1200 (Russian Federation)	Cr16Ni10	Cr16Ni10
JSFR-1500 (Japan)	12Cr-Stee	12Cr-Steel

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX) Configuration of IHX - all designs are shell and straight tube, counterflow, with the primary coolant on the shell side, except where stated
Rapsodie (France)	shell and tubes, interm. coolant ins. tubes
KNK-II (Germany)	cross-counter-flow heat exchanger
FBTR (India)	shell and tubes, counter flow, primary coolant on shell side
PEC (Italy)	straight tube, counter flow, primary coolant on shell side, removable tube bundle
JOYO (Japan)	straight tube, counter flow, primart coolant on shell side, removable tube bundle
DFR (UK)	concentric tubes
BOR-60 (Russian Federation)	shell and straight tubes with floating head
EBR-II (USA)	straight tube counter flow
Fermi (USA)	shell and straight tube counter flow
FFTF (USA)	shell and straight tube counter flow
BR-10 (Russian Federation)	shell and straight tube flow
CEFR (China)	shell and tubes, with primary coolant in shell

Demonstration or Prototype Fast Reactors

Phénix (France)	shell and tubes with primary coolant in shell
SNR-300 (Germany)	straight tube with floating lower head
PFBR (India)	shell and tube, straight tubes, primary coolant on shell side
MONJU (Japan)	straight tube, counter flow, primary coolant on shell side
PFR (UK)	shell and tube, straight tubes, primary coolant in tubes
CRBRP (USA)	shell and tube, vertical, counter flow
BN-350 (Kazakhstan)	2 shells each containing 3 tube bundles, per loop
BN-600 (Russian Federation)	shell and tube, with primary coolant in shell
ALMR (USA)	shell and tube, with primary coolant in shell; kidney shaped
KALIMER-150 (Republic of Korea)	shell and tube, with primary coolant in shell
SVBR-75/100 (Russian Federation)	none
BREST-OD-300 (Russian Federation)	none

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX) Configuration of IHX - all designs are shell and straight tube, counterflow, with the primary coolant on the shell side, except where stated
Super-Phénix 1 (France)	shell and tubes with primary coolant in shell
Super-Phénix 2 (France)	shell and tubes with primary coolant in shell
SNR 2 (Germany)	straight tube, primary coolant on shell side removable bundle
DFBR (Japan)	straight tube,counter flow,withprimary coolant in tubes
CDFR (UK)	shell and tube, with primary coolant in tubes
BN-1600 (Russian Federation)	shell and tube, with primary coolant in shell
BN-800 (Russian Federation)	shell and tube, with primary coolant in shell
EFR	shell and tube, with primary coolant in shell
ALMR (USA)	and tube, with primary coolant in shell; kidney shaped shell
SVBR-75/100 (Russian Federation)	none
BN-1800 (Russian Federation)	shell and tube, with primary coolant in shell
BREST-1200 (Russian Federation)	none
JSFR-1500 (Japan)	straight tube, counter flow, prim. cool. in tubes

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX)		
	Coolant temperature (°C)		
	No. of units per primary loop	Primary inlet	Primary outlet
Rapsodie (France)	1	510	404
KNK-II (Germany)	2	525	360
FBTR (India)	1	380	515
PEC (Italy)	1 (1*)	545 (600 Max*)	400 (450 Max*)
JOYO (Japan)	1	500	350 (370 in MK-I, II)
DFR (UK)	1	350	200
BOR-60 (Russian Federation)	1	600	360
EBR-II (USA)	1	473	371
Fermi (USA)	1	427	288
FFTF (USA)	1	503	360
BR-10 (Russian Federation)	1	470	350
CEFR (China)	2	516	353

Demonstration or Prototype Fast Reactors

Phénix (France)	2	560	395
SNR-300 (Germany)	3	546	377
PFBR (India)	2	544	394
MONJU (Japan)	1	529	397
PFR (UK)	2	560	399
CRBRP (USA)	1	535	388
BN-350 (Kazakhstan)	2	430	280
BN-600 (Russian Federation)	2	535	365
ALMR (USA)	1	478	358
KALIMER-150 (Republic of Korea)	4	529.8	385
SVBR-75/100 (Russian Federation)	none		
BREST-OD-300 (Russian Federation)	none		

* test channel

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX)		
		Coolant temperature (°C)	
	No. of units per primary loop	Primary inlet	Primary outlet
Super-Phénix 1 (France)	2	542	392
Super-Phénix 2 (France)	2	544	395
SNR 2 (Germany)	2	-	-
DFBR (Japan)	1	550	395
CDFR (UK)	2	539	368
BN-1600 (Russian Federation)	2	550	395
BN-800 (Russian Federation)	2	547	354
EFR	2	545	395
ALMR (USA)	1	478	358
SVBR-75/100 (Russian Federation)	none		
BN-1800 (Russian Federation)	2	575	410
BREST-1200 (Russian Federation)	none		
JSFR-1500 (Japan)	1	550	395

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX)	
	Coolant temperature (°C)	
	Secondary inlet	Secondary outlet
Rapsodie (France)	358	498
KNK-II (Germany)	322	504
FBTR (India)	284	510
PEC (Italy)	350 (435 Max*)	495 (585 Max*)
JOYO (Japan)	300 (340 in MK-I, II)	470
DFR (UK)	195	345
BOR-60 (Russian Federation)	320	565
EBR-II (USA)	307	465
Fermi (USA)	269	408
FFTF (USA)	316	459
BR-10 (Russian Federation)	270	380
CEFR (China)	310	495

Demonstration or Prototype Fast Reactors

Phénix (France)	350	540
SNR-300 (Germany)	335	520
PFBR (India)	355	525
MONJU (Japan)	325	505
PFR (UK)	370	540
CRBRP (USA)	344	502
BN-350 (Kazakhstan)	273	453
BN-600 (Russian Federation)	315	510
ALMR (USA)	325	477
KALIMER-150 (Republic of Korea)	339.7	511
SVBR-75/100 (Russian Federation)	none	
BREST-OD-300 (Russian Federation)	none	

* test channel

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX) Coolant temperature (°C)	
	Secondary inlet	Secondary outlet
Super-Phénix 1 (France)	345	525
Super-Phénix 2 (France)	345	525
SNR 2 (Germany)	-	-
DFBR (Japan)	335	520
CDFR (UK)	335	510
BN-1600 (Russian Federation)	345	515
BN-800 (Russian Federation)	309	505
EFR	340	525
ALMR (USA)	325	477
SVBR-75/100 (Russian Federation)	none	
BN-1800 (Russian Federation)	370	540
BREST-1200 (Russian Federation)	none	
JSFR-1500 (Japan)	335	520

7.3. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX)		
	Heat transfer capacity (MW per IHX)	Heat transfer area (m^2) (based on tube O.D, per IHX)	No. of tubes per IHX
Rapsodie (France)	18.6	92.0	888
KNK-II (Germany)	29	420	112
FBTR (India)	25 max	86.5	888
PEC (Italy)	58 (3*)	150 (9.7*)	1185 (183*)
JOYO (Japan)	70 (50 in MK- I, II)	363 (356, 352**)	2088 (1812**)
DFR (UK)	2.5	35	1
BOR-60 (Russian Federation)	30	215	1158
EBR-II (USA)	62	455	3248
Fermi (USA)	66.7	630	1860
FFTF (USA)	133	440	1540
BR-10 (Russian Federation)	4	9.5	85
CEFR (China)	16.4	112.1	540

Demonstration or Prototype Fast Reactors

Phénix (France)	94	450	2279
SNR-300 (Germany)	85	399	846
PFBR (India)	314.7	1612	3600
MONJU (Japan)	238		3200
PFR (UK)	100	239	1808
CRBRP (USA)	325	468	2850
BN-350 (Kazakhstan)	75	558	1029
BN-600 (Russian Federation)	245	590	4974
ALMR (USA)	424	2000	5519
KALIMER-150 (Republic of Korea)	98.75	407	1702
SVBR-75/100 (Russian Federation)	none		
BREST-OD-300 (Russian Federation)	none		

* test channel
** in MK- I, II, respectively

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX)		
	Heat transfer capacity (MW per IHX)	Heat transfer area (m^2) (based on tube O.D, per IHX)	No. of tubes per IHX
Super-Phénix 1 (France)	375	1550	5380
Super-Phénix 2 (France)	450	-	-
SNR 2 (Germany)	-	-	-
DFBR (Japan)	534	1760	4392
CDFR (UK)	475	2718	-
BN-1600 (Russian Federation)	642	2340	6210
BN-800 (Russian Federation)	350	1657	4956
EFR	600	2037	5022
ALMR (USA)	424	2000	5519
SVBR-75/100 (Russian Federation)	none		
BN-1800 (Russian Federation)	667	2447	5226
BREST-1200 (Russian Federation)	none		
JSFR-1500 (Japan)	1765	4405	9200

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX)				
	Dimension, shell (mm)		Dimension, tube (mm)		
	Outer diameter	Thickness	Outer diameter	Thickness	Length
Rapsodie (France)	700	8	14	1	2360
KNK-II (Germany)	1750	-	30	2	-
FBTR (India)	900	8	14	1	3450
PEC (Italy)	874 (350*)	6 (6*)	14 (14*)	1 (1*)	2865 (1200*)
JOYO (Japan)	1840 (1800)**	19 (18)	19 (22.2)	1.0 (1.2)	2930 (4130)
DFR (UK)	165	3.6	100	1.6	10700
BOR-60 (Russian Federation)	1200	20	20	2	3000
EBR-II (USA)	1820	-	16	1.24	3120
Fermi (USA)	1450	-	22.2	1.24	4660
FFTF (USA)	1990	30.2	22	1.2	6050
BR-10 (Russian Federation)	338	14	22	2.0	1590
CEFR (China)	980	25/10	16	1.4	3280

Demonstration or Prototype Fast Reactors

Phénix (France)	1210	-	14	1	5300
SNR-300 (Germany)	1350	-	21	1.4	7150
PFBR (India)	1900/1850	16.5	19	0.8	8050
MONJU (Japan)	3000	30	21.7	1.2	-
PFR (UK)	1441	12	19	1	4426
CRBRP (USA)	2670	41.3	22.2	1.14	7876
BN-350(Kazakhstan)	200x3000***	24	28	2	7000
BN-600 (Russian Federation)	2070	15	16	1.4	6360
ALMR (USA)	1073x4991****	19	15.9	0.89	7263
KALIMER-150 (Republic of Korea)	1046.5	20	12.7	0.8	6000
SVBR-75/100 (Russian Federation)	none				
BREST-OD-300 (Russian Federation)	none				

* test channel
** in MK-I , II, respectively
*** rectangular cross-section
**** kidney shaped cross-section

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX)				
	Dimension, shell (mm)		Dimension, tube (mm)		
	Outer diameter	Thickness	Outer diameter	Thickness	Length
Super- Phénix 1 (France)	1830	8	14	1	6540
Super- Phénix 2 (France)	1940	-	-	-	-
SNR 2 (Germany)	-	-	-	-	-
DFBR (Japan)	2850		25.4	1.0	5400
CDFR (UK)	2500	20	25	1.0	8400
BN-1600 (Russian Federation)	2488	16	16	1.0	7455
BN-800 (Russian Federation)	2020	39	16	1.4	6615
EFR	2302	8	17.1	0.8	7550
ALMR (USA)	1073x4991****	19	15.9	0.89	7263
SVBR-75/100 (Russian Federation)	none				
BN-1800 (Russian Federation)	2450	25	16	1.0	9314
BREST-1200 (Russian Federation)	none				
JSFR-1500 (Japan)	5300	25	25.4	1.1	6000

**** kidney shaped cross-section

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX)	
	Material	
	Shell	Tube
Rapsodie (France)	316	316
KNK-II (Germany)	1.6770	1.6770
FBTR (India)	316	316
PEC (Italy)	316 (316*)	316 (316*)
JOYO (Japan)	316FR (304)**	316FR (304)**
DFR (UK)	18/8/1	18/8/1
BOR-60 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
EBR-II (USA)	304	304
Fermi (USA)	304	304
FFTF (USA)	304	304
BR-10 (Russian Federation)	Cr 18 Ni 9 Ti	Cr 18 Ni 9 Ti
CFER (China)	316	316

Demonstration or Prototype Fast Reactors

Phénix (France)	316	316
SNR-300 (Germany)	1.4948	1.4948
PFBR (India)	316 LN	316 LN
MONJU (Japan)	304	304
PFR (UK)	316 (BS 1501)	316 (BS 3605)
CRBRP (USA)	304 and 316	TP 304H
BN-350 (Kazakhstan)	Cr 18 Ni 9	Cr 18 Ni 9
BN-600 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
ALMR (USA)	304	304
KALIMER-150 (Republic of Korea)	304	304
SVBR-75/100 (Russian Federation)	none	
BREST-OD-300 (Russian Federation)	none	

* test channel

** in MK-I, II

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.3. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX)	
	Material	
	Shell	Tube
Super-Phénix 1 (France)	Cr 18 Ni 12 Mo 2.5 Mn 1.8 Si	-
Super-Phénix 2 (France)	316	316
SNR 2 (Germany)	-	-
DFBR (Japan)	316 FR	316 FR
CDFR (UK)	316	316
BN-1600 (Russian Federation)	Cr 18 Ni 9	Cr 18 Ni 9
BN-800 (Russian Federation)	Cr 16 Ni 11 M 3	Cr 18 Ni 9 M 3
EFR	-	-
ALMR (USA)	304	304
SVBR-75/100 (Russian Federation)	none	
BN-1800 (Russian Federation)	Cr 16 Ni 11 M 3	Cr 18 Ni 9 M 3
BREST-1200 (Russian Federation)	none	
JSFR-1500 (Japan)	12Cr-Steel	12Cr-Steel

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators
	Configuration and type of steam cycle
Rapsodie (France)	no steam generator
KNK-II (Germany)	once-through evaporator, twin tubes
FBTR (India)	once through; triple S shaped tubes
PEC (Italy)	no steam generator
JOYO (Japan)	no steam generator
DFR (UK)	parallel tubes in copper heat transfer block
BOR-60 (Russian Federation)	*
EBR-II (USA)	once through; straight double wall tubes
Fermi (USA)	once through; cross and counter flow; helical coil helical coil
FFTF (USA)	no steam generators
BR-10 (Russian Federation)	no steam generator
CEFR (China)	once through; straight tubes, evaporator and superheater

Demonstration or Prototype Fast Reactors

Phénix (France)	once-through, vertical bank of large S-shaped tubes, each containing small pipes for water
SNR-300 (Germany)	once-through evaporator and separate superheater, tubes straight in 2 loops, helical in 3rd
PFBR (India)	once-through, straight tubes with evaporator and superheater in one unit
MONJU (Japan)	once-through evaporator and separate superheater; helical coiled; intermediate coolant on shell side
PFR (UK)	forced recirculation evaporator and drum separate superheater; separate reheater
CRBRP (USA)	forced recirculation evaporator modules feed one steam drum, separate superheater modules
BN-350 (Kazakhstan)	shell and tubes, Fild's tubes in evaporator, U-tubes in superheater**
BN-600 (Russian Federation)	shell and straight tubes, module type
ALMR (USA)	once-through helical coil
KALIMER-150 (Republic of Korea)	to be determined, evaporator and superheater in one unit
SVBR-75/100 (Russian Federation)	natural recirculation, Fild's tubes, evaporator with steam drum
BREST-OD-300 (Russian Federation)	once-through, helical coil evaporator and superheater in one unit

* five different type once through SG's were tested including those of Czech manufacture

** Czech SG's were in operation in two loops

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators
	Configuration and type of steam cycle
Super-Phénix 1 (France)	once-through evaporator and superheater with helical tubes
Super-Phénix 2 (France)	once-through evaporator and superheater with helical tubes
SNR 2 (Germany)	once-through, straight or coiled tube, intermediate coolant on shell side
DFBR (Japan)	once-through helical tubes
CDFR (UK)	once-through 'J' tubes
BN-1600 (Russian Federation)	not decided finally
BN-800 (Russian Federation)	shell-and straight tubes, module type
EFR	once-through, straight tubes with bellows on shell
ALMR (USA)	once-through helical coil
SVBR-75/100 (Russian Federation)	natural recirculation, Fild's tubes, evaporator with steam drum
BN-1800 (Russian Federation)	once-through, vessel-type (evaporator and superheater in one unit)
BREST-1200 (Russian Federation)	once-through, helical coil evaporator and superheater in one unit
JSFR-1500 (Japan)	once-through, double-wall straight tubes

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators		
	No. of evaporators per secondary loop	No. of superheaters per secondary loop	No. of reheaters per secondary loop
Rapsodie (France)	no steam generator		
KNK-II (Germany)	1*	-	0
FBTR (India)	2*	-	0
PEC (Italy)	no steam generator		
JOYO (Japan)	no steam generator		
DFR (UK)	12	12	0
BOR-60 (Russian Federation)	1	1	0
EBR-II (USA)	8	2	0
Fermi (USA)	1	1	1
FFTF (USA)	no steam generator		
BR-10 (Russian Federation)	no steam generator		
CEFR (China)	1	1	0

Demonstration or Prototype Fast Reactors

Phénix (France)	12	12	12
SNR-300 (Germany)	3	3	1 (steam heated)
PFBR (India)	4*	-	-
MONJU (Japan)	1	1	0
PFR (UK)	1	1	1
CRBRP (USA)	2	1	0
BN-350 (Kazakhstan)	2	2	0
BN-600 (Russian Federation)	8	8	8
ALMR (USA)	1	0	0
KALIMER-150 (Republic of Korea)	1	-	to be determined
SVBR-75/100 (Russian Federation)	2 (6 modules)	-	
BREST-OD-300 (Russian Federation)	1	-	0

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators		
	No. of evaporators per secondary loop	No. of superheaters per secondary loop	No. of reheaters per secondary loop
Super-Phénix 1 (France)	1*	-	0
Super-Phénix 2 (France)	1	1	0
SNR 2 (Germany)	2-4	2-4	0
DFBR (Japan)	1*	-	0
CDFR (UK)	2	2	0
BN-1600 (Russian Federation)	2*	-	0
BN-800 (Russian Federation)	10	10	0
EFR	1*	-	0
ALMR (USA)	1*	-	0
SVBR-75/100 (Russian Federation)	2 (6 modules)	-	-
BN-1800 (Russian Federation)	1*	-	0
BREST-1200 (Russian Federation)	1*	-	0
JSFR-1500 (Japan)	1*	-	0

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

	Steam generators					
	Coolant temperature (°C)					
	Evaporator		Superheater		Reheater	
Plant	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Rapsodie (France)	no steam generator					
KNK-II (Germany)	*	322	504	*	-	-
FBTR (India)	*	284	510	-	-	-
PEC (Italy)	no steam generator					
JOYO (Japan)	no steam generator					
DFR (UK)	295	215	325	295	-	-
BOR-60 (Russian Federation)	*	300	450	*	-	-
EBR-II (USA)	430	304	465	430	-	-
Fermi (USA)	385	290	408	385	269	290
FFTF (USA)	no steam generator					
BR-10 (Russian Federation)	no steam generator					
CEFR (China)	463.3	310	495	463.3		

Demonstration or Prototype Fast Reactors

Phénix (France)	478	350	550	473	550	473
SNR-300 (Germany)	455	335	520	455		
PFBR (India)	*	355	525	*		
MONJU (Japan)	469	325	505	469		
PFR (UK)	480	370	540	470	540	500
CRBRP (USA)	452	344	502	465		
BN-350 (Kazakhstan)	391	260	417	319		
BN-600 (Russian Federation)	449	328	518	449	518	449
ALMR (USA)	*	326	477	*	-	-
KALIMER-150 (Republic of Korea)	*	339	511	*	-	-
SVBR-75/100 (Russian Federation)	435	268	no superheater		-	-
BREST-OD-300 (Russian Federation)	*	420	540	*	-	-

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

	Steam generators					
	Coolant temperature (°C)					
	Evaporator		Superheater		Reheater	
Plant	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
Super-Phénix 1 (France)	*	345	525	*	-	-
Super-Phénix 2 (France)	*	345	525	*	-	-
SNR 2 (Germany)	-	-	-	-	-	-
DFBR (Japan)	*	335	520	*	-	-
CDFR (UK)	510	335	510	335	-	-
BN-1600 (Russian Federation)	*	345	515	*	-	-
BN-800 (Russian Federation)	451	309	505	451	-	-
EFR	*	340	525	*	-	-
ALMR (USA)	*	326	477	*	-	-
SVBR-75/100 (Russian Federation)	435	268	no superheater		-	-
BN-1800 (Russian Federation)	*	370	540	*	-	-
BREST-1200 (Russian Federation)	*	420	540	*	-	-
JSFR-1500 (Japan)	*	335	520	*	-	-

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

	Steam generators			
	Water (steam) temperature (°C)			
	Evaporator		Superheater	
Plant	Inlet	Outlet	Inlet	Outlet
Rapsodie (France)	no steam generator			
KNK-II (Germany)	239	*	*	485
FBTR (India)	200	*	*	480
PEC (Italy)	no steam generator			
JOYO (Japan)	no steam generator			
DFR (UK)	191	194	194	274
BOR-60 (Russian Federation)	200	298	298	440438
EBR-II (USA)	304	304	304	
Fermi (USA)	-	-	-	407
FFTF (USA)	no steam generator			
BR-10 (Russian Federation)	no steam generator			
CEFR (China)	190	370.3	370.3	480

Demonstration or Prototype Fast Reactors

Phénix (France)	249	380	380	516
SNR-300 (Germany)	253	360	355	500
PFBR (India)	235	493	*	*
MONJU (Japan)	240	369	367	487
PFR (UK)	310	330	330	515
CRBRP (USA)	287	331	331	482
BN-350 (Kazakhstan)	158	256	256	415
BN-600 (Russian Federation)	240	366	366	505
ALMR (USA)	215	*	*	454
KALIMER-150 (Republic of Korea)	230	*	*	483.2
SVBR-75/100 (Russian Federation)	225	260	no superheater	
BREST-OD-300 (Russian Federation)	355	*	*	525

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

	Steam generators			
	Water (steam) temperature (°C)			
	Evaporator		Superheater	
Plant	Inlet	Outlet	Inlet	Outlet
Super-Phénix 1 (France)	237	*	*	490
Super-Phénix 2 (France)	237	*	*	490
SNR 2 (Germany)	-	-	-	-
DFBR (Japan)	240	*	*	497
CDFR (UK)	196	-	-	490
BN-1600 (Russian Federation)	240	*	*	495
BN-800 (Russian Federation)	210	382	382	490
EFR	240	*	*	490
ALMR (USA)	215	*	*	454
SVBR-75/100 (Russian Federation)	277	307	no superheater	
BN-1800 (Russian Federation)	270	*	*	~ 530
BREST-1200 (Russian Federation)	355	*	*	525
JSFR-1500 (Japan)	240	*	*	497

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

	Steam generators			
	Water (steam) temperature, reheater (°C)		Pressure of steam at outlet (Mpa)	
Plant	Inlet	Outlet	Superheater	Reheater
Rapsodie (France)	no steam generator			
KNK-II (Germany)	-	-	-	
FBTR (India)	-	-	-	12.6
PEC (Italy)	no steam generator			
JOYO (Japan)	no steam generator			
DFR (UK)	-	-	-	1.3
BOR-60 (Russian Federation)	-		-	8.8
EBR-II (USA)	-	-	-	8.83
Fermi (USA)	171	-	-	4.1
FFTF (USA)	no steam generator			
BR-10 (Russian Federation)	no steam generator			
CEFR (China)	-	-	-	14

Demonstration or Prototype Fast Reactors

Phénix (France)	318	525	16.3	3.5
SNR-300 (Germany)	-	-	16.7	-
PFBR (India)	-	-	17.2	-
MONJU (Japan)	-	-	12.5	
PFR (UK)	325	525	13.5	3.18
CRBRP (USA)			10.69	-
BN-350 (Kazakhstan)	-		4.9	-
BN-600 (Russian Federation)	300	505	13.7	2.6
ALMR (USA)	-	-	15.5	-
KALIMER-150 (Republic of Korea)	no reheater		15.5	
SVBR-75/100 (Russian Federation)	no superheater, pressure outlet of evaporator 4.7			
BREST-OD-300 (Russian Federation)	-	-	26.0	-

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

	Steam generators			
	Water (steam) temperature, reheater (°C)		Pressure of steam at outlet (MPa)	
Plant	Inlet	Outlet	Superheater	Reheater
Super-Phénix 1 (France)	-	-	18.4	-
Super-Phénix 2 (France)	-	-	18.4	-
SNR 2 (Germany)	-	-	-	-
DFBR (Japan)	-	-	17.2	-
CDFR (UK)	-	-	17.4	-
BN-1600 (Russian Federation)	-	-	13.7	-
BN-800 (Russian Federation)	-	-	13.7	-
EFR	-	-	18.5	-
ALMR (USA)	-	-	15.5	-
SVBR-75/100 (Russian Federation)	no superheater, pressure outlet of evaporator 9.5			
BN-1800 (Russian Federation)	275	525	25	3.5
BREST-1200 (Russian Federation)	-	-	26	-
JSFR-1500 (Japan)	-	-	19.2	-

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

	Steam generators		
	Tube material		
Plant	Evaporator	Superheater	Reheater
Rapsodie (France)	no steam generator		
KNK-II (Germany)	1.6770	-	-
FBTR (India)	2.25 Cr-1 Mo stab	2.25 Cr -1 Mo stab	-
PEC (Italy)	no steam generator		
JOYO (Japan)	no steam generator		
DFR (UK)	18/8/1	18/8/1	-
BOR-60 (Russian Federation)	2.25 Cr 1 Mo	2.25 Cr1 Mo and SS	-
EBR-II (USA)	2.25 Cr -1 Mo	2.25 Cr -1 Mo	-
Fermi (USA)	2.25 Cr -1 Mo	2.25 Cr -1 Mo	2.25 Cr -1 Mo
FFTF (USA)	no steam generator		
BR-10 (Russian Federation)	no steam generator		
CEFR (China)	2.25 Cr -1 Mo	2.25 Cr -1 Mo	-

Demonstration or Prototype Fast Reactors

Phénix (France)	2.25 Cr -1 Mo stab.+unstab	321 H	321 H
SNR-300 (Germany)	1.6770, 2.25 Cr-l Mo Nb stab	2.25 Cr -1 Mo Nb stab	-
PFBR (India)	Modified 9 Cr 1 Mo, evaporator and superheater in one unit	-	-
MONJU (Japan)	2.25 Cr -1 Mo	austenitic	
PFR (UK)	2.25 Cr -1 Mo Nb stab	9 Cr-1 Mo	9 Cr-1 Mo
CRBRP (USA)	2.25 Cr -1 Mo	2.25 Cr -1 Mo	-
BN-350 (Kazakhstan)	2.25 Cr -1 Mo	2.25 Cr -1 Mo	-
BN-600 (Russian Federation)	2.25 Cr -1 Mo	Cr 18 Ni 9	Cr 18 Ni 9
ALMR (USA)	2.25 Cr -1 Mo, evaporator and superheater in one unit		-
KALIMER-150 (Republic of Korea)	2.25 Cr -1 Mo, evaporator and superheater in one unit		-
SVBR-75/100 (Russian Federation)	duplex tube, no superheater and reheater		
BREST-OD-300 (Russian Federation)	9Cr -1 Mo, evaporator and superheater in one unit		-

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

	Steam generators		
	Tube material		
Plant	Evaporator	Superheater	Reheater
Super- Phénix 1 (France)	Ni 33 Cr 21 Ti Al Mn	-	-
Super- Phénix 2 (France)	Incoloy 800	-	-
SNR 2 (Germany)	12 Cr or2.25 Cr	1Cr or 2.25 Cr	-
DFBR (Japan)	Mod. 9 Cr 1 Mo	-	-
CDFR (UK)	9 Cr 1 Mo	9Cr 1 Mo	-
BN-1600 (Russian Federation)	2.25 Cr 1 Mo	2.25 Cr 1 Mo	-
BN-800 (Russian Federation)	10Cr 2 Mo VNB	10Cr 2 Mo VNB	-
EFR	9 Cr 1 Mo VNB	9 Cr 1 Mo VNB	-
ALMR (USA)	2.25 Cr 1 Mo, evaporator and superheater in one unit		-
SVBR-75/100 (Russian Federation)	duplex tube, no superheater and reheater		
BN-1800 (Russian Federation)	21Cr 32Ni, evaporator and superheater in one unit		10Cr 2 Mo
BREST-1200 (Russian Federation)	9Cr 1 Mo, evaporator and superheater in one unit		-
JSFR-1500 (Japan)	12Cr-Steel, evaporator and superheater in one unit		-

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators			
	Evaporator tubes			
	Outer diameter (mm)	Thickness (mm)	No. per module	Effective heat transfer area per evaporator module (m^2)
Rapsodie (France)	no steam generator			
KNK-II (Germany)	25/30	2.9	1	4.79
FBTR (India)	33.7	4	7	67
PEC (Italy)	no steam generator			
JOYO (Japan)	no steam generator			
DFR (UK)	25	2	10	16
BOR-60 (Russian Federation)	variable for different SG's			
EBR-II (USA)	36.5	4.57	73	51.1
Fermi (USA)	15.9	1.07	1200	201
FFTF (USA)	no steam generator			
BR-10 (Russian Federation)	no steam generator			
CEFR (China)	16.0	2.5	128	97

Demonstration or Prototype Fast Reactors

Phénix (France)	28	4	7	3.8
SNR-300 (Germany)	17.2	2	211	220
PFBR (India)	17.2	2.3	547	667
MONJU (Japan)	31.8	3.8	150	-
PFR (UK)	25	2.3	498	-
CRBRP (USA)	15.9	2.77	739	517
BN-350 (Kazakhstan)	32	2	816	410
BN-600 (Russian Federation)	16	2.5	349	251
ALMR (USA)	31.8*	5.7*	611*	5954*
KALIMER-150 (Republic of Korea)	23	3.5	224	971
SVBR-75/100 (Russian Federation)	26	1.5	301	93.4
BREST-OD-300 (Russian Federation)	17	3	580	852

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators			
	Evaporator tubes			
	Outer diameter (mm)	Thickness (mm)	No. per module	Effective heat transfer area per evaporator module (m^2)
Super-Phénix 1 (France)	25*	2.6*	357*	2570**
Super-Phénix 2 (France)	25*	-	424*	3100*
SNR 2 (Germany)	-	-	-	-
DFBR (Japan)	31.8*	3.9*	361*	3300*
CDFR (UK)	18*	3.1*	1940*	415*
BN-1600 (Russian Federation)	to be determined			
BN-800 (Russian Federation)	16	2.5	349	295
EFR	16.4*	2.2*	1386*	1740*
ALMR (USA)	31.8*	5.7*	611*	5954*
SVBR-75/100 (Russian Federation)	26	1.5	301	93.4
BN-1800 (Russian Federation)	16	2.0	1921	-
BREST-1200 (Russian Federation)	to be determined			
JSFR-1500 (Japan)	16.0 / 19.0	1.1 / 1.5	7230	12500

* evaporator and superheater in one unit

** Each of the SPX-1 tubes was ~92 m long. There were seven welds per tube, so SPX-1 had about 10000 welds in comparison with ~4000 in Phénix. The flow tubes were butt welded by the TIG (tungsten inert-gas) process with welding metal

*** double wall tube; inner tube/outer tube

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators			
	Superheater tubes			
	Outer diameter (mm)	Thickness (mm)	No. per module	Effective heat transfer area per superheater module (m^2)
Rapsodie (France)	no steam generator			
KNK-II (Germany)	see previous table*			
FBTR (India)	see previous table*			
PEC (Italy)	no steam generator			
JOYO (Japan)	no steam generator			
DFR (UK)	18	1.5	10	3
BOR-60 (Russian Federation)	variable for different SG's			
EBR-II (USA)	36.5	4.57	73	51.1
Fermi (USA)	15.9	1.07		712
FFTF (USA)	no steam generator			
BR-10 (Russian Federation)	no steam generator			
CEFR (China)	16.0	2.5	95	42.1

Demonstration or Prototype Fast Reactors

Phénix (France)	31.8	3.6	7	208
SNR-300 (Germany)	17.2	2.9	211	167.2
PFBR (India)	see previous table*			
MONJU (Japan)	31.8	3.5	150	
PFR (UK)	21	3.05	264	
CRBRP (USA)	15.9	2.77	739	517
BN-350 (Kazakhstan)	16	2	805	227
BN-600 (Russian Federation)	16	2.5	239	146
ALMR (USA)	see previous table*			
KALIMER-150 (Republic of Korea)	see previous table*			
SVBR-75/100 (Russian Federation)	no superheater			
BREST-OD-300 (Russian Federation)	see previous table			

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators			
	Superheater tubes			
	Outer diameter (mm)	Thickness (mm)	No. per module	Effective heat transfer area per superheater module (m^2)
Super-Phénix 1 (France)	see previous table*			
Super-Phénix 2 (France)	see previous table*			
SNR 2 (Germany)	-			
DFBR (Japan)	see previous table*			
CDFR (UK)	see previous table*			
BN-1600 (Russian Federation)	see previous table*			
BN-800 (Russian Federation)	16	2.5	239	161
EFR	see previous table*			
ALMR (USA)	see previous table*			
SVBR-75/100 (Russian Federation)	no superheater			
BN-1800 (Russian Federation)	see previous table*			
BREST-1200 (Russian Federation)	to be determined			
JSFR-1500 (Japan)	see previous table*			

* evaporator and superheater in one unit

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators			
	Reheater tubes			
	Outer diameter (mm)	Thickness (mm)	No. per module	Effective heat transfer area per reheater module (m^2)
Rapsodie (France)	no steam generator			
KNK-II (Germany)	no reheater			
FBTR (India)	no sodium reheater			
PEC (Italy)	no steam generator			
JOYO (Japan)	no steam generator			
DFR (UK)	no reheater			
BOR-60 (Russian Federation)	no reheater			
EBR-II (USA)	no reheater			
Fermi (USA)	15.9	1.07	90	-
FFTF (USA)	no steam generator			
BR-10 (Russian Federation)	no steam generator			
CEFR (China)	no sodium reheater			

Demonstration or Prototype Fast Reactors

Phénix (France)	42.4	2	7	2.6
SNR-300 (Germany)	no sodium reheater			
PFBR (India)	no sodium reheater			
MONJU (Japan)	no sodium reheater			
PFR (UK)	23.9	1.77	216	-
CRBRP (USA)	no reheater			
BN-350 (Kazakhstan)	no reheater			
BN-600 (Russian Federation)	25	2.5	235	224
ALMR (USA)	no sodium reheater			
KALIMER-150 (Republic of Korea)	no sodium reheater			
SVBR-75/100 (Russian Federation)	no reheater			
BREST-OD-300 (Russian Federation)	no lead reheater			

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators			
	Reheater tubes			
	Outer diameter (mm)	Thickness (mm)	No. per module	Effective heat transfer area per reheater module (m^2)
Super-Phénix 1 (France)	no sodium reheater			
Super-Phénix 2 (France)	-			
SNR 2 (Germany)	-			
DFBR (Japan)	no sodium reheater			
CDFR (UK)	no sodium reheater			
BN-1600 (Russian Federation)	no sodium reheater			
BN-800 (Russian Federation)	no sodium reheater			
EFR	no sodium reheater			
SVBR-75/100 (Russian Federation)	no reheater			
BN-1800 (Russian Federation)	to be determined			
BREST-1200 (Russian Federation)	no lead reheater			
JSFR-1500 (Japan)	no sodium reheater			

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators		
	Thermal capacity per evaporator module, (MWt)	Thermal capacity per superheater module, (MWt)	Thermal capacity per reheater module (MWt)
Rapsodie (France)	no steam generators		
KNK-II (Germany)	-	-	-
FBTR (India)	12.5	-	-
PEC (Italy)	no steam generators		
JOYO (Japan)	no steam generators		
DFR (UK)	0.5	0.5	0.5
BOR-60 (Russian Federation)	evaporator and superheater in one unit		
EBR-II (USA)	5.9	7.4	-
Fermi (USA)	45	12	10
FFTF (USA)	no steam generators		
BR-10 (Russian Federation)	no steam generators		
CEFR (China)	27.6	5.6	

Demonstration or Prototype Fast Reactors

Phénix (France)	10	3.37	2.6
SNR-300 (Germany)	55.4	30.1	-
PFBR (India)	158	evaporator and superheater in one unit	
MONJU (Japan)	191	47	-
PFR (UK)	130	55	25
CRBRP (USA)	162.5	325	-
BN-350 (Kazakhstan)	57	18	9.1
BN-600 (Russian Federation)	40.6	10.5	-
ALMR (USA)	850	evaporator and superheater in one unit	
KALIMER-150 (Republic of Korea)	198.35	evaporator and superheater in one unit	
SVBR-75/100 (Russian Federation)	22.5	no superheater and reheater	
BREST-OD-300 (Russian Federation)	175	evaporator and superheater in one unit	

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators		
	Thermal capacity per evaporator module, (MWt)	Thermal capacity per superheater module, (MWt)	Thermal capacity per reheater module (MWt)
Super-Phénix 1 (France)	750**	-	-
Super-Phénix 2 (France)	-	-	-
SNR 2 (Germany)	-	-	-
DFBR (Japan)	534*	-	-
CDFR (UK)	-	-	-
BN-1600 (Russian Federation)	-	-	-
BN-800 (Russian Federation)	50.5	19.5	-
EFR	600*	-	-
ALMR (USA)	850*	-	-
SVBR-75/100(Russian Federation)	22.5	no superheater and reheater	
BN-1800 (Russian Federation)	536*	to be determined	
BREST-1200 (Russian Federation)	to be determined	no lead reheater	
JSFR-1500 (Japan)	1765*	-	-

* evaporator and superheater in one unit

** the outstanding success of it operation has undoubtedly been the demonstration of reliable operation of SGs with high self power

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators
	Principle of leak detection system(s) and type of detector in argon or coolant
Rapsodie (France)	no steam generator
KNK-II (Germany)	hydrogen measuring
FBTR (India)	hydrogen detector
PEC (Italy)	no steam generator
JOYO (Japan)	-
DFR (UK)	NaK drip tray
BOR-60 (Russian Federation)	hydrogen measuring, acoustic noise detection
EBR-II (USA)	hydrogen measuring
Fermi (USA)	hydrogen detection
FFTF (USA)	no steam generator
BR-10 (Russian Federation)	no steam generator
CEFR (China)	hydrogen measuring

Demonstration or Prototype Fast Reactors

Phénix (France)	hydrogen detection
SNR-300 (Germany)	hydrogen detection
PFBR (India)	diffusion of hydrogen through nickel tubes kept under high vacuum; measurement based on sputter ion pump current
MONJU (Japan)	hydrogen meter, cover gas pressure meter and rupture disk sensor
PFR (UK)	hydrogen measuring
CRBRP (USA)	hydrogen and oxygen detection
BN-350 (Kazakhstan)	hydrogen detection and measuring
BN-600 (Russian Federation)	hydrogen detection and measuring
ALMR (USA)	hydrogen measuring
KALIMER-150 (Republic of Korea)	hydrogen measuring, acoustic noise detection
SVBR-75/100 (Russian Federation)	humidity in gas: increase of pressure in gas and lead-bismuth coolant
BREST-OD-300 (Russian Federation)	humidity in gas: increase of pressure in gas and lead coolant

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators Principle of leak detection system(s) and type of detector in argon or coolant
Super-Phénix 1 (France)	hydrogen detection/Nickel membrane detector
Super-Phénix (France)	hydrogen detection
SNR 2 (Germany)	-
DFBR (Japan)	hydrogen measuring
CDFR (UK)	hydrogen measuring
BN-1600 (Russian Federation)	hydrogen detection and measuring
BN-800 (Russian Federation)	hydrogen detection and measuring
EFR	hydrogen measuring, acoustic leak detection
ALMR (USA)	hydrogen measuring
SVBR-75/100 (Russian Federation)	humidity in gas: increase of pressure in gas and lead-bismuth coolant
BN-1800 (Russian Federation)	hydrogen detection and measuring
BREST-1200 (Russian Federation)	humidity in gas: increase of pressure in gas and lead coolant
JSFR-1500 (Japan)	hydrogen measuring

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators
	Position of leak detection system and its capacity to locate a leak
Rapsodie (France)	no steam generator
KNK-I (Germany)	secondary circuit
FBTR (India)	sodium outlet
PEC (Italy)	no steam generator
JOYO (Japan)	no steam generator
DFR (UK)	drip trays in each cubicle
BOR-60 (Russian Federation)	sodium outlet
EBR-II (USA)	sodium outlet
Fermi (USA)	cover gas
FFTF (USA)	no steam generator
BR-10 (Rusisa)	no steam generator
CEFR (China)	sodium and cover gas, no leakage positioning

Demonstration or Prototype Fast Reactors

Phénix (France)	sodium and cover gas
SNR-300 (Germany)	secondary circuit
PFBR (India)	sodium outlet of each SG and common sodium outlet from SG
MONJU (Japan)	five hydrogen meters in each intermediate circuit
PFR (UK)	within each gas space and also under-sodium
CRBRP (USA)	evaporator and superheater outlets and vent lines
BN-350 (Kazakhstan)	on the outlet of the steam generator and in gas
BN-600 (Russian Federation)	on the outlet of each module of the steam generator and in gas
ALMR (USA)	sodium and cover gas
KALIMER-150 (Republic of Korea)	sodium and cover gas
SVBR-75/100 (Russian Federation)	steam condenser of the primary circuit gas system
BREST-OD-300 (Russian Federation)	on the outlet of each SG and in gas

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators Position of leak detection system and its capacity to locate a leak
Super-Phénix 1 (France)	on the sodium outlet and in cover gas
Super-Phénix 2 (France)	sodium and cover gas
SNR 2 (Germany)	not decided
DFBR (Japan)	not decided
CDFR (UK)	not decided
BN-1600 (Russian Federation)	on the outlet of each module of the steam generator and in gas
BN-800 (Russian Federation)	on the outlet of each module of the steam generator and in gas
EFR	hydrogen at sodium inlet and outlet; acoustic noise via waveguides and transducer on steam generator shell
ALMR (USA)	sodium and cover gas
SVBR-75/100 (Russian Federation)	steam condenser of the primary circuit gas system
BN-1800 (Russian Federation)	on the outlet of the steam generator and in gas
BREST-1200 (Russian Federation)	on the outlet of each SG and in gas
JSFR-1500 (Japan)	to be determined

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators	
	Minimum detectable leak rate of steam into sodium	Response time of leak detection system
Rapsodie (France)	no steam generator	
KNK-II (Germany)	-	-
FBTR (India)	0.05 ppm H_2 in sodium	a few minutes
PEC (Italy)	no steam generator	
JOYO (Japan)	no steam generator	
DFR (UK)	-	-
BOR-60 (Russian Federation)	0.03 ppm H_2 in sodium	2 min
EBR-II (USA)	0.032 (g/s leak rate)	40 s
Fermi (USA)	1 ppm	30 s
FFTF (USA)	no steam generator	
BR-10 (Russian Federation)	no steam generator	
CEFR (China)	0.02 ppm	20-45 s

Demonstration or Prototype Fast Reactors

Phénix (France)	0.001 ppm in sodium	a few minutes
SNR-300 (Germany)	-	-
PFBR (India)	40 mg/s	135 s
MONJU (Japan)	0.01	not finalized
PFR (UK)	0.1 g/s (under-sodium system)	72 s
CRBRP (USA)	H_2-0.006 ppm; O_2-0.024 ppm	30 s
BN-350 (Kazakhstan)	0.01ppm (10 ppm*)	2 min (5 min*)
BN-600 (Russian Federation)	0.01 ppm (10 ppm*)	2 min (5 min*)
ALMR (USA)	0.6 g/s	100s
KALIMER-150 (Republic of Korea)	to be determined	
SVBR-75/100 (Russian Federation)	1 kg/h	≤ 1 kg/h
BREST-OD-300 (Russian Federation)	6.25 kg/s	100 s

* in gas space

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators	
	Minimum detectable leak rate of steam into sodium	Response time of leak detection system
Super-Phénix 1 (France)	0.1 g/s	~ 4 min
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	to be determined	
CDFR (UK)	-	-
BN-1600 (Russian Federation)	0.01 ppm (10 ppm*)	1.5 min (3 min*)
BN-800 (Russian Federation)	0.01 ppm (10 ppm*)	25 s (3 min*)
EFR	0.1g/s (H_2); 1g/s (acoustic)	350s (H_2); 20/s (acoustic)
ALMR (USA)	0.6g/s	100 s
SVBR-75/100 (Russian Federation)	1 kg/h	≤ 1 kg/h
BN-1800 (Russian Federation)	0.01 ppm (10 ppm*)	25 s (3 min*)
BREST-1200 (Russian Federation)	6.25 kg/s	1000 s
JSFR-1500 (Japan)	0.1 g/s	1900 s

* in gas space

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Experimental Fast Reactors

Plant	Steam generators Main features of system for discharge of sodium/water reaction products
Rapsodie (France)	no steam generator
KNK-II (Germany)	rupture discs at inlet and outlet of steam generator
FBTR (India)	rupture discs-discharge header-collection tank-hydrogen stack
PEC (Italy)	no steam generator
JOYO (Japan)	no steam generator
DFR (UK)	-
BOR-60 (Russian Federation)	rupture disc-separator tank
EBR-II (USA)	rupture disc-collection tank
Fermi (USA)	rupture disc to centrifugal separator to vent
FFTF (USA)	no steam generator
BR-10 (Russian Federation)	no steam generator
CEFR (China)	rupture disc-discharge pipe-dump tank-hydrogen stack

Demonstration or Prototype Fast Reactors

Phénix (France)	rupture discs-discharge pipe-collection tank- hydrogen stack
SNR-300 (Germany)	rupture discs at inlet and outlet of steam generator
PFBR (India)	rupture of rupture disc leads reaction products to storage tank; from there, H_2 gas is vented through the cyclone separator and chimney to atmosphere
MONJU (Japan)	rupture discs at evaporator and superheater
PFR (UK)	bursting discs to dump tank gases to atmosphere via cyclone separator
CRBRP (USA)	rupture discs-separator tanks-flare stack
BN-350 (Kazakhstan)	rupture disc - separator tanks
BN-600 (Russian Federation)	rupture disc - separator tanks
ALMR (USA)	rupture disc-dicharge pipe-dump tank-hydrogen stack
KALIMER-150 (Republic of Korea)	rupture disc-dicharge pipe-dump tank-hydrogen stack
SVBR-75/100 (Russian Federation)	no coolant-water reaction products
BREST-OD-300 (Russian Federation)	no coolant-water reaction; the disposal of lead oxides is carried by hydrogen lancing

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.4. Steam generators

Commercial Size Reactors

Plant	Steam generators Main features of system for discharge of sodium/water reaction products
Super-Phénix 1 (France)	rupture disc-discharge pipe-dump tank-hydrogen stack
Super-Phénix 2 (France)	rupture disc-discharge pipe-dump tank-hydrogen stack
SNR 2 (Germany)	-
DFBR (Japan)	rupture disc-discharge pipe-dump tank-hydrogen stack
CDFR (UK)	as for PFR
BN-1600 (Russian Federation)	rupture disc-discharge pipe-dump tank-hydrogen stack
BN-800 (Russian Federation)	rupture disc-discharge pipe-dump tank-hydrogen stack
EFR	rupture disc-discharge pipe-dump tank-hydrogen stack
ALMR (USA)	rupture disc-discharge pipe-dump tank-hydrogen stack
SVBR-75/100 (Russian Federation)	no lead-bismuth-water reaction
BN-1800 (Russian Federation)	as for BN-800
BREST-1200 (Russian Federation)	no lead-water reaction; the disposal of lead oxides is carried by hydrogen lancing
JSFR-1500 (Japan)	rupture disc-discharge pipe-dump tank-hydrogen stack

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.5. Turbine generators

Experimental Fast Reactors

Plant	Turbine generators	
	Type	Noumber of turbine generators (total)
Rapsodie (France)	no turbine generators	
KNK-II (Germany)	condensing reheat turbine	1
FBTR (India)	condensing	1
PEC (Italy)	no turbine generators	
JOYO (Japan)	no turbine generators	
DFR (UK)	single cylinder	-
BOR-60 (Russian Federation)	condensing	1
EBR-II (USA)	simple single flow	1
Fermi (USA)	tandem compound single flow	1
FFTF (USA)	no turbine generators	
BR-10 (Russian Federation)	no turbine generators	
CEFR (China)	condensing high single flow	1

Demonstration or Prototype Fast Reactors

Phénix (France)	condensing	-
SNR-300 (Germany)	condensing	1
PFBR (India)	tandem compound, reaction with throttle governing-condensing type	1
MONJU (Japan)	tandem compound	1
PFR (UK)	300 MW tandem compound/reheat/condensing	1
CRBRP (USA)	tandem compound	1
BN-350 (Kazakhstan)	condensing and back-pressure	4*
BN-600 (Russian Federation)	condensing reheat	3
ALMR (USA)	tandem compound	1
KALIMER-150 (Republic of Korea)	not yet decided	1
SVBR-75/100 (Russian Federation)	condensing	1
BREST-OD-300 (Russian Federation)	condensing reheat	1

* used different units

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.5. Turbine generators

Commercial Size Reactors

Plant	Turbine generators	
	Type	No. of turbine generators (total)
Super-Phénix 1 (France)	condensing	2
Super-Phénix 2 (France)	condensing	1
SNR 2 (Germany)	condensing	1
DFBR (Japan)	tandem compound	
CDFR (UK)	tandem compound	2
BN-1600 (Russian Federation)	condensing	2
BN-800 (Russian Federation)	condensing	1
EFR	condensing	1
ALMR (USA)	tandem compound	3 (serving 6 reactors)
SVBR-75/100 (Russian Federation)	condensing	1
BN-1800 (Russian Federation)	condensing reheat	1
BREST-1200 (Russian Federation)	condensing reheat	1
JSFR-1500 (Japan)	tandem compound	1

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.5. Turbine generators

Experimental Fast Reactors

Plant	Turbine generators			
	Power (MW)		Speed (rev./min.)	Minimum condenser pressure (MPa)
	Total	Per generator		
Rapsodie (France)	no turbine generators			
KNK-II (Germany)	58	-	3000	-
FBTR (India)	16	-	3000	0.012
PEC (Italy)	no turbine generators			
JOYO (Japan)	no turbine generators			
DFR (UK)	15	15	3000	-
BOR-60 (Russian Federation)	12	12	3000	0.004
EBR-II (USA)	20	20	3600	0.005
Fermi (USA)	150	150	1800	0.01
FFTF (USA)	no turbine generators			
BR-10 (Russian Federation)	no turbine generators			
CEFR (China)	25	25	3000	0.01

Demonstration or Prototype Fast Reactors

Phénix (France)	270	-	3000	0.002
SNR-300 (Germany)	327	-	3000	0.0047
PFBR (India)	500	-	3000	0.01
MONJU (Japan)	280	280	3600	0.0096
PFR (UK)	250	250	3000	-
CRBRP (USA)	380	-	3600	0.0068
BN-350 (Kazakhstan)	150	50 and 100	3000	0.006
BN-600 (Russian Federation)	600	200	3000	0.004
ALMR (USA)	300	300	3000	0.01
KALIMER-150 (Republic of Korea)	162.2	162.2	not yet decided	-
SVBR-75/100 (Russian Federation)	75	75	3000	0.00626
BREST-OD-300 (Russian Federation)	330	300	3000	0.00343

7. MAIN COMPONENTS OF HEAT TRANSPORT SYSTEM (cont.)

7.5. Turbine generators

Commercial Size Reactors

Plant	Turbine generators			
	Power (MW)		Speed (rev./min.)	Minimum condenser pressure (MPa)
	Total	Per generator		
Super-Phénix 1 (France)	1240	620	3000	0.0058
Super-Phénix 2 (France)	1500	1500	1500	-
SNR 2 (Germany)	-	-	1500	-
DFBR (Japan)	660	660	-	-
CDFR (UK)	1320	660	3000	0.0044
BN-1600 (Russian Federation)	1600	800	3000	0.004
BN-800 (Russian Federation)	1080	1000	3000	0.004
EFR	1580	1580	1500	0.006
ALMR (USA)	600*	600*	3000	0.01
SVBR-75/100 (Russian Federation)	75	75	3000	0.00626
BN-1800 (Russian Federation)	not yet decided		3000	0.004
BREST-1200 (Russian Federation)	1200	1250	3000	not yet decided
JSFR-1500 (Japan)	1500	1500	1500	0.0096

* serving two reactors

8. AUXILIARY SYSTEMS

8.1. Coolant purification system

Experimental Fast Reactors

Plant	Coolant purification system			
	Number of cold traps		Main coolant for	
	Primary	Secondary	Primary circuit cold trap	Secondary circuit cold trap
Rapsodie (France)	2	1 per loop	nitrogen	air
KNK-II (Germany)	-	-	-	-
FBTR (India)	1	2	organic liquid	organic liquid
PEC (Italy)	1 (1*)	2 (1*)	organic liquid	air (air*)
JOYO (Japan)	2	1	nitrogen gas	air
DFR (UK)	17	24	air	air
BOR-60 (Russian Federation)	2	2	water	air
EBR-II (USA)	1	1	NaK	organic liquid
Fermi (USA)	1	1	NaK	NaK
FFTF (USA)	1	3	NaK	air
BR-10 (Russian Federation)	1	2	organic liquid and water	
CEFR (China)	2	2	organic liquid/Na-K alloy	

Demonstration or Prototype Fast Reactors

Phénix (France)	2	1 per loop	organic liquid	organic liquid
SNR-300 (Germany)	4	3	-	-
PFBR (India)	2	2	nitrogen gas	air
MONJU (Japan)	2	6	nitrogen gas	air
PFR (UK)	1	1	air	air
CRBRP (USA)	2	6	NaK	gas blower
BN-350 (Kazakhstan)	6	6	NaK	NaK
BN-600 (Russian Federation)	4	6	gas	gas
ALMR (USA)	6	6	nitrogen gas	air
KALIMER-150 (Republic of Korea)	not yet decided		gas	gas
SVBR-75/100 (Russian Federation)	hydrogen regeneration of lead oxides, insoluble impurities filtration			
BREST-OD-300 (Russian Federation)	4 filters and hydrogen regeneration of lead oxides			no sec. loop

* test channel

8. AUXILIARY SYSTEMS (cont.)

8.1. Coolant purification system

Commercial Size Reactors

Plant	Coolant purification system			
	Number of cold traps		Main coolant for	
	Primary	Secondary	Primary circuit cold trap	Secondary circuit cold trap
Super-Phénix 1 (France)	2	1 per loop	nitrogen gas	organic liquid
Super-Phénix 2 (France)	1	1 per loop	gas	gas
SNR 2 (Germany)	-	-	-	-
DFBR (Japan)	3	2 per loop	nitrogen gas	air
CDFR (UK)	1	4	air	air
BN-1600 (Russian Federation)	2	6	gas	gas
BN-800 (Russian Federation)	3	6	air	air
EFR	1	6	nitrogen gas	air
ALMR (USA)	6	6	nitrogen gas	air
SVBR-75/100 (Russian Federation)	hydrogen regeneration of lead oxides, insoluble impurities filtration			
BN-1800 (Russian Federation)	2	6	air	air
BREST-1200 (Russian Federation)	4 filters and hydrogen regeneration of lead oxides			no sec. loop
JSFR-1500 (Japan)	2	4	nitrogen gas	air

8.1. Coolant purification system

Experimental Fast Reactors

Plant	Coolant purification system					
	Volume of mesh region in cold trap (m^3)		Maximum permissible impurity concentration (primary) (ppm)			Maximum acceptable plugging temperature in primary circuit (s) (°C)
	Primary	Secondary	Oxygen	Hydrogen	Carbon	
Rapsodie (France)	0.18	0.18	-	-	-	130
KNK-II (Germany)		-	-	-	-	130
FBTR (India)	0.2	0.2	10	-	-	-
PEC (Italy)	not defined	7 (7*)	not defined			
JOYO (Japan)	1.15	0.764	12	-	-	-
DFR (UK)	0.5	0.75	5	-	-	-
BOR-60 (Russian Federation)	0.3	0.3	10	0.5	30.0	150.0
EBR-II (USA)	0.068**	0(meshless)	5.4***	0.46***	no limit	
Fermi (USA)	1.5	1.5	-	-	-	130
FFTF (USA)	1.55	0.74****	5	0.4	-	0.01
BR-10 (Russian Federation)	0.052	0.052	50	-	20	160
CEFR (China)	1.65/2.9	1.65	10	0.5	20	150

Demonstration or Prototype Fast Reactors

Phénix (France)	2	3	-	-	-	150
SNR-300 (Germany)	-			-	-	-
PFBR (India)	2.5	9.2	3.0	1.0	25	150
MONJU (Japan)	1.35	5	10	0.17	-	-
PFR (UK)	1.2	1.0	10	0.3	-	150
CRBRP (USA)	1.70	2.69	2(427°C): 0.2/5	(427°C): 0.3	-	-
BN-350 (Kazakhstan)	3	3	10	6	40	150
BN-600 (Russian Federation)	6.8*****	6.8	10	0.5	10	150
ALMR (USA)	2.8	8.7	10	-	-	-
KALIMER-150 (Republic of Korea)	not yet decided					
SVBR-75/100 (Russian Federation)	lead-bismuth coolant		-	-	-	
BREST-OD-300 (Russian Federation)	lead coolant		0.04-3.25		-	-

* test channel
** seven 0.0097 m^3 mesh cylinders
*** based on 350°F limit on plugging temperature
**** per trap
***** volume of the cold trap
****** unplugging temperature

8. AUXILIARY SYSTEMS (cont.)

8.1. Coolant purification system

Commercial Size Reactors

Plant	Coolant purification system					
	Volume of mesh region in cold trap (m^3)		Maximum permissible impurity concentration (primary) (ppm)			Maximum acceptable plugging temperature in primary circuit (s) (°C)
	Primary	Secondary	Oxygen	Hydrogen	Carbon	
Super-Phénix 1 (France)	0.4	2.8	3	0.25	50	155******
Super-Phénix 2 (France)				3	50	
SNR 2 (Germany)	not determined					
DFBR (Japan)	1.5	7.0	10			
CDFR (UK)	not determined					
BN-1600 (Russian Federation)	10	1.9	10	0.5	15	150
BN-800 (Russian Federation)	6.5	6.5	10	0.5	15	150
EFR	1.5	2.1	5	0.3	50	150
ALMR (USA)	2.8	8.7	10	-	-	-
SVBR-75/100 (Russian Federation)	lead-bismuth coolant					
BN-1800 (Russian Federation)	6.5	6.5	10	0.5	15	150
BREST-1200 (Russian Federation)	lead coolant		0.04-3.25			
JSFR-1500 (Japan)	2.2	3.4	2	-	to be determined	

****** unplugging temperature

8. AUXILIARY SYSTEMS (cont.)

8.1. Coolant purification system

Experimental Fast Reactors

Plant	Coolant purification system			
	Maximum permissible impurity concentration (secondary) (ppm)			Maximum acceptable plugging temperature in secondary circuit(s) (°C)
	Oxygen	Hydrogen	Carbon	
Rapsodie (France)	-	-	-	30
KNK-II (Germany)	-	-	-	-
FBTR (India)	10	0.12	-	130
PEC (Italy)	7 (7*)	not defined	-	-
JOYO (Japan)	20	-	-	-
DFR (UK)	5	-	-	-
BOR-60 (Russian Federation)	10	0.5	30.0	150
EBR-II (USA)	no limit	0.2	no limit	-
Fermi (USA)	-	-	-	150
FFTF (USA)	5	0.4	0.01	-
BR-10 (Russian Federation)	-		-	150
CEFR (China)	10	0.5	20	150

Demonstration or Prototype Fast Reactors

Phénix (France)	-	-	-	180
SNR-300 (Germany)	-	-	-	-
PFBR (India)	3	0.2	25	150
MONJU (Japan)	10	0.17	-	-
PFR (UK)	10	0.3	-	-
CRBRP (USA)	2	0.2	not controlled (0.3 ppm possible)	150
BN-350 (Kazakhstan)	10	6	40	150
BN-600 (Russian Federation)	10	0.5	30	150
ALMR (USA)	-	-	-	-
KALIMER-150 (Republic of Korea)	-	not yet decided	-	-
SVBR-75/100 (Russian Federation)	-	no secondary loops	-	-
BREST-OD-300 (Russian Federation)	-	no secondary loops	-	-

* test channel

8. AUXILIARY SYSTEMS (cont.)

8.1. Coolant purification system

Commercial Size Reactors

Plant	Coolant purification system			
	Maximum permissible impurity concentration (secondary) (ppm)			Maximum acceptable plugging temperature in secondary circuit(s) (°C)
	Oxygen	Hydrogen	Carbon	
Super-Phénix 1 (France)	5	0.2	50	170**
Super-Phénix 2 (France)	3	-	50	-
SNR 2 (Germany)	not determined			
DFBR (Japan)	10	-	0.17	-
CDFR (UK)	not determined			
BN-1600 (Russian Federation)	10	0.5	50	150
BN-800 (Russian Federation)	10	0.1	50	150
EFR	3 (7 short-term)	<0.21		150
ALMR (USA)	-	-	-	180°C (short-term)
SVBR-75/100 (Russian Federation)	no secondary loops			
BN-1800 (Russian Federation)	10	0.1	50	150
BREST-1200 (Russian Federation)	no secondary loops			
JSFR-1500 (Japan)	5	133 ppb	to be determined	-

** unplugging temperature

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

Plant	Cover gas system	
	Principal function (primary)	Design principle, e.g. constant mass (CM) or constant pressure (CP)
Rapsodie (France)	VH, P, IHX	CP
KNK-II (Germany)	VH, P	-
FBTR (India)	V, P, IHX	CP
PEC (Italy)	VH, P (VH,P*)	-
JOYO (Japan)	VH, P,IHX	CP
DFR (UK)	V, LE, BV	-
BOR-60 (Russian Federation)	VH, P	CP
EBR-II (USA)	VH, P	-
Fermi (USA)	V, VH, P,IHX, LE, MS	-
FFTF (USA)	VH, P	-
BR-10 (Russian Federation)	V, LE, BV	CP
CEFR (China)	V, VH, MS	CP

Demonstration or Prototype Fast Reactors

Phénix (France)	V, P, IHX	CP
SNR-300 (Ggermany)	VH, P	-
PFBR (India)	V, LE	CP
MONJU (Japan)	VH, P, IHX	CP
PFR (UK)	VH, MS	-
CRBRP (USA)	VH, FCH, MS, P, LE	-
BN-350 (Kazakhstan)	VH, P	CP
BN-600 (Russian Federation)	VH, P	CP
ALMR (USA)	VH	-
KALIMER-150 (Republic of Korea)	VH	CP
SVBR-75/100 (Russian Federation)	V	CM
BREST-OD-300 (Russian Federation)	VH, P, LE, MS	CP

* test channel

V - buffers reactor vessel
VH - buffers reactor vessel head or roof
P - buffers pump seals
IHX - buffers IHX
LE&BV - buffers loop expansion tanks and bypass vessel
MS - buffers all mechanism seals

8.2. Cover gas system

Commercial Size Reactors

Plant	Cover gas system	
	(secondary) (ppm)	Design principle, e.g. constant mass (CM) or constant pressure (CP)
Super-Phénix 1 (France)	VH,P,IHX,MS	CP
Super-Phénix 2 (France)	VH,P,IHX,MS	-
SNR 2 (Germany)	VH,P	-
DFBR(Japan)	VH,P,IHX	CP
CDFR (UK)	VH,P	-
BN-1600 (Russian Federation)	VH,P	CP
BN-800 (Russian Federation)	VH,P	CP
EFR	VH,P,MS	CM
ALMR (USA)	VH	CM
SVBR-75/100 (Russian Federation)	V	CM
BN-1800 (Russian Federation)	not yet decided	CM
BREST-1200 (Russian Federation)	VH, P, LE, MS	CP
JSFR-1500 (Japan)	VH, P, IHX	CP

V - buffers reactor vessel
VH - buffers reactor vessel head or roof
P - buffers pump seals
IHX - buffers IHX
LE&BV - buffers loop expansion tanks and bypass vessel
MS - buffers all mechanism seals

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

Plant	Cover gas system	
	Principal function (secondary)	Design principle e.g. constant mass (CM) or constant pressure (CP)
Rapsodie (France)	P	-
KNK-II (Germany)	P	-
FBTR (India)	P	CP
PEC (Italy)	LE & BV, P (LE & BV*)	-
JOYO (Japan)	P	CP
DFR (UK)	LE & BV	CP
BOR-60 (Russian Federation)	P	CP
EBR-II (USA)	P	-
Fermi (USA)	P, LE, SGH, IHX	-
FFTF (USA)	P	-
BR-10 (Russian Federation)	LE & BV	CP
CEFR (China)	P, LE & BV, SGH, CT	CP

Demonstration or Prototype Fast Reactors

Phénix (France)	P	CP
SNR-300 (Germany)	P	-
PFBR (India)	LE	CP
MONJU (Japan)	SGH,P	CP
PFR (UK)	TP,P,V	-
CRBRP (USA)	P,LE	-
BN-350 (Kazakhstan)	SGH,P	CP
BN-600 (Russian Federation)	P,CT	CP
ALMR (USA)	LE & BV, SGH	-
KALIMER-150 (Republic of Korea)	SGH	not yet decided
SVBR-75/100 (Russian Federation)	no secondary loops	-
BREST-OD-300 (Russian Federation)	no secondary loops	-

* test channel

P - buffers pump seals
LE&BV - buffers loop expansion tanks and bypass vessel
SGH - buffers steam generator head
TP - buffers tube plates
V - buffers valve actuators
CT - buffers compensation tank seals

8.2. Cover gas system

Commercial Size Reactors

Plant	Cover gas system	
	Principal function (secondary)	Design principle e.g. constant mass (CM) or constant pressure (CP)
Super-Phénix 1 (France)	P, LE & BV, SGH,CT	CP
Super-Phénix 2 (France)	P, LE & BV, SGH,CT	-
SNR 2 (Germany)	P	-
DFBR (Japan)	P, SGH	CP
CDFR (UK)	TP, P	-
BN-1600 (Russian Federation)	P, CT	CP
BN-800 (Russian Federation)	P, CT	CP
EFR	P, LE & BV,SGH	CP
ALMR (USA)	LE & BV, SGH	-
SVBR-75/100 (Russian Federation)	no secondary loops	-
BN-1800 (Russian Federation)	-	CM
BREST-1200 (Russian Federation)	no secondary loops	-
JSFR-1500 (Japan)	P, SGH	CP

P - buffers pump seals
LE&BV - buffers loop expansion tanks and bypass vessel
SGH - buffers steam generator head
TP - buffers tube plates
V - buffers valve actuators
CT - buffers compensation tank seals

8.2. Cover gas system

Experimental Fast Reactors

	Cover gas system
Plant	When used for the inertisation of:
Rapsodie (France)	LC
KNK-II (Germany)	LC
FBTR (India)	LC
PEC (Italy)	LC, FC (LC,FC*)
JOYO (Japan)	LC
DFR (UK)	-
BOR-60 (Russian Federation)	FC
EBR-II (USA)	FC
Fermi (USA)	LC
FFTF (USA)	LC,FC
BR-10 (Russian Federation)	P
CEFR (China)	P, FC

Demonstration or Prototype Fast Reactors

Phénix (France)	LC
SNR-300 (Germany)	LC
PFBR (India)	LC
MONJU (Japan)	LC
PFR (UK)	P,FC
CRBRP (USA)	LC,SGH, P
BN-350 (Kazakhstan)	FC
BN-600 (Russian Federation)	FC
ALMR (USA)	LC, P, FC
KALIMER-150 (Republic of Korea)	P, FC
SVBR-75/100 (Russian Federation)	FC
BREST-OD-300 (Russian Federation)	FC

* test channel

LC - loop cells
P - handling flasks or pots
FC - fuel transfer cells

8.2. Cover gas system

Commercial Size Reactors

	Cover gas system
Plant	When used for the inertisation of:
Super-Phénix 1 (France)	P, FC
Super-Phénix 2 (France)	P, FC
SNR 2 (Germany)	LC, P
DFBR (Japan)	LC, P
CDFR (UK)	FC
BN-1600 (Russian Federation)	FC
BN-800 (Russian Federation)	FC
EFR	LC, P, FC
ALMR (USA)	LC, P, FC
SVBR-75/100 (Russian Federation)	FC
BN-1800 (Russian Federation)	not yet decided
BREST-1200 (Russian Federation)	FC
JSFR-1500 (Japan)	P, FC

LC - loop cells
P - handling flasks or pots
FC - fuel transfer cells

8.2. Cover gas system

Experimental Fast Reactors

Plant	Cover gas system		
	Gas		Other systems
	Primary circuit(s)	Secondary circuit(s)	
Rapsodie (France)	helium	argon	nitrogen
KNK-II (Germany)	argon	argon	nitrogen
FBTR (India)	argon	argon	nitrogen
PEC (Italy)	argon	argon	argon & nitrogen
JOYO (Japan)	argon	argon	nitrogen
DFR (UK)	argon	argon	-
BOR-60 (Russian Federation)	argon	argon	nitrogen
EBR-II (USA)	argon	argon	air
Fermi (USA)	argon	argon	nitrogen
FFTF (USA)	argon	argon	nitrogen
BR-10 (Russian Federation)	argon	argon	air
CEFR (China)	argon	argon	nitrogen

Demonstration or Prototype Fast Reactors

Phénix (France)	argon	argon	nitrogen
SNR-300 (Germany)	argon	argon	nitrogen
PFBR (India)	argon	argon	nitrogen
MONJU (Japan)	argon	argon	nitrogen
PFR (UK)	argon	argon	argon
CRBRP (USA)	argon	argon	nitrogen
BN-350 (Kazakhstan)	argon	argon	air
BN-600 (Russian Federation)	argon	argon	air
ALMR (USA)	helium	argon	air
KALIMER-150 (Republic of Korea)	helium	argon	not yet decided
SVBR-75/100 (Russian Federation)	argon	no secondary circuits	-
BREST-OD-300 (Russian Federation)	argon	no secondary circuits	argon

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Commercial Size Reactors

Plant	Cover gas system		
	Gas		Other systems
	Primary circuit(s)	Secondary circuit(s)	
Super-Phénix 1 (France)	argon	argon	argon and nitrogen
Super-Phénix 2 (France)	argon	argon	nitrogen
SNR 2 (Germany)	argon	argon	helium
DFBR (Japan)	argon	argon	nitrogen (LC); argon (P)
CDFR (UK)	argon	argon	nitrogen
BN-1600 (Russian Federation)	argon	agon	air
BN-800 (Russian Federation)	argon	argon	air
EFR	argon	argon	nitrogen
ALMR (USA)	helium	argon	air
SVBR-75/100 (Russian Federation)	argon	no secondary circuits	-
BN-1800 (Russian Federation)	argon	argon	not yet decided
BREST-1200 (Russian Federation)	argon	no secondary circuits	argon
JSFR-1500 (Japan)	argon	argon	argon

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

Plant	Cover gas system		
	Gas pressure (at operation) (MPa)		Other systems
	Primary	Secondary	
Rapsodie (France)	0.002	0.03	-
KNK-II (Germany)	0.002	0.45	0.0001
FBTR (India)	sl.ab.atm.*	sl.ab.atm.*	sl.ab.atm.*
PEC (Italy)	0.002 (0.06**) gauge	0.005 gauge	0.004 gauge
JOYO (Japan)	0.001	0.02	0.005
DFR (UK)	0.025	0.035	-
BOR-60 (Russian Federation)	0.049	0.049	sl.ab.atm.*
EBR-II (USA)	sl.ab.atm.*	0.0414	sl.bel. atm.*
Fermi (USA)	0.1	0.13-0.29	0.1
FFTF (USA)	0.003 gauge	0.61 gauge	0.002 gauge
BR-10 (Russian Federation)	0.03 gauge	0.03 gauge	-
CEFR (China)	0.05	0.2	sl.ab.atm.*

Demonstration or Prototype Fast Reactors

Phénix (France)	sl.ab.atm.*	sl.ab.atm.*	sl.ab.atm.*
SNR-300 (Germany)	0.152	-	0.469
PFBR (India)	0.111 ±0.001	0.4 ±0.05	sl.ab.atm.*
MONJU (Japan)	0.05	0.1	sl.ab.atm.*
PFR (UK)	sl.ab.atm.*	sl.ab.atm.*	sl.ab.atm.*
CRBRP (USA)	0.105	0.117 abs.	sl.ab.atm.*
BN-350 (Kazakhstan)	0.186 abs.	0.245 abs.	sl.ab.atm.*
BN-600 (Russian Federation)	0.137 abs.	0.245	sl.ab.atm.*
ALMR (USA)	-	0.128	sl.ab.atm.*
KALIMER-150 (Republic of Korea)	0.1913	not yet decided	
SVBR-75/100 (Russian Federation)	0.11	no secondary circuits	-
BREST-OD-300 (Russian Federation)	sl.ab.atm.*	no secondary circuits	sl.ab.atm.*

* slightly above atmosphere or slightly below atmosphere
** test channel

8.2. Cover gas system

Commercial Size Reactors

Plant	Cover gas system		
	Gas pressure (at operation) (MPa)		Other systems
	Primary	Secondary	
Super-Phénix 1 (France)	0.007-0.011*	0.13-0.16*	0.025-0.0025*
Super-Phénix 2 (France)	sl.ab.atm.*	sl.ab.atm.*	-
SNR 2 (Germany)	sl.ab.atm.*	-	-
DFBR (Japan)	0.09	0.15	sl.ab.atm.*
CDFR (UK)	sl.ab.atm.*	sl.ab.atm.*	-
BN-1600 (Russian Federation)	0.137 abs.	0.245 abs.	sl.ab.atm.*
BN-800 (Russian Federation)	0.149 abs.	0.245 abs.	sl.ab.atm.*
EFR	0.105-0.123	0.22-0.25	sl.ab/bel.atm.*
ALMR (USA)	-	0.128	al.ab.atm.*
SVBR-75/100 (Russian Federation)	0.11	no secondary circuits	-
BN-1800 (Russian Federation)	0.245	0.245	not yet decided
BREST-1200 (Russian Federation)	sl.ab.atm.*	no secondary circuits	al.ab.atm.*
JSFR-1500 (Japan)	0.17	0.3	sl.ab.atm.*

* slightly above atmosphere or slightly below atmosphere

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

Plant	Cover gas system Method of gas sampling Primary	Secondary	Other systems
Rapsodie (France)	on-line	-	-
KNK-II (Germany)	-	-	-
FBTR (India)	flow through	sampler	-
PEC (Italy)	on-line	none	-
JOYO (Japan)	capsule pot	cylindrical pot	cylindrical pot
DFR (UK)	buffer tanks with interlocks	-	-
BOR-60 (Russian Federation)	periodic on-line sampling	-	-
EBR-II (USA)	grab sample	grab sample	-
Fermi (USA)	-	-	-
FFTF (USA)	on-line	grab sample	on-line
BR-10 (Russian Federation)	grab sample	grab sample	-
CEFR (China)	on-line	grab sample	grab sample

Demonstration or Prototype Fast Reactors

Phénix (France)	on-line	-	-
SNR-300 (Germany)	-	-	-
PFBR (India)	on-line	-	-
MONJU (Japan)	on-line and off - line monitoring	-	-
PFR (UK)	on-line and discrete sampling	-	-
CRBRP (USA)	on-line	grab sample	on-line
BN-350 (Kazakhstan)	periodic on-line sampling	-	-
BN-600 (Russian Federation)	periodic on-line sampling	-	-
ALMR (USA)	grab sample	grab sample	grab sample
KALIMER-150 (Republic of Korea)	on-line	not yet decided	-
SVBR-75/100 (Russian Federation)	on-line	no secondary circuits	-
BREST-OD-300 (Russian Federation)	periodoc on-line sampling	no secondary circuits	-

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Commercial Size Reactors

Plant	Cover gas system		
	Method of gas sampling		
	Primary	Secondary	Other systems
Super-Phénix 1 (France)	on-line	periodic discrete sampling	on-line (fuel transfer)
Super-Phénix 2 (France)	on-line	-	-
SNR 2 (Germany)	-	-	-
DFBR (Japan)	-	-	-
CDFR (UK)	periodic discrete sampling	periodic discrete sampling	not determined
BN-1600 (Russian Federation)	periodic on-linesampling		-
BN-800 (Russian Federation)	on-line sampling		not determined
EFR	periodic on-line sampling		not determined
ALMR (USA)	grab sample	grab sample	grab sample
SVBR-75/100 (Russian Federation)	on-line	no secondary circuits	-
BN-1800 (Russian Federation)	on-line sampling		not yet decided
BREST-1200 (Russian Federation)	periodoc on-line sampling	no secondary circuits	-
SFR-1500 (Japan)	to be determined	to be determined	to be determined

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

	Cover gas system
Plant	Method of gas analysis (primary)
Rapsodie (France)	mass spectrometry, gas chromatography
KNK-II (Germany)	-
FBTR (India)	mass spectrometry, gas chromatography
PEC (Italy)	gas chromatography, ionization chamber
JOYO (Japan)	gas chromatography
DFR (UK)	-
BOR-60 (Russian Federation)	gas chromatography
EBR-II (USA)	thermal conductivity, flame emission, Ge-Li gamma scan; mass spectrometry
Fermi (USA	-
FFTF (USA)	gas chromatography
BR-10 (Russian Federation)	gamma spectrometry
CEFR (USA)	gas chromatograph, gamma spectrometry

Demonstration or Prototype Fast Reactors

Phénix (France)	mass spectrometry, gas chromatography, ionization chamber
SNR-300 (Germany)	gas chromatography
PFBR (India)	gas chromatography, ionization chamber, gamma spectrometry
MONJU (Japan)	-
PFR (UK)	gas chromatography, gamma spectrometry, mass spectrometry
CRBRP (USA)	gas chromatography
BN-350 (Kazakhstan)	gas chromatography, ionization chamber
BN-600 (Russian Federation)	gas chromatography, ionization chamber
ALMR (USA)	mass spectrometry, gas chromatography
KALIMER-150 (Republic of Korea)	gas chromatography
SVBR-75/100 (Russian Federation)	gas chromatography, ionization chamber
BREST-OD-300 (Russian Federation)	gas chromatography, measure O_2, H_2, H_2O vapor and radio-activity

8.2. Cover gas system

Commercial Size Reactors

	Cover gas system
Plant	Method of gas analysis (primary)
Super-Phénix 1 (France)	gas chromatography, ionization chamber, gamma spectrometry
Super-Phénix 2 (France)	not determined
SNR 2 (Germany)	not determined
DFBR (Japan)	not determined
CDFR (UK)	not determined
BN-1600 (Russian Federation)	gas chromatography
BN-800 (Russian Federation)	gas chromatography
EFR	gas chromatography
ALMR (USA)	mass spectrometry, gas chromatography, hydrocarbon analysis
SVBR-75/100 (Russian Federation)	gas chromatography, ionization chamber
BN-1800 (Russian Federation)	not yet decided
BREST-1200 (Russian Federation)	gas chromatography, measure O_2, H_2, H_2O vapor and radio-activity
JSFR-1500 (Japan)	to be determined

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

	Cover gas system	
	Method of gas analysis	
Plant	Secondary	Other systems
Rapsodie (France)	-	-
KNK-II (Germany)	-	-
FBTR (India)	mass spectrometry and gas chromatography	-
PEC (Italy)	-	-
JOYO (Japan)	gas chromatography	gas chromatography
DFR (UK)	-	-
BOR-60 (Russian Federation)	gas chromatography	-
EBR-II (USA)	thermal conductivity, H_2-diffusion meter	-
Fermi (USA)	gas chromatography	measure O_2, H_2, and radioactivity
FFTF (USA)	-	-
BR-10 (Russian Federation)	measure O_2	-
CEFR (China)	gas chromatography	gamma spectrometry

Demonstration or Prototype Fast Reactors

Phénix (France)	-	measure O_2, H_2O vapour, and radioactivity
SNR-300 (Germany)	gas chromatography	-
PFBR (India)	-	-
MONJU (Japan)	-	-
PFR (UK)	-	
CRBRP (USA)	gas chromatography	measure O_2, H_2O vapor, and radioactivity
BN-350 (Kazakhstan)	gas chromatography	-
BN-600 (Russian Federation)	gas chromatography	-
ALMR (USA)	gas chromatography and mass spectrometry	-
KALIMER-150 (Republic of Korea)	gas chromatography	not yet decided
SVBR-75/100 (Russian Federation)	no secondary circuits	-
BREST-OD-300 (Russian Federation)	no secondary circuits	measure O_2, H_2, H_2O vapor, and radioactivity

8.2. Cover gas system

Commercial Size Reactors

	Cover gas system Method of gas analysis	
Plant	Secondary	Other systems
Super-Phénix 1 (France)	none	gas chromatography, measure O_2, H_2O and radioactivity
Super-Phénix 2 (France)	not determined	-
SNR 2 (Germany)	not determined	-
DFBR (Japan)	not determined	-
CDFR (UK)	not determined	not determined
BN-1600 (Russian Federation)	gas chromatography	-
BN-800 (Russian Federation)	gas chromatography	-
EFR	gas chromatography	not determined
ALMR (USA)	gas chromatography and mass spectrometry	-
SVBR-75/100 (Russian Federation)	no secondary circuits	-
BN-1800 (Russian Federation)	not yet decided	
BREST-1200 (Russian Federation)	no secondary circuits	gas chromatography, measure O_2, H_2, H_2O vapor and radioactivity
JSFR-1500 (Japan)	to be determined	to be determined

8. AUXILIARY SYSTEMS (cont.)

8.2. Cover gas system

Experimental Fast Reactors

	Cover gas system
Plant	Cover gas clean-up system (principle)
Rapsodie (France)	active carbon filter before discharge
KNK-II (Germany)	active carbon filter
FBTR (India)	filtration before discharge
PEC (Italy)	carbon delay bed and cryogenic column
JOYO (Japan)	cryogenic activated charcoal bed
DFR (UK)	vapour traps
BOR-60 (Russian Federation)	aerosol filters
EBR-II (USA)	cryo distillation
Fermi (USA)	vapour trap, cyclone separator
FFTF (USA)	carbon delay bed and cold trap
BR-10 (Russian Federation)	no gas clean-up system
CEFR (China)	aerosol filters and active carbon bed

Demonstration or Prototype Fast Reactors

Phénix (France)	active carbon bed and cryogenic effect
SNR-300 (Germany)	active carbon filter
PFBR (India)	dynamic absorption into activated charcoal bed at cryogenic temperature
MONJU (Japan)	charcoal delay bed
PFR (UK)	aerosol and absolute filters
CRBRP (USA)	cryogenic still
BN-350 (Kazakhstan)	aerosol filters
BN-600 (Russian Federation)	aerosol filters
ALMR (USA)	activated carbon bed
KALIMER-150 (Republic of Korea)	not yet decided
SVBR-75/100 (Russian Federation)	aerosol filters, vapor steam condenser
BREST-OD-300 (Russian Federation)	aerosol, oxygen and hydrogen filters

8.2. Cover gas system

Commercial Size Reactors

	Cover gas system
Plant	Cover gas clean-up system (principle)
Super-Phénix 1 (France)	active carbon bed and cryogenic effect
Super-Phénix 2 (France)	sweeping and filtering
SNR 2 (Germany)	not determined
DFBR (Japan)	mist/vapour trap
CDFR (UK)	not determined
BN-1600 (Russian Federation)	aerosol filters
BN-800 (Russian Federation)	aerosol filters
EFR	aerosol filters and activated carbon bed
ALMR (USA)	activated carbon bed
SVBR-75/100 (Russian Federation)	aerosol filters, vapor steam condenser
BN-1800 (Russian Federation)	aerosol filters
BREST-1200 (Russian Federation)	aerosol, oxygen and hydrogen filters
JSFR-1500 (Japan)	mist/vapour trap and filtering

8.3. Decay heat removal system

Experimental Fast Reactors

	Decay heat removal system
Plant	Type
Rapsodie (France)	NCM
KNK-II (Germany)	NCM
FBTR (India)	NCM
PEC (Italy)	ES
JOYO (Japan)	PM
DFR (UK)	TS
BOR-60 (Russian Federation)	NCM, TS
EBR-II (USA)	ES
Fermi (USA)	NCM, PM
FFTF (USA)	NCM
BR-10 (Russian Federation)	NCM and forced flow (battery)
CEFR (China)	NCM, TS

Demonstration or Prototype Fast Reactors

Phénix (France)	PM, RV
SNR-300 (Germany)	NCM
PFBR (India)	ES, PM, TS
MONJU (Japan)	ES, PM
PFR (UK)	PM, TS
CRBRP (USA)	PM, NCM, ES
BN-350 (Kazakhstan)	PM
BN-600 (Russian Federation)	NCM, PM
ALMR (USA)	RV
KALIMER-150 (Republic of Korea)	RV
SVBR-75/100 (Russian Federation)	NCM, RV
BREST-OD-300 (Russian Federation)	NCM, PM, TS

NCM - removal of decay heat by natural convection, through main coolant loops
ES - removal of decay heat through special heat removal loops to air (forced flow)
PM - removal of decay heat through main coolant loops by pony motors
TS - removal of decay heat through thermal syphon loops to air (natural convection only)
RV - removal of heat through reactor vessel by radiation and convection

8.3. Decay heat removal system

Commercial Size Reactors

	Decay heat removal system
Plant	Type
Super-Phénix 1 (France)	ES,PM,TS,RV
Super-Phénix 2 (France)	ES,TS
SNR 2 (Germany)	-
DFBR (Japan)	ES,PM
CDFR (UK)	PM,NCM, ES,TS
BN-600 (Russian Federation)	PM,TS
BN-800 (Russian Federation)	NCM,PM,ES and TS
EFR	NCM,PM,ES and TS
ALMR (USA)	RV
SVBR-75/100 (Russian Federation)	NCM, RV
BN-1800 (Russian Federation)	not yet decided
BREST-1200 (Russian Federation)	NCM, PM, TS
JSFR-1500 (Japan)	NCM (1DRACS+2PRACS)

NCM - removal of decay heat by natural convection, through main coolant loops
ES - removal of decay heat through special heat removal loops to air (forced flow)
PM - removal of decay heat through main coolant loops by pony motors
TS - removal of decay heat through thermal syphon loops to air (natural convection only)
RV - removal of heat through reactor vessel by radiation and convection

8. AUXILIARY SYSTEMS (cont.)

8.3. Decay heat removal systems

Experimental Fast Reactors

Plant	Decay heat removal systems	
	Capacity for emergency removal of decay heat (MWth)	Delay before operation in an emergency situation(s)
Rapsodie (France)	0.35	1800
KNK-II (Germany)	-	-
FBTR (India)	0.35	600
PEC (Italy)	capable of handling 5% of nominal power (not defined*)	in continuance operation (not defined*)
JOYO (Japan)	2.6	simultaneous with reactor scram
DFR (UK)	2.2	0
BOR-60 (Russian Federation)	-	15
EBR-II (USA)	0.35	on-line continuously
Fermi (USA)	30	-
FFTF (USA)	capable of handling 8% of rated power	< 60
BR-10 (Russian Federation)	battery 108 A. h, 220 V	0.2
CEFR (China)	0.525x2	< 60

Demonstration or Prototype Fast Reactors

Phénix (France)	12	1800
SNR-300 (Germany)	12	-
PFBR (India)	4x8	1800
MONJU (Japan)	45	simultaneous with reactor scram
PFR (UK)	15	120
CRBRP (USA)	PM: 100, ES-1: 18, ES-2: 45, ES-3: 10, NCM: not available	automatic
BN-350 (Kazakhstan)	30	15
BN-600 (Russian Federation)	45	15
ALMR (USA)	1.8***	0
KALIMER-150 (Republic of Korea)	2.6	0
SVBR-75/100 (Russian Federation)	1.5	100 h
BREST-OD-300 (Russian Federation)	3.5	on-line continuously in hot reserve

* test channel

*** 5.7 MW (th) peak at 21 hours

8.3. Decay heat removal systems

Commercial Size Reactors

Plant	Decay heat removal systems	
	Capacity for emergency removal of decay heat (MWth)	Delay before operation in an emergency situation (s)
Super-Phénix 1 (France)	48 + 15	~ 1800
Super-Phénix 2 (France)	~ 100	~ 1800
SNR 2 (Germany)	-	-
DFBR (Japan)	14	-
CDFR (UK)	80	60
BN-1600 (Russian Federation)	120 (PM), 110**(TS)	15 (PM) 60 (TS)
BN-800 (Russian Federation)	80	60
EFR	90	0 to 1800
ALMR (USA)	1.8***	0
SVBR-75/100 (Russian Federation)	1.5	100 h
BN-1800 (Russian Federation)	80	not yet decided
BREST-1200 (Russian Federation)	to be decided	on-line continuously in hot reserve
JSFR-1500 (Japan)	23 in each heat exchanger	simultaneous with reactor scram

** for loops, 27.5 MWth each

*** 5.7 MW (th) peak at 21 hours

8.4. Preheating system

Experimental Fast Reactors

	Preheating system
Plant	Primary circuit(s)
Rapsodie (France)	hot nitrogen
KNK-II (Germany)	-
FBTR (India)	hot nitrogen
PEC (Italy)	electrical resistance trace heating elements
JOYO (Japan)	hot nitrogen and electric trace heating
DFR (UK)	space and trace heating
BOR-60 (Russian Federation)	hot gas and electrical heating
Fermi (USA)	induction and resistance
FFTF (USA)	electrical resistance trace heating elements
BR-10 (Russian Federation	hot gas and electrical heating
CEFR (China)	hot nitrogen and electrical heating

Demonstration or Prototype Fast Reactors

Phénix (France)	hot nitrogen and electrical resistance
SNR-300 (Germany)	hot nitrogen and trace heating
PFBR (India)	hot nitrogen
MONJU (Japan)	electric trace heating
PFR (UK)	hot argon
CRBRP (USA)	electrical resistance
BN-350 (Kazakhstan)	hot gas and electrical heating
BN-600 (Russian Federation)	hot gas and electrical heating
ALMR (USA)	hot gas
KALIMER-150 (Republic of Korea)	to be decided
SVBR-75/100 (Russian Federation)	saturated steam
BREST-OD-300 (Russian Federation)	hot air

8. AUXILIARY SYSTEMS (cont.)

8.4. Preheating system

Commercial Size Reactors

	Preheating system
Plant	Primary circuit(s)
Super-Phénix 1 (France)	hot nitrogen*
Super-Phénix 2 (France)	hot nitrogen
SNR 2 (Germany)	not decided
DFBR (Japan)	hot gas
CDFR (UK)	to be determined
BN-1600 (Russian Federation)	hot gas and electrical heating
BN-800 (Russian Federation)	hot gas and electrical heating
EFR	hot nitrogen
ALMR (USA)	hot gas
SVBR-75/100 (Russian Federation)	saturated steam
BN-1800 (Russian Federation)	electrical heating
BREST-1200 (Russian Federation)	hot air
JSFR-1500 (Japan)	to be determined

* for initial sodium filling

8.4. Preheating system

Experimental Fast Reactors

	Preheating system
Plant	Secondary circuit(s)
Rapsodie (France)	electrical heating
KNK-II (Germany)	-
FBTR (India)	electrical heating
PEC (Italy)	electrical resistance trace heating
JOYO (Japan)	electrical trace heating
DFR (UK)	space and trace heating
BOR-60 (Russian Federation)	electrical heating
EBR-II (USA)	induction resistance
Fermi (USA)	induction and resistance
FFTF (USA)	electrical resistance trace heating
BR-10 (Russian Federation)	electrical heating
CEFR (China)	hot nitrogen and electrical heating

Demonstration or Prototype Fast Reactors

Phénix (France)	electrical heating
SNR-300 (Germany)	-
PFBR (India)	electrical trace heating
MONJU (Japan)	electric trace heating
PFR (UK)	trace heating
CRBRP (USA)	electrical resistance
BN-350 (Kazakhstan)	electrical heating
BN-600 (Russian Federation)	electrical heating
ALMR (USA)	not decided
KALIMER-150 (Republic of Korea)	to be decided
SVBR-75/100 (Russian Federation)	no secondary circuit
BREST-OD-300 (Russian Federation)	no secondary circuit

8.4. Preheating system

Commercial Size Reactors

	Preheating system
Plant	Secondary circuit(s)
Super-Phénix 1 (France)	electrical heating
Super-Phénix 2 (France)	electrical heating
SNR 2 (Germany)	not determined
DFBR (Japan)	electrical heating
CDFR (UK)	to be determined
BN-1600 (Russian Federation)	electrical heating
BN-800 (Russian Federation)	electrical heating
EFR	electrical heating
ALMR (USA)	electrical heating
SVBR-75/100 (Russian Federation)	no secondary circuit
BN-1800 (Russian Federation)	electrical heating
BREST-1200 (Russian Federation)	no secondary circuit
JSFR-1500 (Japan)	to be determined

8.4. Preheating system

Experimental Fast Reactors

Plant	Preheating system Preheating temperature (°C)	
	Primary	Secondary
Rapsodie (France)	250	-
KNK-II (Germany)	200	-
FBTR (India)	150	150
PEC (Italy)	200	200
JOYO (Japan)	150-230	150-230
DFR (UK)	-	-
BOR-60 (Russian Federation)	250	250
EBR-II (USA)	305	-
Fermi (USA)	200	200
FFTF (USA)	316	204
BR-10 (Russian Federation)	200	200
CEFR (China)	200-250	200-250

Demonstration or Prototype Fast Reactors

Phénix (France)	150	200
SNR-300 (Germany)	200	-
PFBR (India)	150	150
MONJU (Japan)	200	200
PFR (UK)	200	200
CRBRP (USA)	204	-
BN-350 (Kazakhstan)	250	250
BN-600 (Russian Federation)	200	250
ALMR (USA)	200	200
KALIMER-150 (Republic of Korea)	150-200	to be decided
SVBR-75/100 (Russian Federation)	180	no secondary circuit
BREST-OD-300 (Russian Federation)	420-470	no secondary circuit

8.4. Preheating system

Commercial Size Reactors

Plant	Preheating system	
	Preheating temperature (°C)	
	Primary	Secondary
Super-Phénix 1 (France)	150	180
Super-Phénix 2 (France)	230	-
SNR 2 (Germany)	not determined	-
DFBR (Japan)	150-250	150-250
CDFR (UK)	not determined	-
BN-1600 (Russian Federation)	200	250
BN-800 (Russian Federation)	200	250
EFR	150	230
ALMR (USA)	200	200
SVBR-75/100 (Russian Federation)	180	no secondary circuit
BN-1800 (Russian Federation)	electrical heating	-
BREST-1200 (Russian Federation)	420-470	no secondary circuit
JSFR-1500 (Japan)	to be determined	to be determined

9. SHIELDING, CONTAINMENT AND SAFETY FEATURES

9.1. Shielding objectives (neutron and other limits at different important locations)

Experimental Fast Reactors

Plant	Shielding objectives (neutron and other limits at different important locations)			
	Reactor vessel (dpa)	Core support structure (dpa)	Above-core structure (dpa)	Activity of secondary sodium (Bq/kg)
Rapsodie (France)	-	-	-	-
KNK-II (Germany)	-	-	-	-
FBTR (India)	$7.17x10^{-9}$ A/kg in accessible areas	-	-	-
PEC (Italy)	10^{21}nvt (E > 0.1 Mev)	-	-	-
JOYO (Japan)	below 2.10^{-5} Sv (γ and n) in accessible areas	-	-	-
DFR (UK)	-	-	-	-
BOR-60 (Russian Federation)	34 dpa	$12x10^{22}$	$15x10^{22}$	< $3.7x10^{4}$
EBR-II (USA)	-	-	-	-
Fermi (USA)	-	-	-	-
FFTF (USA)	10% TE*	10% TE*	10% TE*	-
BR-10 (Russian Federation)	34 dpa ($7x10^{22}$ E > 0.1 MeV)	-	-	-
CEFR (China)	0.5	3.4	0.1	$7x10^{4}$

Demonstration or Prototype Fast Reactors

Phenix (France)	-	2.0	0.1	10^{5}
SNR-300 (Germany)	-	-	-	-
PFBR (India)	$<10^{-10}$	< 0.001	< 0.001	$62x10^{3}$
MONJU (Japan)	-	-	-	-
PFR (UK)	$1.8x10^{-10}$ A/kg above vessel roof and near secondary sodium pipes	-	-	-
CRBRP (USA)	10% TE*	-	10% TE*	-
BN-350 (Kazakhstan)	$1.4x10^{21}$	$1.6x10^{22}$	$3x10^{21}$	< $3.7x10^{4}$
BN-600 (Russian Federation)	$1.5x10^{19}$	$4.5x10^{21}$	$3.8x10^{21}$	$1.7x10^{3}$
ALMR (USA)	4.1	4.1	4.1	-
KALIMER-150 (Republic of Korea)	to be decided			
SVBR-75/100 (Russian Federation)	10	0.22	0.6	no secondary circuit(s)
BREST-OD-300 (Russian Federation)	$2.7x10^{20}$	$3.4x10^{23}$	$5x10^{22}$	no secondary circuit(s)

* total elongation

9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

9.1. Shielding objectives (neutron and other limits at different important locations)

Commercial Size Reactors

Plant	Shielding objectives (neutron and other limits at different important locations)			
	Reactor vessel (dpa)	Core support structure (dpa)	Above-core structure (dpa)	Activity of secondary sodium (Bq/kg)
Super-Phenix 1 (France)	< 0.005	< 1.5		$2x10^4$
Super-Phenix 2 (France)	not determined			
SNR 2 (Germany)	not determined			
DFBR (Japan)	-	-	-	$7.4x10^4$**
CDFR (UK)	1/20 IAEA recommended limit			
BN-1600 (Russian Federation)	$1.9x10^{17}$	$7.1x10^{22}$	$6.9x10^{22}$	$1.4x10^4$
BN-800 (Russian Federation)	$4.5x10^{17}$	$1.7x10^{22}$ (6.7dpa)	$4.2x10^{22}$ (16dpa)	$4.4x10^4$
EFR	-	1	$1.9x10^9$n/cm^2/s	$3x10^4$
ALMR (USA)	not determined			
SVBR-75/100 (Russian Federation)	10	0.22	0.6	no secondary circuit(s)
BN-1800 (Russian Federation)	$1.2x10^{11}$	$8x10^{21}$	-	0.02
BREST-1200 (Russian Federation)	not determined			
JSFR-1500 (Japan)	to be determined	$5x10^{21}$ n/cm^2	$1x10^{21}$ n/cm^2	$7.4x10^4$*

** dose rate below 6 μSv/h (γ = n) in accessible areas

9.2. Shielding materials

Experimental Fast Reactors

Plant	Shielding materials	
	Radial shield within primary vessel	Radial (biological) shield outside primary vessel
Rapsodie (France)	stainless steel	concrete
KNK-II (Germany)	gray iron	high density concrete
FBTR (India)	stainless steel	concrete
PEC (Italy)	nikel reflector elements and B_4C shield elements	high density concrete
JOYO (Japan)	stainless steel	graphite, concrete
DFR (UK)	steel and borated graphite,top plugs only borated graphite	concrete
BOR-60 (Russian Federation)	stainless steel	cast iron and high density concrete
EBR-II (USA)	graphite and borated graphite	borated graphite and reinforced concrete
Fermi (USA)	stainless steel	reinforced concrete
FFTF (USA)	stainless steel	high density concrete and B_4C
BR-10 (Russian Federation)	-	cast iron, water concrete
CEFR (China)	SS + B_4C covered by SS	reinforced concrete

Demonstration or Prototype Fast Reactors

Phénix (France)	graphite and stainless steel	concrete
SNR-300 (Germany)	stainless steel	serpentine concrete
PFBR (India)	SS & B_4C	concrete
MONJU (Japan)	stainless steel	concrete and steel
PFR (UK)	graphite in steel	concrete and steel
CRBRP (USA)	SA-316	concrete
BN-350 (Kazakhstan)	stainless steel	concrete and steel
BN-600 (Russian Federation)	graphite and stainless steel	concrete
ALMR (USA)	304 + B_4C	concrete
KALIMER-150 (Republic of Korea)	304 + B_4C covered by SS	concrete
SVBR-75/100 (Russian Federation)	SS+ B_4C +Pb-Bi	H_2O+steel+ concrete
BREST-OD-300 (Russian Federation)	SS	high density concrete

9.2. Shielding materials

Commercial Size Reactors

Plant	Shielding materials	
	Radial shield within primary vessel	Radial (biological) shield outside primary vessel
Super-Phénix 1 (France)	stainless steel	concrete
Super-Phénix 2 (France)	SS + boron	concrete
SNR 2 (Germany)	steel	concrete and steel
DFBR (Japan)	SS + B_4C	concrete and steel
CDFR (UK)	steel	concrete and steel
BN-1600 (Russian Federation)	stainless steel	concrete
BN-800 (Russian Federation)	SS+graphite and borated graphite	concrete
EFR	SS + B_4C pins and blocks	concrete
ALMR (USA)	304 + B_4C covered by SS	concrete
SVBR-75/100 (Russian Federation)	SS+ B_4C +Pb-Bi	H_2O+steel+ concrete
BN-1800 (Russian Federation)	SS+graphite and borated graphite	concrete
BREST-1200 (Russian Federation)	SS	high density concrete
JSFR-1500 (Japan)	SS + Zr-H	steel and concrete

9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

9.2. Shielding materials

Experimental Fast Reactors

Plant	Shielding materials	
	Axial shield inside primary vessel	Axial shield in or above the reactor roof
Rapsodie (France)	-	-
KNK-II (Germany)	-	-
FBTR (India)	-	-
PEC (Italy)	-	-
JOYO (Japan)	-	-
DFR (UK)	-	-
BOR-60 (Russian Federation)	SS	SS, CS, graphite
EBR-II (USA)	-	-
Fermi (USA)	-	-
FFTF (USA)	-	-
BR-10 (Russian Federation)	SS, B_4C	parafin, B_4C, SS
CEFR (China)	SS	SS + reinforced concrete

Demonstration or Prototype Fast Reactors

Phénix (France)	SS, B_4C	concrete and steel (CS)
SNR-300 (Germany)	-	-
PFBR (India)	SS, B_4C, graphite	heavy density concrete
MONJU (Japan)	SS	CS
PFR (UK)	-	-
CRBRP (USA)	-	-
BN-350 (Kazakhstan)	SS	SS, CS, graphite
BN-600 (Russian Federation)	SS	SS, CS, graphite
ALMR (USA)	steel	steel
KALIMER-150 (Republic of Korea)	SS	not determined
SVBR-75/100 (Russian Federation)	SS+ B_4C +Pb-Bi	B_4C +steel
BREST-OD-300 (Russian Federation)	SS, Pb	concrete, CS

9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

9.2. Shielding materials

Commercial Size Reactors

Plant	Shielding materials	
	Axial shield inside primary vessel	Axial shield in or above the reactor roof
Super-Phénix 1 (France)	SS + B_4C pins	CS
Super-Phénix 2 (France)	not determined	-
SNR 2 (Germany)	not determined	-
DFBR (Japan)	B_4C	heavy concrete and steel
CDFR (UK)	not determined	-
BN-1600 (Russian Federation)	SS	SS, CS, graphite
BN-800 (Russian Federation)	SS	SS, CS, graphite
EFR	SS + B_4C pins	850 mm solid steel roof
ALMR (USA)	not determined	-
SVBR-75/100 (Russian Federation)	SS+ B_4C +Pb-Bi	B_4C, steel
BN-1800 (Russian Federation)	SS	SS, CS, graphite
BREST-1200 (Russian Federation)	SS, Pb	concrete, CS
JSFR-1500 (Japan)	SS + B_4C	steel and concrete

9.3. Containment

Experimental Fast Reactors

Plant	Containment		
	Geometry of secondary containment building	Material	Vented (V) or not vented (NV) to atmosphere through filters
Rapsodie (France)	cylindrical with dome	steel	-
KNK-II (Germany)	cylindrical with dome	steel	-
FBTR (India)	cylindrical with dome	concrete	-
PEC (Italy)	cylindrical with dome	carbon steel	-
JOYO (Japan)	cylindrical with dome	carbon steel	-
DFR (UK)	sphere	steel	NV
BOR-60 (Russian Federation)	rectangular building	concrete	-
EBR-II (USA)	cylindrical with dome	carbon steel	-
Fermi (USA)	cylindrical with dome	carbon steel	-
FFTF (USA)	cylindrical with dome	carbon steel	-
BR-10 (Russian Federation)	rectangular building	concrete	-
CEFR (China)	square with dome	concrete & steel	V

Demonstration or Prototype Fast Reactors

Phénix (France)	rectangular	concrete	NV
SNR-300 (Germany)	rectangular	-	steel and concrete
PFBR (India)	rectangular	reinforced concrete	NV
MONJU (Japan)	cylindrical with dome	carbon steel	NV
PFR (UK)	rectangular	concrete and steel	NV
CRBRP (USA)	cylindrical with dome	carbon steel	-
BN-350 (Kazakhstan)	ordinary rectangular bldg.	concrete	NV
BN-600 (Russian Federation)	ordinary rectangular bldg	concrete	NV
ALMR (USA)	cylindrical with dome	arbon steel	NV
KALIMER-150 (Republic of Korea)	cylindrical with dome	2.25Cr 1 Mo	NV
SVBR-75/100 (Russian Federation)	cylindrical with dome	concrete	V
BREST-OD-300 (Russian Federation)	rectangular building	concrete, CS	V

9.3. Containment

Commercial Size Reactors

Plant	Containment		
	Geometry of secondary Containment building	Material	Vented (V) or not vented (NV) to atmosphere through filters
Super-Phénix 1 (France)	cylindrical with dome	concrete	NV
Super-Phénix 2 (France)	rectangular bldg	concrete	-
SNR 2 (Germany)	cylindrical	concrete	-
DFBR (Japan)	rectangular building	steel and concrete	NV
CDFR (UK)	cylindrical with dome	steel and concrete	-
BN-1600 (Russian Federation)	cylindrical building	concrete	-
BN-800 (Russian Federation)	rectangular building	concrete	NV
EFR	cylindrical building	reinforced concrete	V
ALMR (USA)	cylindrical with dome	carbon steel	NV
SVBR-75/100 (Russian Federation)	cylindrical with dome	concrete	V
BN-1800 (Russian Federation)	rectangular building	concrete	NV
BREST-1200 (Russian Federation)	rectangular building	concrete, CS	V
JSFR-1500 (Japan)	rectangular	concrete and steel	V

9.3. Containment

Experimental Fast Reactors

Plant	Containment	
	Gross volume (m^3)	Maximum design pressure (MPa)
Rapsodie (France)	15000	0.235
KNK-II (Germany)	5000	0.25
FBTR (India)	15000	0.025
PEC (Italy)	18000	0.15
JOYO (Japan)	18600	0.15
DFR (UK)	11500	0.125
BOR-60 (Russian Federation)	-	-
EBR-II (USA)	14000	0.166
Fermi (USA)	7900	0.32
FFTF (USA)	64100	0.067
BR-10 (Russian Federation)	-	-
CEFR (China)	17000	0.1

Demonstration or Prototype Fast Reactors

Phénix (France)	31000	0.040
SNR-300 (Germany)	323000	0.024
PFBR (India)	87000	0.25
MONJU (Japan)	130000	0.03
PFR (UK)	74000	0.005
CRBRP (USA)	170000	0.170
BN-350 (Kazakhstan)	-	-
BN-600 (Russian Federation)	-	-
ALMR (USA)	112	0.172
KALIMER-150 (Republic of Korea)	1036	0.254
SVBR-75/100 (Russian Federation)	2000	0.03
BREST-OD-300 (Russian Federation)	-	-

9.3. Containment

Commercial Size Reactors

	Containment	
Plant	Gross volume (m^3)	Maximum design pressure (MPa)
Super-Phénix 1 (France)	dome - 6500 containment - 170000	dome -0.3 containment - 0.004
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	180000	*
DFBR (Japan)	27000	0.05
CDFR (UK)	40200	0.1
BN-1600 (Russian Federation)	not defined	
BN-800 (Russian Federation)	-	-
EFR	136000	0.05
ALMR (USA)	-	-
SVBR-75/100 (Russian Federation)	80000	0.03
BN-1800 (Russian Federation)	to be defined	
BREST-1200 (Russian Federation)	to be defined	
JSFR-1500 (Japan)	20000	0.18

* structures are determined by large airplane crash considerations

9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

9.3. Containment

Experimental Fast Reactors

	Containment	
	Seismic acceleration (designed) (g)	
Plant	Horizontal	Vertical
Rapsodie (France)	0.10-0.20	0.20-0.50
KNK-II (Germany)	-	-
FBTR (India)	0.1	0.05
PEC (Italy)	0.30	0.10
JOYO (Japan)	0.15	0.075
DFR (UK)	-	-
BOR-60 (Russian Federation)	0.1	0.07
EBR-II (USA)	containment designed in accordance with Uniform Building Code, in its contemporary version	
Fermi (USA)	0.1	-
FFTF (USA)	0.250	0.166
BR-10 (Russian Federation)	0.1	0.07
CEFR (China)	0.107	0.071

Demonstration or Prototype Fast Reactors

Phénix (France)	0.15-0.30	0.30-0.60
SNR-300 (Germany	0.044	0.005
PFBR (India)	0.078 OBE (PGA) 0.156 SSE (PGA)	0.052 OBE (PGA) 0.104 SSE (PGA)
MONJU (Japan)	-	-
PFR (UK)	-	-
CRBRP (USA)	0.125	0.125
BN-350 (Kazakhstan)	-	-
BN-600 (Russian Federation)	0.1	0.07
ALMR (USA)	0.3-0.5	0.3-0.5
KALIMER-150 (Republic of Korea)	0.3	0.2
SVBR-75/100 (Russian Federation)	0.24-0.38	1.0
BREST-OD-300 (Russian Federation)	0.1	0.07

9.3. Containment

Commercial Size Reactors

	Containment	
	Seismic acceleration (designed) (g)	
Plant	Horizontal	Vertical
Super-Phénix 1 (France)	0.1-0.2	0.07-0.14
Super-Phénix 2 (France)	-	-
SNR 2 (Germany)	-	-
DFBR (Japan)	-	-
CDFR (UK)	0.25	0.17
BN-1600 (Russian Federation)	-	-
BN-800 (Russian Federation)	0.1	0.07
EFR	0.25/0.2*	0.17/0.13*
SVBR-75/100 (Russian Federation)	0.24-0.38	1.0
BN-1800 (Russian Federation)	0.1	0.07
BREST-1200 (Russian Federation)	0.1	0.07
JSFR-1500 (Japan)	-	equivalent M7.1

* using UK/USNRC soil response spectr

9. SHIELDING, CONTAINMENT AND SAFETY FEATURES (cont.)

9.4. Additional safety features

Experimental Fast Reactors

Plant	Additional safety features
Rapsodie (France)	DW, TGV
KNK-II (Germany)	EP
FBTR (India)	DW
PEC (Italy)	EP, DW
JOYO (Japan)	DW, CI
DFR (UK)	DW
BOR-60 (Russian Federation)	TPGV*
EBRII (USA)	blast shield, isolation system with containment building
Fermi (USA)	DW, CI, TGV, EC, meltdown pan
FFTF (USA)	EP, EC
BR-10 (Russian Federation)	TPGV
CEFR (China)	CI, TGV, EC, NP, PC

Demonstration or Prototype Fast Reactors

Phénix (France)	TGV
SNR-300 (Germany)	TGV,EC, NP, CI, PC
PFBR (India)	CI, TGV, EC, NP, PC
MONJU (Japan)	EP,CI, TEV, EC
PFR (UK)	NP, leak jacket which would contain sodium above core level
CRBRP (USA)	EP, CI, TGV
BN-350 (Kazakhstan)	TPGV
BN-600 (Russian Federation)	TGV, NP
ALMR (USA)	DW, CI, TGV, EC, NP, PC
KALIMER-150 (Republic of Korea)	TGV, EC, NP, PC
SVBR-75/100 (Russian Federation)	TGV, EC, NP
BREST-OD-300 (Russian Federation)	DW, TGV

* on parts of the primary loops to limit effect of pipe rupture

EP - elevated piping guard vessel to limit effect of pipe rupture
DW - double walls of primary loops
CI - containment isolation on increased radiation
TGV - reactor tank guard vessel
TPGV - tank and piping guard vessels
EC - elevations of the core, IHX dump HX to ensure natural convection cooling
NP - no penetrations below sodium level
PC - provision for collecting and cooling core debris following core meltdown or partial meltdown

9.4. Additional safety features

Commercial Size Reactors

Plant	Additional safety features
Super-Phénix 1 (France)	CI, TGV, PC
Super-Phénix 2 (France)	CI, TGV
SNR 2 (Germany)	CI, TGV, EC, NP
DFBR (Japan)	EP, DW, CI, TGV, NP
CDFR (UK)	TGV
BN-1600 (Russian Federation)	TGV, NP
BN-800 (Russian Federation)	TGV, NP, PC
EFR	CI, TGV, EC, NP, PC
ALMR (USA)	to be defined
SVBR-75/100 (Russian Federation)	TGV, EC, NP
BN-1800 (Russian Federation)	to be defined
BREST-1200 (Russian Federation)	DW, TGV
JSFR-1500 (Japan)	DW, CI, TGV, TPGV, EC, NP, PC

EP - elevated piping guard vessel to limit effect of pipe rupture
DW - double walls of primary loops
CI - containment isolation on increased radiation
TGV - reactor tank guard vessel
TPGV - tank and piping guard vessels
EC - elevations of the core, IHX dump HX to ensure natural convection cooling
NP - no penetrations below sodium level
PC - provision for collecting and cooling core debris following core meltdown or partial meltdown

10. PROTECTION AND CONTROL

10.1. Main criteria for initiating automatic shutdown

Experimental Fast Reactors

Plant	Main criteria for initiating automatic shutdown
Rapsodie (France)	HF, FiL,HT,HRF,LCL,LEP,LPF,DND,EQ, TT,HIT
KNK-II (Germany)	HF, HRT, HT, LF, HRF
FBTR (India)	HF, FIL, HT, HRF, LNF, LEP, LSF, DND
PEC (Italy)	HF, LEP, HRF, HT, LPF, LSF, DND
JOYO (Japan)	HF, LPF, LCL, etc.
DFR (UK)	HF, HT, HRF, LEP, LPF
BOR-60 (Russian Federation)	HF, HT, HRF, LCL, LEP, LPF, LSF
EBR-II (USA)	HF, HT, EQ, LPF
Fermi (USA)	HF, LSF, HT, LPF, leakage in SG
FFTF (USA)	HF, HT, LPF, LSF, CFI
BR-10 (Russian Federation)	HF, F1L, HT, HRF, LCL, LEP, LSF
CEFR (China)	HF, HT, HRF, LCL, LEP, LPF, DND, EQ, HIT

HT - High primary coolant outlet temperatures
HRF - High rate of flux change (reactivity)
HRT - High rate of coolant temperature change
LPF - Low ratio of primary coolant flow to core flux
HPF - High ratio of primary coolant flow to core flux
CFI - Primary-to-secondary coolant flow imbalance
HIT - High primary coolant inlet temperature
HPSS - High pressure in secondary coolant system
HCE - High coolant level in pipe enclosure
HCP - High coolant level in primary pump tank
CI - Containment isolation demand
TT - Turbine trip,
HD - Hydrogen detection
HF - High neutron flux (linear)
FiL - Failure of i loops
LNF - Low neutron flux indication
LCL - Low coolant level in reactor vessel
LEP - Loss of electrical power
LSF - Low secondary coolant flow
HRF1 - High rate-of-change of flow rate
ABNS - Acoustic boiling noise signal
DND - Delayed neutron detection signal
EQ - Earthquake,
HR - High radiation in containment,
LCI - Low coolant level in IHX

10. PROTECTION AND CONTROL (cont.)

10.1. Main criteria for initiating automatic shutdown

Demonstration or Prototype Fast Reactors

Plant	Main criteria for initiating automatic shutdown
Phénix (France)	HF,HRF,LEP,DND,EQ,HRT, in SG
SNR-300 (Germany)	HF,HRT,HT,HRF,LPF,LSF,CFI,DND,EQ,LCL
PFBR (India)	HF,HT,HRF,LNF,LPF,DND,HIT
MONJU (Japan)	HF,HRF,LCL,HT,LEP,LPF,LSF,DND,EQ
PFR (UK)	HF,HT,HRF,LNF,LCL,LEP,LPF,HRF1,DND
CRBRP (USA)	HF,HT,CFI,LPF,LCL
BN-350 (Kazakhstan)	HF,HT,HRF,LCL,LEP,LPF,F2L,DND
BN-600 (Russian Federation)	HF,HT,HRF,LCL,LEP,LPF,F2L,DND, EQ
ALMR (USA)	HF,DPF,LCL,HPSS,HIT*,HT*,HR*
KALIMER-150 (Republic of Korea)	HF,HRF,HT,LCL,LEP,HIT,HPSS
SVBR-75/100 (Russian Federation)	HF,FiL.HT,HRF,LEP,EQ,TT
BREST-OD-300 (Russian Federation)	HF,HT,LPF,LCL,LEF,EQ,HIT,HRF

Commercial Size Reactors

Super-Phénix 1 (France)	HF,LPF,HT,HRF,LEP,EQ,HD,DND,HIT,HR
Super-Phénix 2 (France)	LPF,HF,HT,HRF,LEP,EQ,HD,DND
SNR 2 (Germany)	HF,HT,LPF,DND
DFBR (Japan)	HF,HT,HRF,LCL,LEP,LPF,DND,EQ,LCI,LSF,
CDFR (UK)	HF,HT,HRT,LCL,LEP,HRF1,ABNS,DND,LPF
BN-1600 (Russian Federation)	HF,HT,HRF,LPF,F2L,EQ
BN-800 (Russian Federation)	HF,HT,HRF,LCL,LEP,LPF,EQ,F2L,DND
EFR	HF,HT,LPF,LSF,CFI,DND,EQ,HRF,ABNS,LEP
BN-1800 (Russian Federation)	HF,HT,HRF,LCL,LEP,LPF,EQ,F2L,DND
BREST-1200 (Russian Federation)	HF,HT,LPF,LCL,LEF,EQ,HIT,HRF
JSFR-1500 (Japan)	HF,HT,HRF,LCL,LEP,LPF,DND,EQ,HPSS,TT,HD

* used by protection system only if control system directed runback fails

HT - High primary coolant outlet temperatures
HRF - High rate of flux change (reactivity)
HRT - High rate of coolant temperature change
LPF - Low ratio of primary coolant flow to core flux
HPF - High ratio of primary coolant flow to core flux
CFI - Primary-to-secondary coolant flow imbalance
HIT - High primary coolant inlet temperature
HPSS - High pressure in secondary coolant system
HCE - High coolant level in pipe enclosure
HCP - High coolant level in primary pump tank
CI - Containment isolation demand
TT - Turbine trip,
HD - Hydrogen detection

HF - High neutron flux (linear)
FiL - Failure of i loops
LNF - Low neutron flux indication
LCL - Low coolant level in reactor vessel
LEP - Loss of electrical power
LSF - Low secondary coolant flow
HRF1 - High rate-of-change of flow rate
ABNS - Acoustic boiling noise signal
DND - Delayed neutron detection signal
EQ - Earthquake,
HR - High radiation in containment,
LCI - Low coolant level in IHX

10. PROTECTION AND CONTROL (cont.)

10.2. Principal shutdown systems

Experimental Fast Reactors

Plant	Principal shutdown systems
Rapsodie (France)	6 control rods (CR)
KNK-II (Germany)	2 CR
FBTR (India)	6 CR*
PEC (Italy)	11 CR* comprising 2 CIRS**
JOYO (Japan)	safety CR
DFR (UK)	12 bottom-entry fuel rods and 3 top entry boron shut-off rods
BOR-60 (Russian Federation)	safety and regulating control rods
EBR-II (USA)	drive-out of CR containing fuel
Fermi (USA)	safety rods
FFTF (USA)	3 primary and 6 secondary CR* comprising 2 CIRS**
BR-10 (Russian Federation)	bottom-entry Ni-reflector
CEFR (China)	5 CR (primary) and 23safety rods (secondary)

Demonstration or Prototype Fast Reactors

Phenix (France)	6 CR
SNR-300 (Germany)	2 redundant diverse systems
PFBR (India)	12 CR* comprising 2 CIRS**
MONJU (Japan)	main CR and back up CR
PFR (UK)	5 control and 5 shut-off rods held by 2 guard lines
CRBRP (USA)	two independent and diverse systems; primary system has 9 rods; secondary system has 6 rods
BN-350 (Kazakhstan)	safety and regulating CR
BN-600 (Russian Federation)	safety and regulating CR
ALMR (USA)	9 CR with diverse shutdown systems
KALIMER-150 (Republic of Korea)	6 CR with diverse shutdown systems
SVBR-75/100 (Russian Federation)	safety and regulating CR
BREST-OD-300 (Russian Federation)	2 CIRS

* CR - control rods
** CIRS - completely independent reactor shut-down systems

10.2. Principal shutdown systems

Commercial Size Reactors

Plant	Principal shutdown systems
Super-Phenix 1 (France)	2 redundant systems
Super-Phenix 2 (France)	2 redundant systems
SNR 2 (Germany)	2 redundant diverse systems
DFBR (Japan)	2 redundant diverse systems
CDFR (UK)	18 regulating rods and 6 shut-off rods and 6 alternative shut-down rods held by 2 guard-lines
BN-1600 (Russian Federation)	safety and regulating CR
BN-800 (Russian Federation)	safety and regulating CR
EFR	2 redundant diverse systems
ALMR (USA)	9 control rods with diverse shutdown systems
SVBR-75/100 (Russian Federation)	safety and regulating CR
BN-1800 (Russian Federation)	to be defined
BREST-1200 (Russian Federation)	2 CIRS
JSFR-1500 (Japan)	2 redundant diverse systems

* CR - control rods

** CIRS - completely independent reactor shut-down systems

10.3. Reactor power control

Experimental Fast Reactors

Plant	Reactor power control
Rapsodie (France)	manual
KNK-II (Germany)	load following
FBTR (India)	manual
PEC (Italy)	manual
JOYO (Japan)	manual
DFR (UK)	steady operation at full power
BOR-60 (Russian Federation)	automatic and manual
EBR-II (USA)	manual or automatic*
Fermi (USA)	automatic
FFTF (USA)	manual
BR-10 (Russian Federation)	automatic and manual
CEFR (China)	manual or automatic

Demonstration or Prototype Fast Reactors

Phénix (France)	primarily manual
SNR-300 (Germany)	grid following/automatic or manual
PFBR (India)	manual
MONJU (Japan)	power control on outlet temperature or manual
PFR (UK)	manual or power control on outlet temperature
CRBRP (USA)	automatic; load following
BN-350 (Kazakhstan)	automatic power control
BN-600 (Russian Federation)	automatic power control on outlet Na and steam temperature
ALMR (USA)	grid following/automatic or manual
KALIMER-150 (Republic of Korea)	manual/automatic
SVBR-75/100 (Russian Federation)	manual and automatic
BREST-OD-300 (Russian Federation)	automatic and manual

* also in transient as well as steady-state mode of operation

10.3. Reactor power control

Commercial Size Reactors

Plant	Reactor power control
Super-Phénix 1 (France)	base load operation
Super-Phénix 2 (France)	grid following
SNR 2 (Germany)	grid following, automatic
DFBR (Japan)	base load operation
CDFR (UK)	grid following
BN-1600 (Russian Federation)	automatic power control on outlet Na and steam T
BN-800 (Russian Federation)	automatic power control on outlet Na and steam T
EFR	grid following, automatic
ALMR (USA)	grid following/automatic or manual
SVBR-75/100 (Russian Federation)	manual and automatic
BN-1800 (Russian Federation)	automatic power control on outlet Na and steam T
BREST-1200 (Russian Federation)	automatic and manual
JSFR-1500 (Japan)	automatic

10.3. Reactor power control

Experimental Fast Reactors

Plant	Reactor power control
Rapsodie (France)	manual
KNK-II (Germany)	constant coolant ΔT
FBTR (India)	constant primary flow and coolant inlet temperature
PEC (Italy)	manual
JOYO (Japan)	constant coolant inlet temperature and flow rate
DFR (UK)	steady operation at full flow required to maintain specified ΔP through core
BOR-60 (Russian Federation)	manual
Fermi (USA)	constant flow rate
FFTF (USA)	manual
BR-10 (Russian Federation)	constant coolant, ΔT
CEFR (China)	constant coolant ΔT

Demonstration or Prototype Fast Reactors

Phénix (France)	control coolant ΔT of each subassembly
SNR-300 (Germany)	constant coolant ΔT
PFBR (India)	period, reactivity and reactor power
MONJU (Japan)	programme control (proportional to the reactor power) for nominally constant coolant ΔT or manual
PFR (UK)	manual or constant steam pressure
CRBRP (USA)	automatic; load following
BN-350 (Kazakhstan)	constant flow rate
BN-600 (Russian Federation)	constant coolant ΔT
ALMR (USA)	core outlet temperature with flux trim
KALIMER-150 (Republic of Korea)	to be defined
SVBR-75/100 (Russian Federation)	level of coolant in separator, power level
BREST-OD-300 (Russian Federation)	coolant outlet temperature of each subassembly in inner core, coolant level, coolant inlet temperature

10.3. Reactor power control

Commercial Size Reactors

Plant	Reactor power control
Super-Phénix 1 (France)	core coolant outlet temperature
Super-Phénix 2 (France)	control ΔT of each instrumented subassembly
SNR 2 (Germany)	core coolant outlet T control, variable flow, constant coolant ΔT
DFBR (Japan)	outlet T control, variable flow, variable coolant ΔT following pre-set power
CDFR (UK)	automatic control, following pre set power and core core coolant outlet temperature
BN-1600 (Russian Federation)	constant coolant ΔT
BN-800 (Russian Federation)	constant coolant ΔT
EFR	constant reactor coolant inlet temperature
ALMR (USA)	core outlet temperature with flux trim
SVBR-75/100(Russian Federation)	level of coolant in separator, power level
BN-1800 (Russian Federation)	constant coolant ΔT
BREST-1200 (Russian Federation)	coolant outlet temperature of each subassembly in inner core, coolant level, coolant inlet temperature
JSFR-1500 (Japan)	constant coolant inlet ,outlet temperature and flow rate

10.3. Reactor power control

Experimental Fast Reactors

	Reactor power control
Plant	Plant response designed to cope with seizure or stopping of a primary pump
Rapsodie (France)	automatic scram by low flow
KNK-II (Germany)	automatic scram
FBTR (India)	automatic scram
PEC (Italy)	automatic scram and all pumps operate with pony motors
JOYO (Japan)	automatic scram by auxiliary relay of motor power supply or pump outlet flow
DFR (UK)	diesel generator electric supply to primary EM pony
BOR-60 (Russian Federation)	automatic scram
EBR-II (USA)	auxiliary EM pump with battery power supply
Fermi (USA)	power set back to 67%, secondary pump in same loop stopped
FFTF (USA)	automatic scram and all pumps operate with pony motors
BR-10 (Russian Federation)	automatic scram, pumps with battery power supply
CEFR (China)	automatic scram and all pumps operate with pony motors

Demonstration or Prototype Fast Reactors

Phénix (France)	automatic scram
SNR-300 (Germany)	automatic scram, pony motors operate pumps for decay heat removal
PFBR (India)	automatic scram
MONJU (Japan)	automatic scram by pump outlet flow or turning speed
PFR (UK)	automatic engagement of battery backed pony motors on primary pumps (10% flow) and automatic scram
CRBRP (USA)	automatic scram; pony motors operate available pumps; steam drum is vented to air-cooled condenser
BN-350 (Kazakhstan)	automatic scram
BN-600 (Russian Federation)	automatic scram
ALMR (USA)	automatic scram, pony motors operate available pumps, DHR ystem available
KALIMER-150 (Republic of Korea)	automatic scram, pony pumps are activated
SVBR-75/100 (Russian Federation)	automatic scram
BREST-OD-300 (Russian Federation)	automatic scram

10.3. Reactor power control

Commercial Size Reactors

	Reactor power control
Plant	Plant response designed to cope with seizure or stopping of a primary pump
Super-Phénix 1 (France)	automatic scram
Super-Phénix 2 (France)	power reduction and shutdown
SNR 2 (Germany)	automatic scram
DFBR (Japan)	automatic scram with pony motor pump operation
CDFR (UK)	automatic engagement of battery- backed pony motors on primary pumps (10% flow)
BN-1600 (Russian Federation)	automatic scram
BN-800 (Russian Federation)	automatic scram
EFR	automatic scram
ALMR (USA)	automatic scram, pony motors operate available pumps, DHR system available
SVBR-75/100 (Russian Federation)	automatic scram
BN-1800 (Russian Federation)	automatic scram
BREST-1200 (Russian Federation)	automatic scram
JSFR-1500 (Japan)	automatic scram and natural circulation DHR

10. PROTECTION AND CONTROL (cont.)

10.4. Method of detection of coolant leaks

Experimental Fast Reactors

	Method of detection of coolant leaks
Plant	Type of detector
Rapsodie (France)	conductivity and aerosol detectors
KNK-II (Germany)	electrical contact
FBTR (India)	conductivity and aerosol detectors
PEC (Italy)	continuity and aerosol detector
JOYO (Japan)	direct contact type (and aerosol type)
DFR (UK)	conductivity detectors
BOR-60 (Russian Federation)	electrical contact
EBR-II (USA)	electrical contact
Fermi (USA)	H_2 detectors, sodium level indicators
FFTF (USA)	electrical contact and aerosol detector
BR-10 (Russian Federation)	electrical contact and aerosol detectors
CEFR (China)	electrical contact, smoke and aerosol detectors

Demonstration or Prototype Fast Reactors

Phénix (France)	electrical contact, aerosol detectors
SNR-300 (Germany)	electrical contact, radiation and sodium fire detectors
PFBR (India)	electrical contact and aerosol detectors
MONJU (Japan)	gas sampling type and contact type
PFR (UK)	electrical contact and sodium fire detectors
CRBRP (USA)	radiation, aerosol detectors and electrical contact
BN-350 (Kazakhstan)	electrical contact, radiation, aerosol detectors
BN-600 (Russian Federation)	electrical contact, radiation, aerosol detectors
ALMR (USA)	electrical contact and aerosol detectors
KALIMER-150 (Republic of Korea)	electrical contact and aerosol detectors
SVBR-75/100 (Russian Federation)	to be defined
BREST-OD-300 (Russian Federation)	control coolant level and concrete temperature

10. PROTECTION AND CONTROL (cont.)

10.4. Method of detection of coolant leaks

Commercial Size Reactors

	Method of detection of coolant leaks
Plant	Type of detector
Super-Phénix 1 (France)	electrical contact, aerosol detectors
Super-Phénix 2 (France)	electrical contact,aerosol detectors
SNR 2 (Germany)	electrical contact, smoke detectors
DFBR (Japan)	electrical contact, aerosol detectors, sodium-ion and smoke detectors
CDFR (UK)	various conductivity detectors
BN-1600 (Russian Federation)	electrical contact, radiation, aerosol detectors
BN-800 (Russian Federation)	electrical contact, radiation, aerosol detectors
EFR	electrical contact, thermocouples, smoke and aerosol detectors
ALMR (USA)	electrical contact and aerosol detectors
SVBR-75/100(Russian Federation)	to be defined
BN-1800 (Russian Federation)	electrical contact, radiation, aerosol detectors
BREST-1200 (Russian Federation)	control coolant level and concrete temperature
JSFR-1500 (Japan)	sodium ion detector (laser type)

11. REFUELLING

11.1. Refuelling methods

Experimental Fast Reactors

	Refuelling methods
Plant	Method used within primary vessel
Rapsodie (France)	2 RP and 2 VM
KNK-II (Germany)	-
FBTR (India)	2 VM and 2 RP
PEC (Italy)	under VH by PM in 1 RP
JOYO (Japan)	VM in 2 RP
DFR (UK)	VM in 2 RP
BOR-60 (Russian Federation)	VM in 2 RP
EBR-II (USA)	VM in 2 RP and transfer arm
Fermi (USA)	VM, fixed exit port, RP with offset mechanism
FFTF (USA)	3 VM each in 1 RP
BR-10 (Russian Federation)	2RP and 1 VM
CEFR (China)	VM in 2 RP, IVS

Demonstration or Prototype Fast Reactors

Phénix (France)	fixed offset arm in 1 RP, IVS
SNR-300 (Germany)	VM in 3 RP
PFBR (India)	fixed offset arm in 2 RP, IVS
MONJU (Japan)	fixed offset arm in 1 RP
PFR (UK)	PM in 1 RP, IVS
CRBRP (USA)	VM in 3 RP
BN-350 (Kazakhstan)	VM in 2 RP, IVS
BN-600 (Russian Federation)	2 VM in 2 RP, IVS
ALMR (USA)	2 PM in 2 RP
KALIMER-150 (Republic of Korea)	PM, RP, IVS
SVBR-75/100 (Russian Federation)	VM
BREST-OD-300 (Russian Federation)	2RP+VM+rotating mechanism +horizontal transfer mechanism

RP - rotating plug
VM - Vertical mechanism (direct lift)
VH - vessel head
FM - fixed-arm mechanism
PM - pantograph mechanism
IVS - fuel store within primary vessel

11. REFUELLING (cont.)

11.1. Refuelling methods

Commercial Size Reactors

	Refuelling methods
Plant	Method used within primary vessel
Super-Phénix 1 (France)	2 VM in 2 RP
Super-Phénix 2 (France)	1 VM in 2 RP
SNR 2 (Germany)	under head to transfer position
DFBR (Japan)	VM and PM in 2 RP
CDFR (UK)	1 VM in 2 RP
BN-1600 (Russian Federation)	VM in 3 RP, IVS
BN-800 (Russian Federation)	VM in 3 RP, IVS
EFR	RP, VM, FM, IVS
ALMR (USA)	2 PM in 2 RP
SVBR-75/100 (Russian Federation)	VM
BN-1800 (Russian Federation)	VM in 3 RP, IVS
BREST-1200 (Russian Federation)	2RP,VM, to be defined
JSFR-1500 (Japan)	1 PM in 1 RP

RP - rotating plug
VM - Vertical mechanism (direct lift)
VH - vessel head
FM - fixed-arm mechanism
PM - pantograph mechanism
IVS - fuel store within primary vessel

11.1. Refuelling methods

Experimental Fast Reactors

Plant	Refuelling methods	
	Methods used to store spent fuel	Method used to handle fuel outside primary vessel
Rapsodie (France)	OSC	MF
KNK-II (Germany)	through FHP by TM to OPV	
FBTR (India)	by TM to OSC	
PEC (Italy)	through FHP by MC to transfer and external examination cells	
JOYO (Japan)	through port in outer rotating plug via MC on gantry	
DFR (UK)	mobile flask to OSC	
BOR-60 (Russian Federation)	OPV	MF
EBR-II (USA)	through FHP by cask car through airlock	
Fermi (USA)	through FHP by cask car through airlock	
FFTF (USA)	through 1 of 3 FHP by MC on gantry	
BR-10 (Russian Federation)	OSC	MF
CEFR (China)	ORB (54) for primary, OSC (943) for secondary	MF

Demonstration or Prototype Fast Reactors

Phénix (France)	ORB (43) + OSC	TA
SNR-300 (Germany)	through FHP by MC on bridge crane	
PFBR (India)	ORB (156) + OSC (711) in DM water pool	TA
MONJU (Japan)	through TM to OPV by FHP to OSC	
PFR (UK)	through FHP by MC on overhead crane to OPV	
CRBRP (USA)	through port in outer plug via MC on gantry	FHP
BN-350 (Kazakhstan)	through elevator by TM to OPV	FHP
BN-600 (Russian Federation)	through elevator by TM to OPV	MF
BREST-OD-300 (Russian Federation)	storage in primary vessel+VM+TM	MF,VM
KALIMER-150 (Republic of Korea)	through FHP by MC to outside reactor bilding	MF, FHP
SVBR-75/100 (Russian Federation)**	OSC (55)	MF

MC - mobile cask
TM - transfer mechanism
FHP - fixed head port
ORB - storage in diagrid positions outside radial blanket
RS - storage in rotor or basket within primary vessel
OPV - storage outside primary vessel but inside secondary containment
OSC - storage outside secondary containment [Figure in parentheses, e.g., RS(20), indicates number of storage positions]
MF - mobile transfer flask
TA - transfer within an A-frame
FHP - transfer within a fixed head port

11.1. Refuelling methods

Commercial Size Reactors

Plant	Refuelling methods	
	Methods used to store spent fuel	Method used to handle fuel outside primary vessel
Super-Phénix 1 (France)	OSC (1344)	TA
Super-Phénix 2 (France)	OSC (1300)	TA
SNR 2 (Germany)	through FHP via fixed TM in inerted cells	
DFBR (Japan)		
CDFR (UK)	through fixed transfer lock to OPV	
BN-1600 (Russian Federation)	through elevator by TM to OPV	FHP
BN-800 (Russian Federation)	through elevator by TM to OPV	FHP
EFR	ORB (234)+(OPV (800)+OSC	TA
ALMR (USA)*	RS	MF
SVBR-75/100 (Russian Federation)	OSC (55)	MF
BN-1800 (Russian Federation)	through elevator by TM to OPV	FHP
BREST-1200 (Russian Federation)	storage in primary vessel+VM+TM	to be defined
JSFR-1500 (Japan)	through MC to OSC	MF

* the same methods used to store spent fuel for ALMR demo

MC - mobile cask
TM - transfer mechanism
FHP - fixed head port
ORB - storage in diagrid positions outside radial blanket
RS - storage in rotor or basket within primary vessel
OPV - storage outside primary vessel but inside secondary containment
OSC - storage outside secondary containment [Figure in parentheses, e.g., RS(20), indicates number of storage positions]
MF - mobile transfer flask
TA - transfer within an A-frame
FHP - transfer within a fixed head port

11.2. Cooling during refueling

Experimental Fast Reactors

Plant	Cooling during refueling
	Cooling method of fuel subassembly during handling in vessel
Rapsodie (France)	sodium immersion
KNK-II (Germany)	by argon
FBTR (India)	sodium immersion
PEC (Italy)	sodium immersion
JOYO (Japan)	sodium immersion
DFR (UK)	forced cooling system in charge machine
BOR-60 (Russian Federation)	sodium immersion
EBR-II (USA)	sodium immersion
Fermi (USA)	finned pots, sodium immersion
FFTF (USA)	sodium immersion
BR-10 (Russian Federation)	sodium immersion
CEFR (China)	sodium immersion

Demonstration or Prototype Fast Reactors

Phénix (France)	sodium immersion
SNR-300 (Germany)	not determined
PFBR (India)	sodium immersion
MONJU (Japan)	sodium immersion
PFR (UK)	sodium immersion
CRBRP (USA)	sodium immersion
BN-350 (Kazakhstan)	sodium immersion
BN-600 (Russian Federation)	sodium immersion
ALMR (USA)	sodium immersion
KALIMER-150 (Republic of Korea)	sodium immersion
SVBR-75/100 (Russian Federation)	lead-bismuth immersion, by argon
BREST-OD-300 (Russian Federation)	lead immersion, by argon

11. REFUELLING (cont.)

11.2. Cooling during refueling

Commercial Size Reactors

Plant	Cooling during refueling Cooling method of fuel subassembly during handling in vessel
Super-Phenix 1 (France)	sodium immersion
Super-Phenix 2 (France)	sodium immersion
SNR 2 (Germany)	not determined
DFBR (Japan)	sodium immersion
CDFR (UK)	sodium immersion
BN-1600 (Russian Federation)	sodium immersion
BN-800 (Russian Federation)	sodium immersion
EFR	sodium immersion
ALMR (USA)	sodium immersion
SVBR-75/100 (Russian Federation)	lead-bismuth immersion, by argon
BN-1800 (Russian Federation)	sodium immersion
BREST-1200 (Russian Federation)	lead immersion, by argon
JSFR-1500 (Japan)	sodium immersion

11.2. Cooling during refueling

Experimental Fast Reactors

Plant	Cooling during refueling Cooling method of fuel subassembly during handling outside the primary vessel
Rapsodie (France)	natural convection in argon
KNK-II (Germany)	by argon
FBTR (India)	no special provision
PEC (Italy)	sodium pots and forced ventilation through the subassembly and radiation to a cold wall cooled by air under forced convection
JOYO (Japan)	argon
DFR (UK)	forced cooling system in charge inactive
BOR-60 (Russian Federation)	by argon
EBR-II (USA)	by argon
Fermi (USA)	finned pots
FFTF (USA)	radiation to a cold wall cooled by air under forced convection
BR-10 (Russian Federation)	natural convection in argon
CEFR (China)	by argon if necessary

Demonstration or Prototype Fast Reactors

Phénix (France)	Na-filled bucket. Natural convection in bucket and argon cooling outside bucket
SNR-300 (Germany)	not determined
PFBR (India)	Na-filled pot under natural convection and subsequently forced convection in nitrogen
MONJU (Japan)	Na -filled pot
PFR (UK)	Na-filled bucket. Natural convection in bucket and argon cooling outside bucket
CRBRP (USA)	transfer in sodium-filled pot, heat transfer through argon to finned tube cooled by forced air
BN-350 (Kazakhstan)	by nitrogen
BN-600 (Russian Federation)	without forced cooling
ALMR (USA)	by helium within flask and naturally circulating air outside flask
KALIMER-150 (Republic of Korea)	gas cooled in flask and air cooled outside flask
SVBR-75/100 (Russian Federation)	air cooling
BREST-OD-300 (Russian Federation)	by argon

11.2. Cooling during refueling

Commercial Size Reactors

Plant	Cooling during refueling Cooling method of fuel subassembly during handling outside the primary vessel
Super-Phénix 1 (France)	Na-filled buckets under natural convection in argon gas
Super-Phénix 2 (France)	not determined
SNR 2 (Germany)	not determined
DFBR (Japan)	sodium filled pot in argon-filled flask with air- cooled wall
CDFR (UK)	convection in Na and forced cooling with argon
BN-1600 (Russian Federation)	without forced cooling
BN-800 (Russian Federation)	without forced cooling
EFR	Na-filled pot under natural and forced convection in nitrogen
ALMR (USA)	by helium within flask and naturally circulating air outside flask
SVBR-75/100 (Russian Federation)	air cooling
BN-1800 (Russian Federation)	thout forced cooling
BREST-1200 (Russian Federation)	by argon
JSFR-1500 (Japan)	argon

11.2. Cooling during refueling

Experimental Fast Reactors

Plant	Cooling during refueling Maximum allowable fuel pin cladding temperature during handling (°C)
Rapsodie (France)	650
KNK-II (Germany)	650
FBTR (India)	650
PEC (Italy)	450
JOYO (Japan)	470
DFR (UK)	-
BOR-60 (Russian Federation)	600
EBR-II (USA)	depends on type of fuel and necessity for rapid fuel handling for post irradiation examination or other reasons
Fermi (USA)	-
FFTF (USA)	538
BR-10 (Russian Federation)	600
CEFR (China)	700

Demonstration or Prototype Fast Reactors

Phénix (France)	700
SNR-300 (Germany)	not determined
PFBR (India)	650
MONJU (Japan)	-
PFR (UK)	630
CRBRP (USA)	675
BN-350 (Kazakhstan)	600
BN-600 (Russian Federation)	600
ALMR (USA)	675
KALIMER-150 (Republic of Korea)	not determined
SVBR-75/100 (Russian Federation)	600
BREST-OD-300 (Russian Federation)	450

11.2. Cooling during refueling

Commercial Size Reactors

Plant	Cooling during refueling Maximum allowable fuel pin cladding temperature during handling (°C)
Super-Phénix 1 (France)	650
Super-Phénix 2 (France)	700
SNR 2 (Germany)	not determined
DFBR (Japan)	700
CDFR (UK)	650
BN-1600 (Russian Federation)	600
BN-800 (Russian Federation)	600
EFR	650
ALMR (USA)	675
SVBR-75/100 (Russian Federation)	600
BN-1800 (Russian Federation)	650
BREST-1200 (Russian Federation)	to be determined
JSFR-1500 (Japan)	600 within 30 days, 630 within 24 hr

11.3. Method of identifying subassemblies and core components during handling operations

Experimental Fast Reactors

Plant	Method of identifying subassemblies and core components during handling operations
Rapsodie (France)	visual
KNK-II (Germany)	visual
FBTR (India)	visual
PEC (Italy)	visual with optical aids
JOYO (Japan)	1 TV (reactor vessel)
DFR (UK)	introscope through top shield
BOR-60 (Russian Federation)	visual with optical aids
EBR-II (USA)	visual with optical aids
Fermi (USA)	visual with optical aids
FFTF (USA)	in two shielded argon-filled hot cells
BR-10 (Russian Federation)	visual
CEFR (China)	conputer control and visual with optical aids if necessary

Demonstration or Prototype Fast Reactors

Phénix (France)	visual
SNR-300 (Germany)	vessel: outer inspection by TV
PFBR (India)	visual
MONJU (Japan)	visual with optical aids
PFR (UK)	remote viewing
CRBRP (USA)	visual with optical aids, dimensional measurement
BN-350 (Kazakhstan)	visual with optical aids
BN-600 (Russian Federation)	visual with optical aids
ALMR (USA)	visual with optical aids
KALIMER-150 (Republic of Korea)	not determined
SVBR-75/100 (Russian Federation)	mechanical positioning
BREST-OD-300 (Russian Federation)	visual with optical aids, identification bulges on tail of subassemblies

11.3. Method of identifying subassemblies and core components during handling operations

Commercial Size Reactors

Plant	Method of identifying subassemblies and core components during handling operations
Super-Phénix 1 (France)	visual
Super-Phénix 2 (France)	visual
SNR 2 (Germany)	
DFBR (Japan)	visual
CDFR (UK)	remote viewing
BN-1600 (Russian Federation)	visual with optical aids
BN-800 (Russian Federation)	visual with optical aids
EFR	visual with TV camera
ALMR (USA)	visual with optical aids
SVBR-75/100 (Russian Federation)	mechanical positioning
BN-1800 (Russian Federation)	visual with optical aids
BREST-1200 (Russian Federation)	visual with optical aids, identification bulges on tail of subassemblies
JSFR-1500 (Japan)	to be determined

11.4. Main method of removing coolant from subassemblies and core components

Experimental Fast Reactors

Plant	Main method of removing coolant from subassemblies and core components
Rapsodie (France)	nitrogen with steam and washing
KNK-II (Germany)	-
FBTR (India)	-
PEC (Italy)	-
JOYO (Japan)	argon with steam
DFR (UK)	-
BOR-60 (Russian Federation)	nitrogen with steam or alcoholic solution cleaning and washing
EBR-II (USA)	-
Fermi (USA)	-
FFTF (USA)	-
BR-10 (Russian Federation)	nitrogen with steam and washing
CEFR (China)	nitrogen with steam and washing

Demonstration or Prototype Fast Reactors

Phénix (France)	washing with CO_2 and H_2O
SNR-300 (Germany)	not determined
PFBR (India)	nitrogen with steam and washing
MONJU (Japan)	-
PFR (UK)	steam cleaning and washing
CRBRP (USA)	-
BN-350 (Kazakhstan)	argon with steam and washing
BN-600 (Russian Federation)	argon with steam and washing
ALMR (USA)	drip drying in helium atmosphere
KALIMER-150 (Republic of Korea)	to be determined
SVBR-75/100 (Russian Federation)	none
BREST-OD-300 (Russian Federation)	drip drying in argon atmosphere

11.4. Main method of removing coolant from subassemblies and core components

Commercial Size Reactors

Plant	Main method of removing coolant from subassemblies and core components
Super-Phénix 1 (France)	washing with CO_2 and H_2O
Super-Phénix 2 (France)	not determined
SNR 2 (Germany)	not determined
DFBR (Japan)	cleaning with high temperature argon
CDFR (UK)	not determined
BN-1600 (Russian Federation)	not determined
BN-800 (Russian Federation)	argon with steam and washing
EFR	washing with CO_2 and H_2O
ALMR (USA)	drip drying in helium atmosphere
SVBR-75/100 (Russian Federation)	none
BN-1800 (Russian Federation)	argon with steam and washing
BREST-1200 (Russian Federation)	drip drying in argon atmosphere
JSFR-1500 (Japan)	argon with steam

12. IN-SERVICE INSPECTION PROVISIONS

12.1. Primary vessel and internals

Experimental Fast Reactors

Plant	Primary vessel and internals	
	Provision for routine ISI of inside of primary vessel and internal structure	Provision for routine ISI of outer surface of primary vessel
Rapsodie (France)	DM	-
KNK-II (Germany)	-	-
FBTR (India)	-	AD
PEC (Italy)	optical DM at vessel, mechanical DM of internals	
JOYO (Japan)	USV, UGV, DM	-
DFR (UK)	-	-
BOR-60 (Russian Federation)	AD	-
EBR-II (USA)	-	-
Fermi (USA)	internal-visual with optical aids (limited extent)	
FFTF (USA)	-	TV
BR-10 (Russian Federation)	-	-
CEFR (China)	-	AD, VI

Demonstration or Prototype Fast Reactors

Phénix (France)	-	-
SNR-300 (Germany)	-	-
PFBR (India)	USV, UGV, DM	AD,US,VI
MONJU (Japan)	-	AD,VI
PFR (UK)	-	-
CRBRP (USA)	-	TV
BN-350 (Kazakhstan)	UGV	AD, Elcon
BN-600 (Russian Federation)	UGV	AD, Elcon
ALMR (USA)	-	VI
KALIMER-150 (Republic of Korea)	USV, UGS, DM	VI, Elcon, AD, US, FV
SVBR-75/100 (Russian Federation)	none	-
BREST-OD-300 (Russian Federation)	UGV, DM	VI, AD, US

USV - under-sodium viewing
UGV - under-gas viewing, e.g. optical periscope
DM - displacement monitoring by ultrasonic detectors
TV - tracked vehicle
FV - free-moving vehicle
AD - aerosol detection of primary vessel leak
VI - visual inspection by optical equipment
EC - eddy current measurements
Elcon - electrical contact
US - ultrasonic measurements

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.1. Primary vessel and internals

Commercial Size Reactors

Plant	Primary vessel and internals	
	Provision for routine ISI of inside of primary vessel and internal structure	Provision for routine ISI of outer surface of primary vessel
Super-Phénix 1 (France)	USV*,UGV*	Elcon/VI*,US*,FV*
Super-Phénix 2 (France)	not determined	
SNR 2 (Germany)	not determined	
DFBR (Japan)	-	
CDFR (UK)	US, TV	
BN-1600 (Russian Federation)	not determined	AD, Elcon
BN-800 (Russian Federation)	UGV	AD, Elcon
EFR	UGV,DM	VI,US,TV
ALMR (USA)	-	VI
SVBR-75/100 (Russian Federation)	none	-
BN-1800 (Russian Federation)	UGV	AD, Elcon
BREST-1200 (Russian Federation)	UGV	VI, AD, Elcon
JSFR-1500 (Japan)	USV with free-moving vehicle	VI ,US, FV

* periodic inspection during shutdown

USV - under-sodium viewing
UGV - under-gas viewing, e.g. optical periscope
DM - displacement monitoring by ultrasonic detectors
TV - tracked vehicle
FV - free-moving vehicle
AD - aerosol detection of primary vessel leak
VI - visual inspection by optical equipment
EC - eddy current measurements
Elcon - electrical contact
US - ultrasonic measurements

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.2. Primary circuit pipes

Experimental Fast Reactors

Plant	Primary circuit pipes
Rapsodie (France)	displacement monitoring of the vessel inlet and outlet
KNK-II (Germany)	n.a.
FBTR (India)	-
PEC (Italy)	visual inspection of primary piping at reactor shutdown
JOYO (Japan)	sodium leakage monitoring, visual examination, ultrasonic test, displacement measurement, and test piece surveillance
DFR (UK)	visual (occasional entry)
BOR-60 (Russian Federation)	leak detectors
EBR-II (USA)	n.a.
Fermi (USA)	-
FFTF (USA)	periscopes for visual inspection of primary piping and valves
BR-10 (Russian Federation)	sodium leak monitoring, visual examination
CEFR (China)	n.a.

Demonstration or Prototype Fast Reactors

Phénix (France)	n.a.
SNR-300 (Germany)	n.a.
PFBR (India)	n.a.
MONJU (Japan)	sodium leakage monitoring and visual and volumetric examinations
PFR (UK)	n.a.
CRBRP (USA)	camera mounted on arm to inspect piping and guard vessels
BN-350 (Kazakhstan)	leak detectors
BN-600 (Russian Federation)	n.a.
ALMR (USA)	n.a.
KALIMER-150 (Republic of Korea)	n.a.
SVBR-75/100 (Russian Federation)	n.a.
BREST-OD-300 (Russian Federation)	VI, EC, US, TV, FV*

* steam (water) pipes

VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.2. Primary circuit pipes

Commercial Size Reactors

Plant	Primary circuit pipes
Super-Phénix 1 (France)	n.a.
Super-Phénix 2 (France)	n.a.
SNR 2 (Germany)	n.a.
DFBR (Japan)	sodium leakage monitoring and visual and volumetric examinations
CDFR (UK)	n.a.
BN-1600 (Russian Federation)	n.a.
BN-800 (Russian Federation)	n.a.
EFR	n.a.
ALMR (USA)	n.a.
SVBR-75/100(Russian Federation)	n.a.
BN-1800 (Russian Federation)	n.a.
BREST-1200 (Russian Federation)*	VI, EC, US, TV, FV
JSFR-1500 (Japan)	VI,US

* steam (water) pipes

VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.3. Secondary circuit pipes

Experimental Fast Reactors	
Plant	Secondary circuit pipes
Rapsodie (France)	-
KNK-II (Germany)	-
FBTR (India)	-
PEC (Italy)	manned access is permissible
JOYO (Japan)	LD and test piece surveillance
DFR (UK)	VI, LD
BOR-60 (Russian Federation)	LD
EBR-II (USA)	periodic inspection, and as needed*
Fermi (USA)	-
FFTF (USA)	manned access
BR-10 (Russian Federation)	LD,VI
CEFR (China)	VI,EC,US,LD, SD

Demonstration or Prototype Fast Reactors

Phenix (France)	LD, SD
SNR-300 (Germany)	-
PFBR (India)	LD
MONJU (Japan)	LD, VI
PFR (UK)	LD, SD
CRBRP (USA)	in-containment - as 12.2. ex-containment - manual techniques
BN-350 (Kazakhstan)	LD
BN-600 (Russian Federation)	LD, SD
ALMR (USA)	LD, SD
KALIMER-150 (Republic of Korea)	LD, SD, VI, US
SVBR-75/100 (Russian Federation)	n.a.
BREST-OD-300 (Russian Federation)	n.a.

* e.g. after October 1983 earthquake

VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle
LD - leak detectors (electrical contact)
SD - smoke detectors

12.3. Secondary circuit pipes

Commercial Size Reactors

Plant	Secondary circuit pipes
Super-Phenix 1 (France)	LD,VI,SD/US**, X-rays**
Super-Phenix 2 (France)	LD,VI
SNR 2 (Germany)	not determined
DFBR (Japan)	LD,VI
CDFR (UK)	LD,SD
BN-1600 (Russian Federation)	LD,SD
BN-800 (Russian Federation)	LD,SD
EFR	VI,EC,US,LD
ALMR (USA)	LD,SD
SVBR-75/100 (Russian Federation)	n.a.
BN-1800 (Russian Federation)	LD,SD
BREST-1200 (Russian Federation)	n.a.
JSFR-1500 (Japan)	VI,US

** periodic inspection during shutdown

VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.4. Intermediate heat exchangers (IHX)

Experimental Fast Reactors

Plant	Intermediate heat exchangers (IHX)
Rapsodie (France)	-
KNK-II (Germany)	-
FBTR (India)	-
PEC (Italy)	-
JOYO (Japan)	sodium leakage monitoring and test piece surveillance
DFR (UK)	
BOR-60 (Russian Federation)	leak detectors, control Na level, argon pressure
EBR-II (USA)	as needed
Fermi (USA)	tube bundles can be removed for inspection
FFTF (USA)	periscopes for visual inspection of primary piping and valves
BR-10 (Russian Federation)	radioactive sodium leak monitoring

Demonstration or Prototype Fast Reactors

Phenix (France)	sodium leakage monitoring
SNR-300 (Germany)	-
PFBR (India)	LD
MONJU (Japan)	sodium leakage monitoring and visual examination
PFR (UK)	special flask and lifting equipment available
CRBRP (USA)	camera mounted on arm to inspect exterior and guard vessel
BN-350 (Kazakhstan)	LD, control Na level and Ar pressure
BN-600 (Russian Federation)	control Na level and Ar pressure
ALMR (USA)	-
KALIMER -150 (Republic of Korea)	LD
SVBR-75/100 (Russian Federation)	n.a.
BREST-OD-300 (Russian Federation)	n.a.

USV - under-coolant viewing
UGV - under-gas viewing e.g. optical periscope
DM - displacement monitoring by ultrasonic detectors
VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle
LD - leak detection

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.4. Intermediate heat exchangers (IHX)

Commercial Size Reactors

Plant	Intermediate heat exchangers (IHX)
Super-Phenix 1 (France)	LD
Super-Phenix 2 (France)	continuous monitoring of leaks
SNR 2 (Germany)	-
DFBR (Japan)	-
CDFR (UK)	-
BN-1600 (Russian Federation)	control Na level and argon pressure
EFR	LD
ALMR (USA)	-
SVBR-75/100 (Russian Federation)	n.a.
BN-1800 (Russian Federation)	control Na level and argon pressure
BREST-1200 (Russian Federation)	n.a.
JSFR-1500 (Japan)	sodium leakage monitoring and visual examination

USV - under-coolant viewing
UGV - under-gas viewing e.g. optical periscope
DM - displacement monitoring by ultrasonic detectors
VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle
LD - leak detection

12. IN-SERVICE INSPECTION PROVISIONS (cont.)

12.5. Steam generator units

Experimental Fast Reactors

Plant	Steam generator units
Rapsodie (France)	none
KNK-II (Germany)	-
FBTR (India)	continuous monitoring of leaks
PEC (Italy)	none
JOYO (Japan)	none
DFR (UK)	none
BOR-60 (Russian Federation)	leak detectors, control of Na level and Ar pressure, RVI
EBR-II (USA)	periodic and as needed
Fermi (USA)	RVI, tube sheet is accessible
FFTF (USA)	none
BR-10 (Russian Federation)	no steam generator
CEFR (China)	RVI, EC, US,LD

Demonstration or Prototype Fast Reactors

Phénix (France)	LD
SNR-300 (Germany)	-
PFBR (India)	LD, EC
MONJU (Japan)	sodium leakage monitoring and visual and volumetric examinations
PFR (UK)	LD
CRBRP (USA)	exterior-manual techniques tubing-ultrasonic probes
BN-350 (Kazakhstan)	LD, control of Na level and Ar pressure, RVI
BN-600 (Russian Federation)	LD, control of Na level and Ar pressure, RVI
ALMR (USA)	-
KALIMER-150 (Republic of Korea)	LD, US, EC, RVI
SVBR-75/100 (Russian Federation)	LD, US, EC
BREST-OD-300 (Russian Federation)	DM, RVI, US, VI, control of lead level and Ar pressure

RVI - regular visual inspection of tube-bores and structures
USV - under-sodium viewing
UGV - under-gas viewing e.g. optical periscope
DM - displacement monitoring by ultrasonic detectors
VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle
LD - leak detection

12.5. Steam generator units

Commercial Size Reactors

Plant	Steam generator units
Super-Phénix 1 (France)	LD/US*, RVI*
Super-Phénix 2 (France)	accessibility to each tube
SNR 2 (Germany)	not determined
DFBR (Japan)	LD
CDFR (UK)	hydrogen detectors
BN-1600 (Russian Federation)	LD, control of Na level and Ar pressure, RVI
BN-800 (Russian Federation)	LD, control of Na level and Ar pressure, RVI
EFR	RVI, US,LD
ALMR (USA)	not determined
SVBR-75/100 (Russian Federation)	LD, US, EC
BN-1800 (Russian Federation)	LD, control of Na level and Ar pressure, RVI
BREST-1200 (Russian Federation)	DM, RVI, US, VI, control of lead level and Ar pressure
JSFR-1500 (Japan)	EC, US

* periodic inspection during shutdown

RVI - regular visual inspection of tube-bores and structures
USV - under-sodium viewing
UGV - under-gas viewing e.g. optical periscope
DM - displacement monitoring by ultrasonic detectors
VI - visual inspection by optical equipment
EC - eddy current measurements
US - ultrasonic measurements
TV - tracked vehicle
FV - free-moving vehicle
LD - leak detection

13. FAST REACTOR DESIGNS

13.1. Experimental fast reactors

13.1.1. BR-5/10

BR-5 was the first reactor in the world using sodium as a coolant and plutonium oxide as a fuel (Status of liqued metal cooled fast breeder reactors, Technical Reports Series, No. 246, IAEA, Vienna, 1985, p. 89). The main purpose of the reactor was to gain burnup data on PuO2 and other fuel types, to obtain experience in operation of radioactive sodium systems.

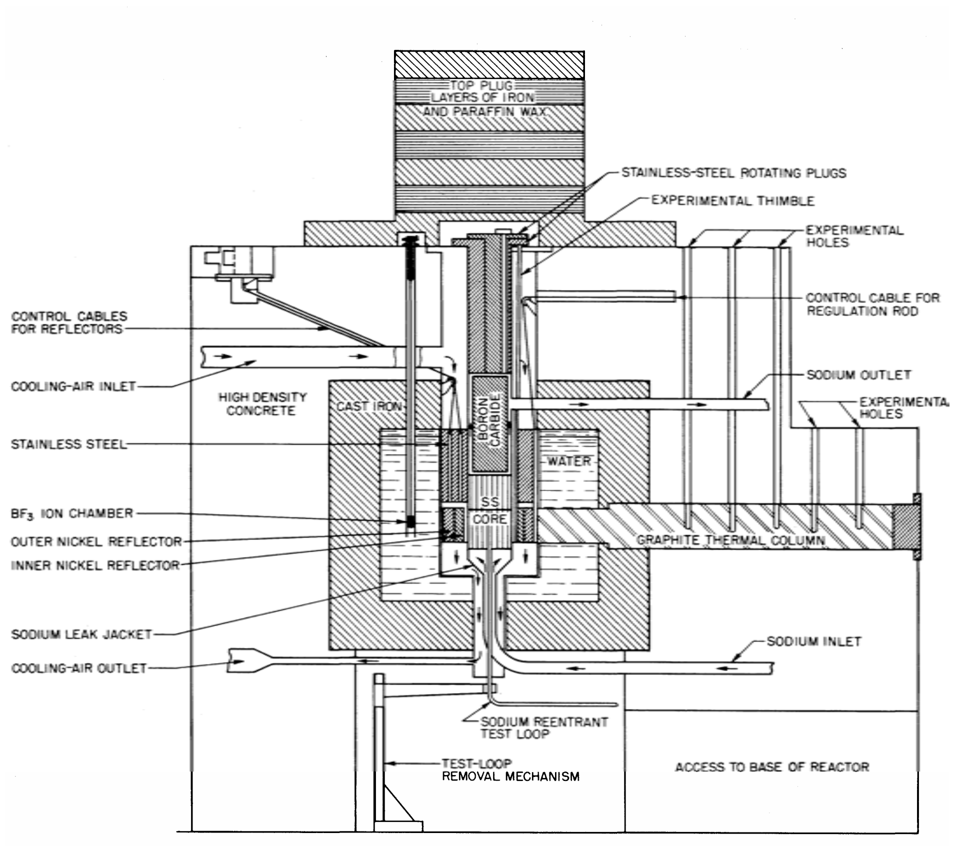
By October 1960 with 2.5% plutonium burnup, the leakage of fission products into the sodium became pronounced. By September 1961, the cesium activity in the sodium was 70% of total cesium. The reactor was shutdown, unloaded and the subassemblies were steam blust cleaned. The primary system was drained and cleaned with steam; about 11 tons of steam was used. Contamination of the primary system was reduced 50%. The system was then filled with pure water twice. There was no decrease in activity. The reactor system was then cleaned with a solution of 5% nitric acid at about 50ºC for three successive flushes to reduce the activity two to threefold. The primary system was further subjected to a 0.5% $KMnO_4$ and 5% HNO_3 + 1% $H_2C_2O_4$ at 70ºC. The primary system was drilled by vacuum, heat and filled with distilled sodium. The reactor was placed back in operation in March 1962 after a 6-month shutdown. Operation with a small portion of failed fuel cladding took place in the future, and during this period special emphasis was laid on studying the contamination of the coolant and the cover gas by solid and gaseous products, and the retention of radioactive constituents. By the end of 1964 a maximum burnup of the PuO_2 fuel of 6.7% had been reached.

From 1965 on BR-5 was operated with a 90% U^{235} enriched uranium monocarbide fuel. The maximum burnup was 6.2at.%, and unsealed fuel elements were detected with 1.6 at.% owing to cladding carburization from the fuel side.

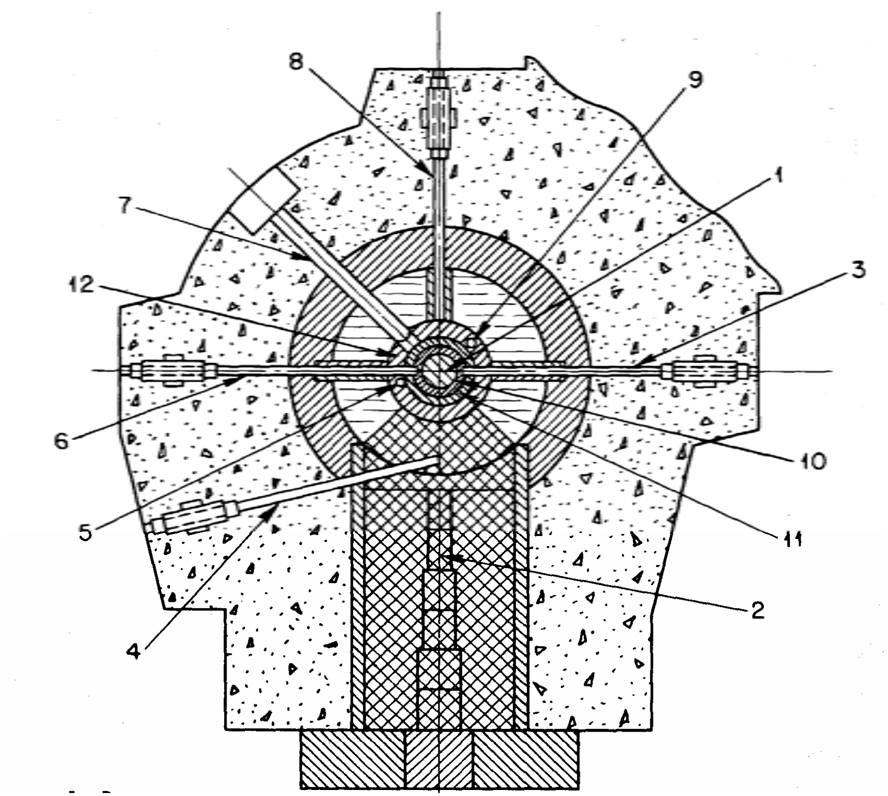
1971–72 the BR-5 plant was modified and enlarged to permit a power level of 10 MW(th), and was called BR-10. Operating of BR-10 started in March 1973 at a power level up to 7.5 MW(th). Until September 1979 a maximum burnup of 14.2 at.% was reached.

From October 1979 until early 1983 BR-10 was extensive reconstructed including the reactor vessel replacement by new one. The reactor was brought up to a power of 8 MW(th) in November 1983. Two cores (~1300 fuel pins) have been irradiated with mononitride fuel and the maximum burnup reached beyond 10 at.%. All the fuel pins remaine intact.

Problems in reactor components operation were almost entirely due to comparatively often pumps repaire: its life determined by ball-bearing; it averaged 10 000 hr. Electromagnetic pumps (EMP) were successfully operated for sodium pumping in auxiliary circuits. Therefore it was decided to replace the primary and secondary mechanical pumps by EMP.

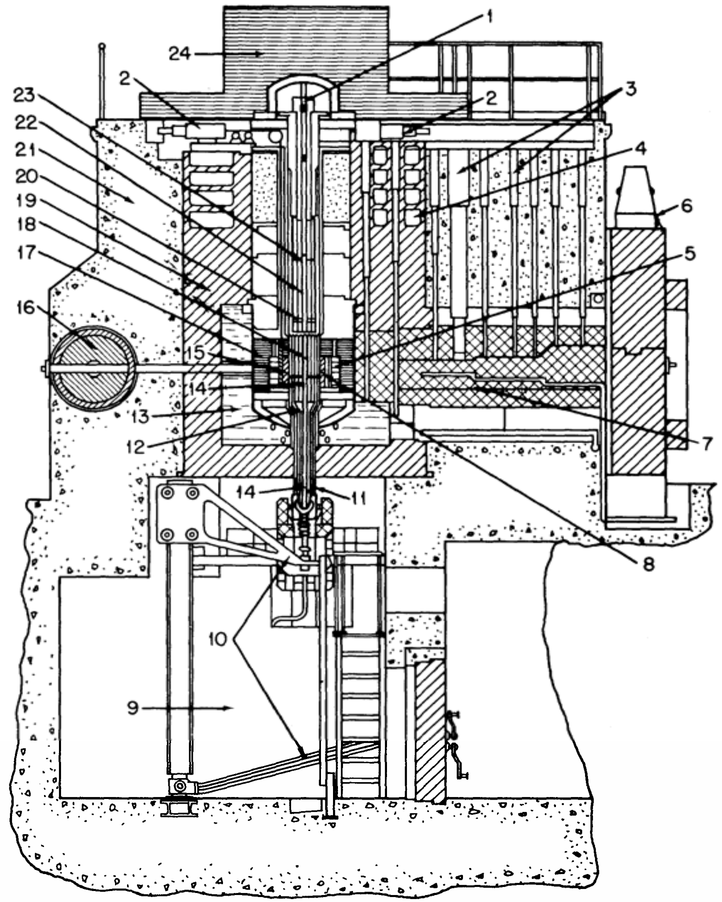


BR-5/10 reactor vertical cross section.



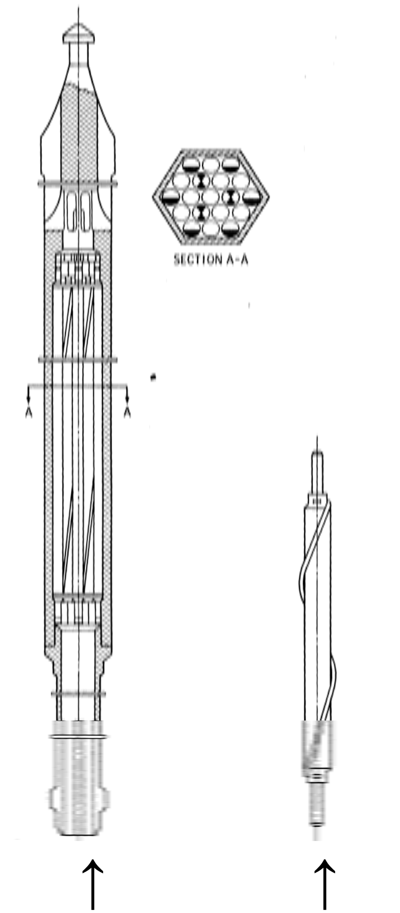
1-reactor, 2-thermal column, 3, 4, 6, 7, 8-horizontal beam holes, 5, 9-vertical beam holes, 10-inner movable cylinder reflector, 11-outer movable cylinder reflector, 12-stationary nickel reflector

BR-5/10 horizontal cross-section.

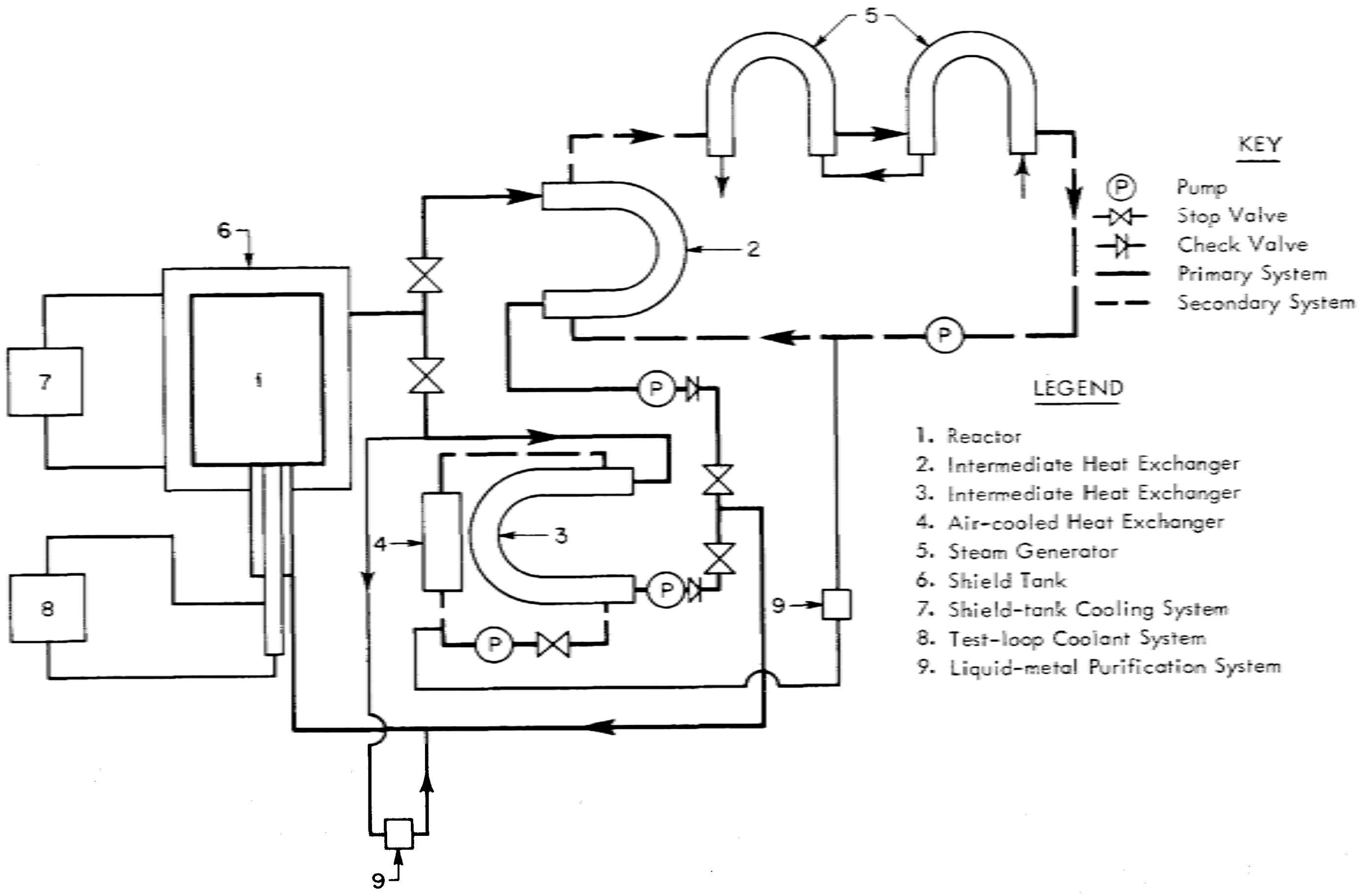


1-transfer mechanism, 2-control and safety drive mechanism, 3-experimental holes, 4-shield, 5-outer reflector, 6-shilding door for the thermal column, 7-thermal column, 8-movable reflector, 9-reactor vault, 10-handling gear for test loop, 11-coolant inlet, 12-reactor jacket, 13-water shield tank, 14-test loop, 15-control rod, 16-gate valve for neutron beam channel, 17-stationary nickel shield, 18-core, 19-cast-iron shielding, 20-primary reactor pipe, 21-concrete shield, 22-rotating plugs for fuel-element transfer, 23-sodium level, 24-top shield

BR-5/10 general arrangement.



BR-5/10 fuel subassembly



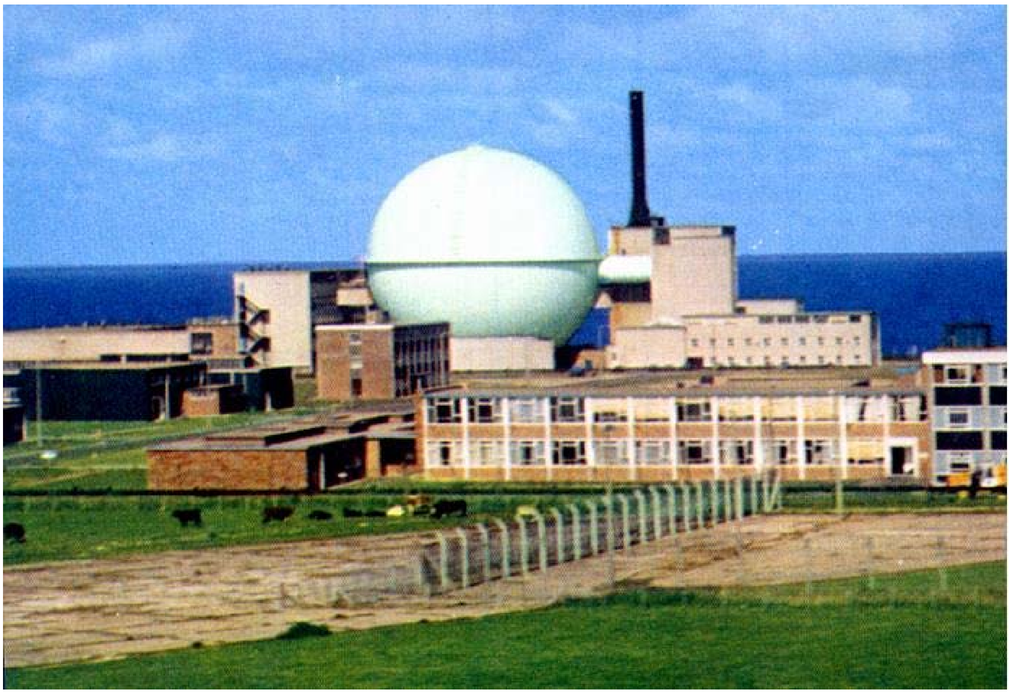
BR-5/10 flow sheet (steam generator was used at the beginning stage of operation).

13.1.2. DFR

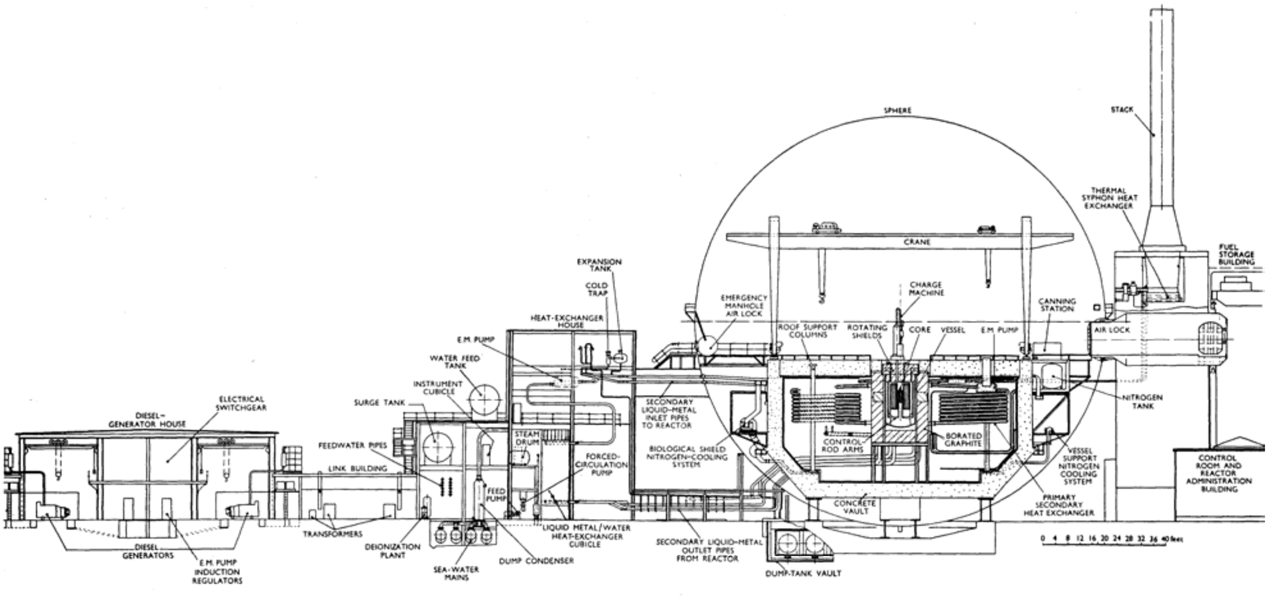
The philosophy of Dounreay fast reactor (DFR), (full power 60 MWth/15MWe, sodium-potassium coolant) was to have the experimental part of the system only inside the reactor vessel, and in the outside zone every effort was to be made to minimize the risk of breakdown of the cooling system. This explains the unusual feature of 24 coolant loops, which results in a size of pumps and heat exchanger where experience had been accumulated in previous experimental work.

The DFR was designed primarily to confirm the feasibility of the fast reactor concept, but quickly assumed a more enduring role as a test bed for candidate fuel, clad and structural materials. After several years of successful operation, the DFR was shut down in 1967/68 for one year to locate and repair a small leak in one of the coolant outlet pipes inside the reactor vessel. The leak disappeared every time the reactor was shut down, making it very difficult to locate and assess. The DFR continued to operate until March 1977, when it was finally shut down. At its closure, mixed oxide fuel experiments had reached a peak burnup of over 20%. Fuel pins with leaking cladding were irradiated following failure to a further 3 at.% burnup with little deterioration. Until 1967 the major problem of damage to cladding materials was embrittlement. However, in 1967, evidence was firstly announced of considerable void swelling taking place in austenitic stainless steels irradiated to high fluences in the DFR. This phenomenon has since then tended to dominate the attention in the development of cladding and duct materials. A high nickel alloy was developed in the UK as reference cladding material.

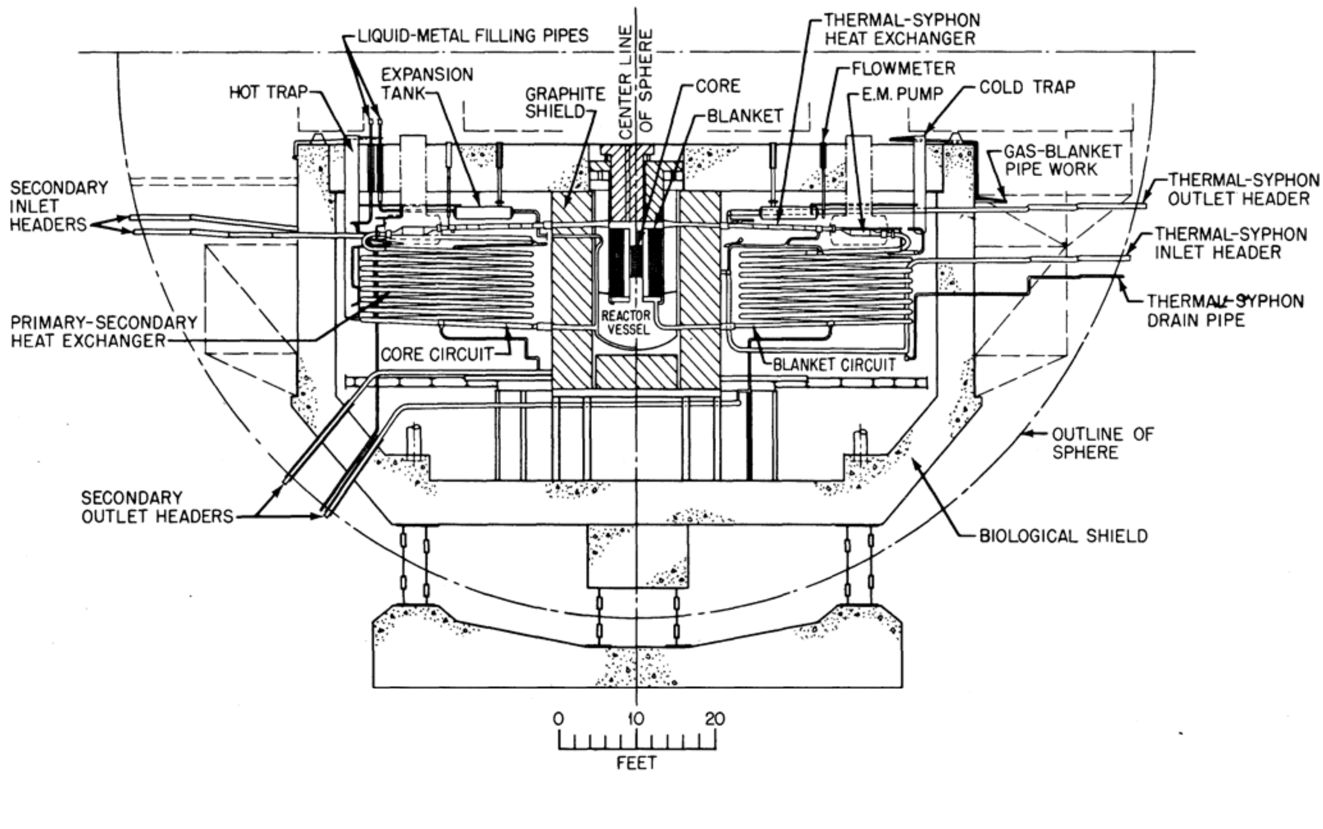
During the final stages of normal power operation of the DFR, a series of experiments were performed with the objective of exposing bundles of typical mixed oxide fuel pins to coolant boiling for prolonged periods. The series, known as the DFR special experiments programme, were comprised of eight separate experiments; they utilized both unirradiated and previously irradiated fuel pins; and, in three experiments, included a thin steel plate simulating a local blockage in the heated section. Experimental data on boiling in tube bundles shown that the in-core sodium boiling process in fact does not reach high superheat, but rather comprises a series of local pressurization and flow reversals which voids part of an assembly for a short period of time. Detailed analyses have shown substantial spatial and temporal incoherence in the boiling process, with incoherent chugging and a few assemblies "leading" the rest of core.



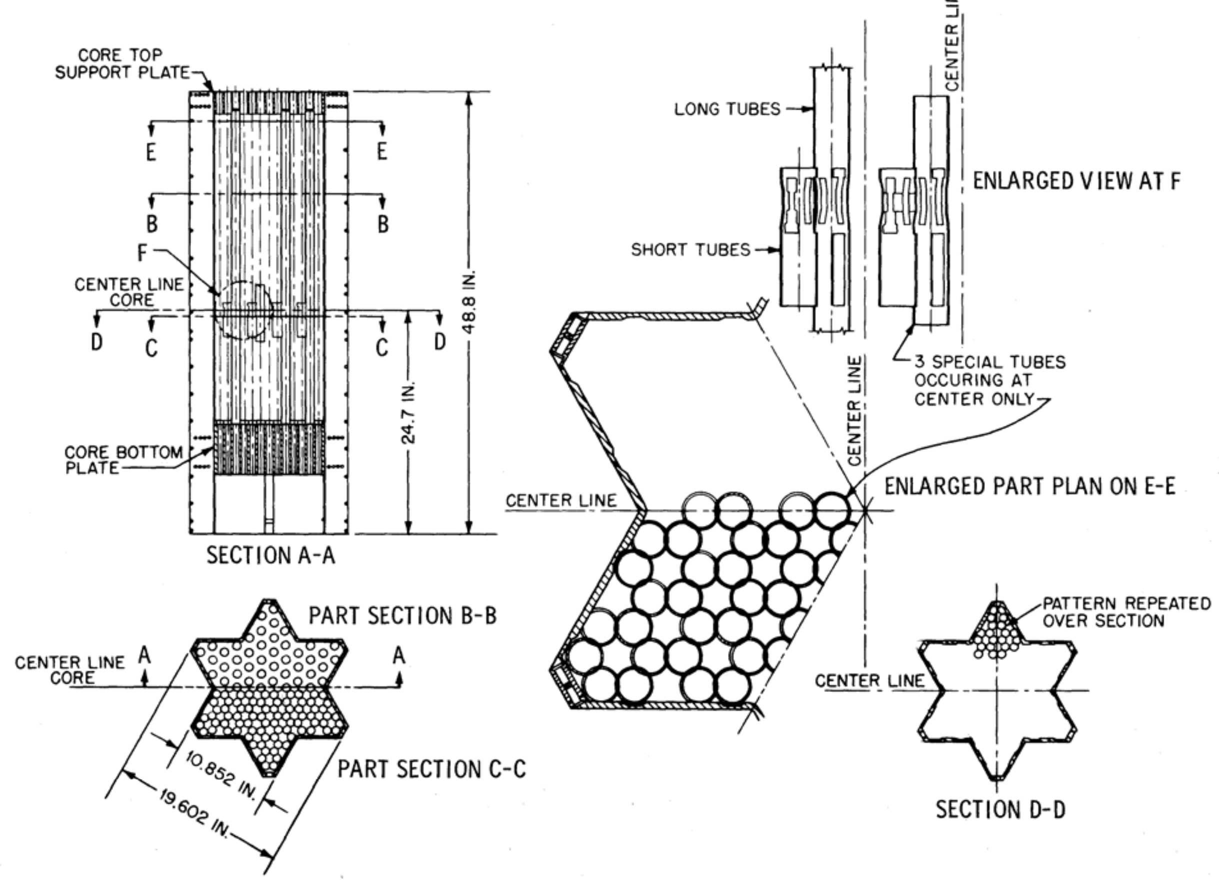
DFR overall survey.



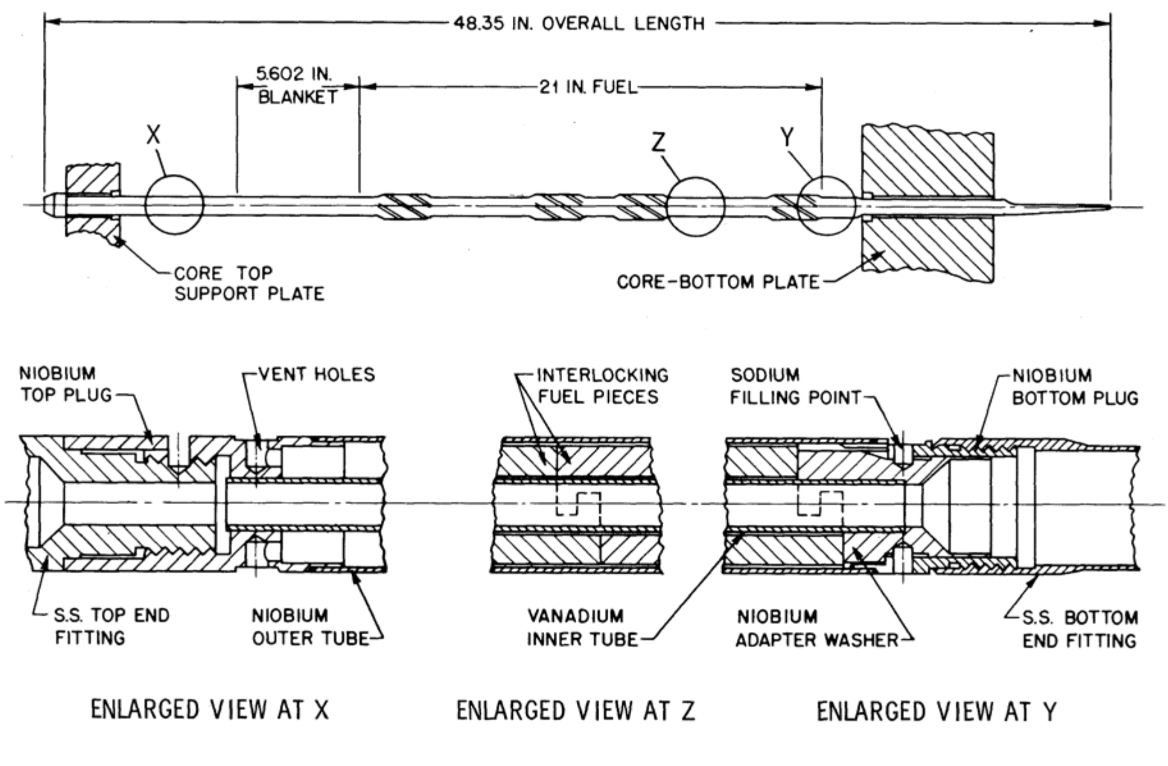
DFR plant cross section.



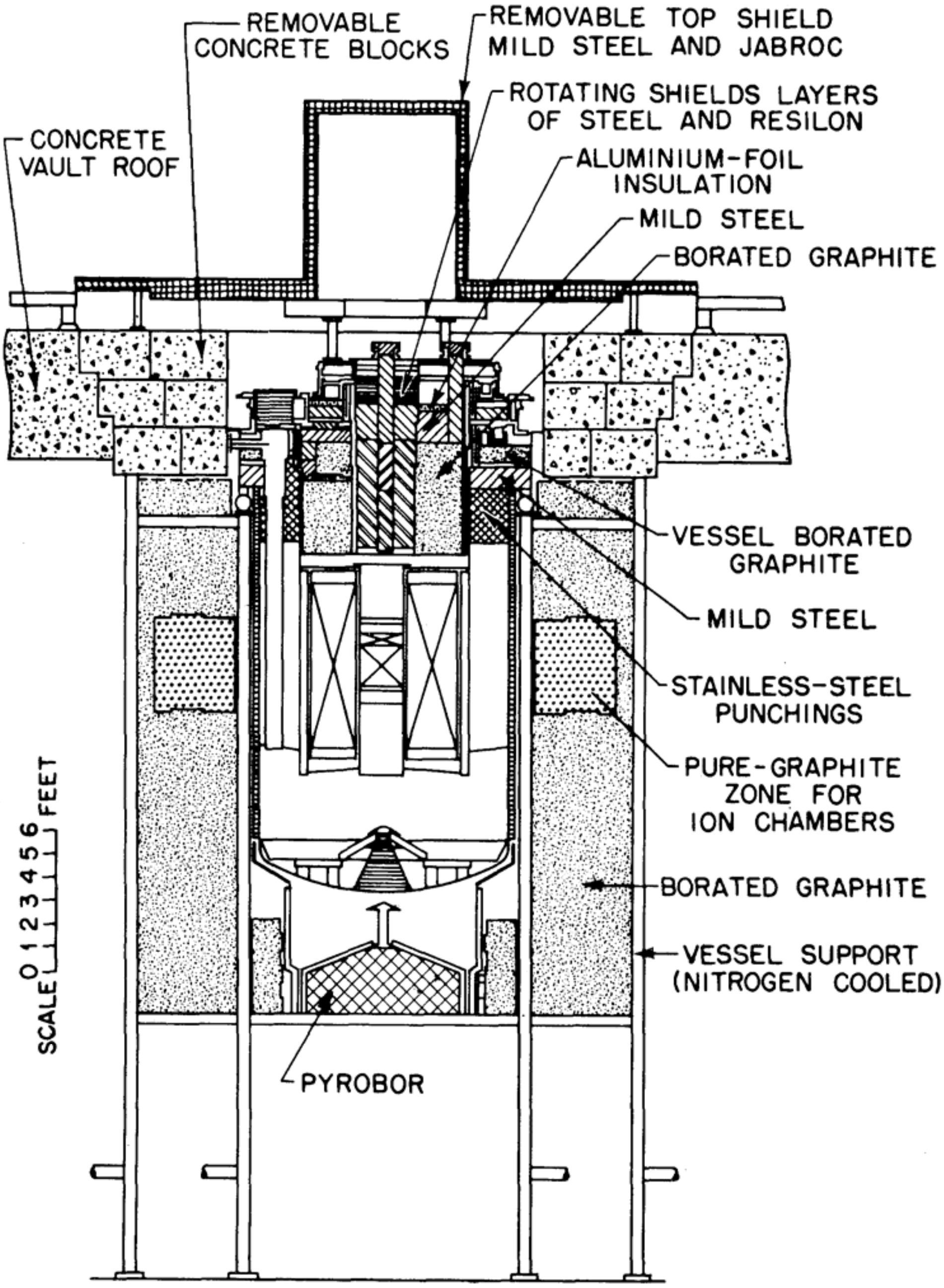
DFR reactor primary circuit.



DFR core details.



DFR fuel subassembly details.


REMOVABLE CONCRETE BLOCKS
REMOVABLE TOP SHIELD MILD STEEL AND JABROC
ROTATING SHIELDS LAYERS OF STEEL AND RESILON
CONCRETE VAULT ROOF
ALUMINIUM-FOIL INSULATION
MILD STEEL
BORATED GRAPHITE
VESSEL BORATED GRAPHITE
MILD STEEL
STAINLESS-STEEL PUNCHINGS
PURE-GRAPHITE ZONE FOR ION CHAMBERS
BORATED GRAPHITE
VESSEL SUPPORT (NITROGEN COOLED)
SCALE 0 1 2 3 4 5 6 FEET
PYROBOR

DFR shield.

13.1.3.Fermi

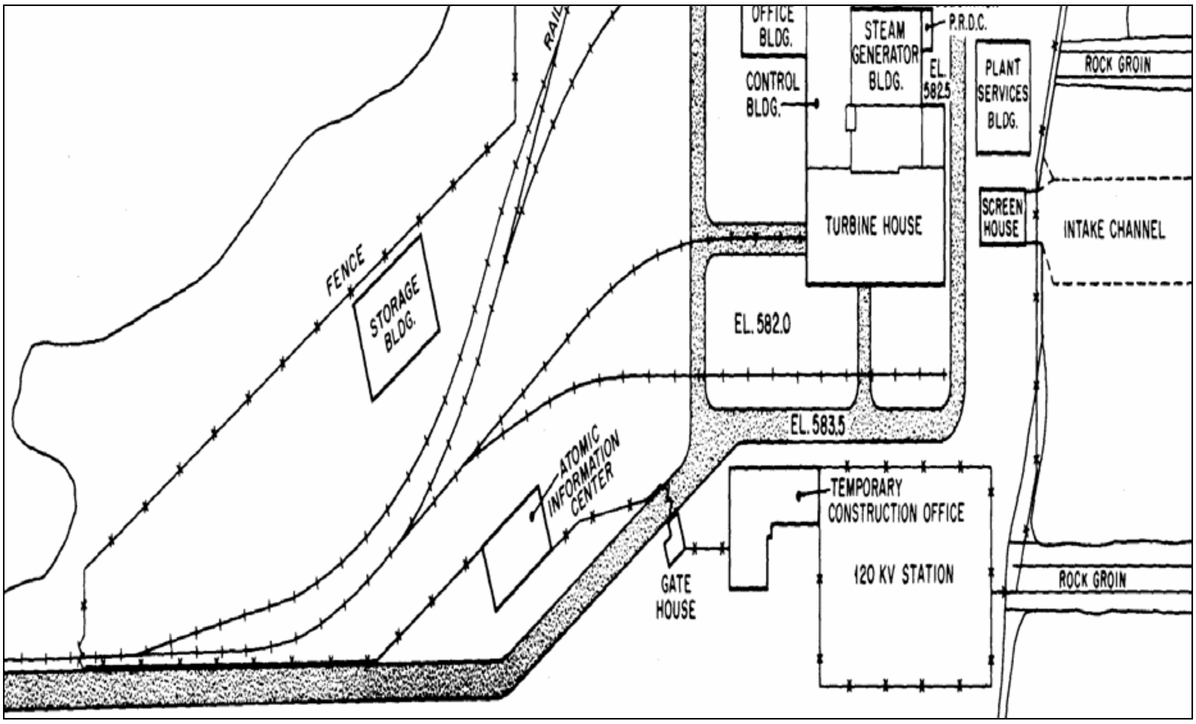
The sodium cooled Enrico Fermi Fast Breeder Reactor (EFFBR) was a 200 MW(th), 60 MW(e) specifically designed, built and operated to evalute the economics of operating a commecial prototyp (at that time) FBR for electricity generation.

The 1000ºF preoperatonal tests of graphite directly around the reactor vessel (iside the insulation) indicated that the materal failed. That showed the borated graphite did not confirm to design spesification and would have to be replaced. Tests on the remainder of the material outside the insulation in the primary shield tank indicated that this graphitic material also needed replacement. It was apparent that moisture and oxygen control is a must in the use of high temperature ggraphite. All graphite in the primary shield tank was replaced with high density high temperature reactor-grade graphite. Any boron used was in the form of boron carbide.

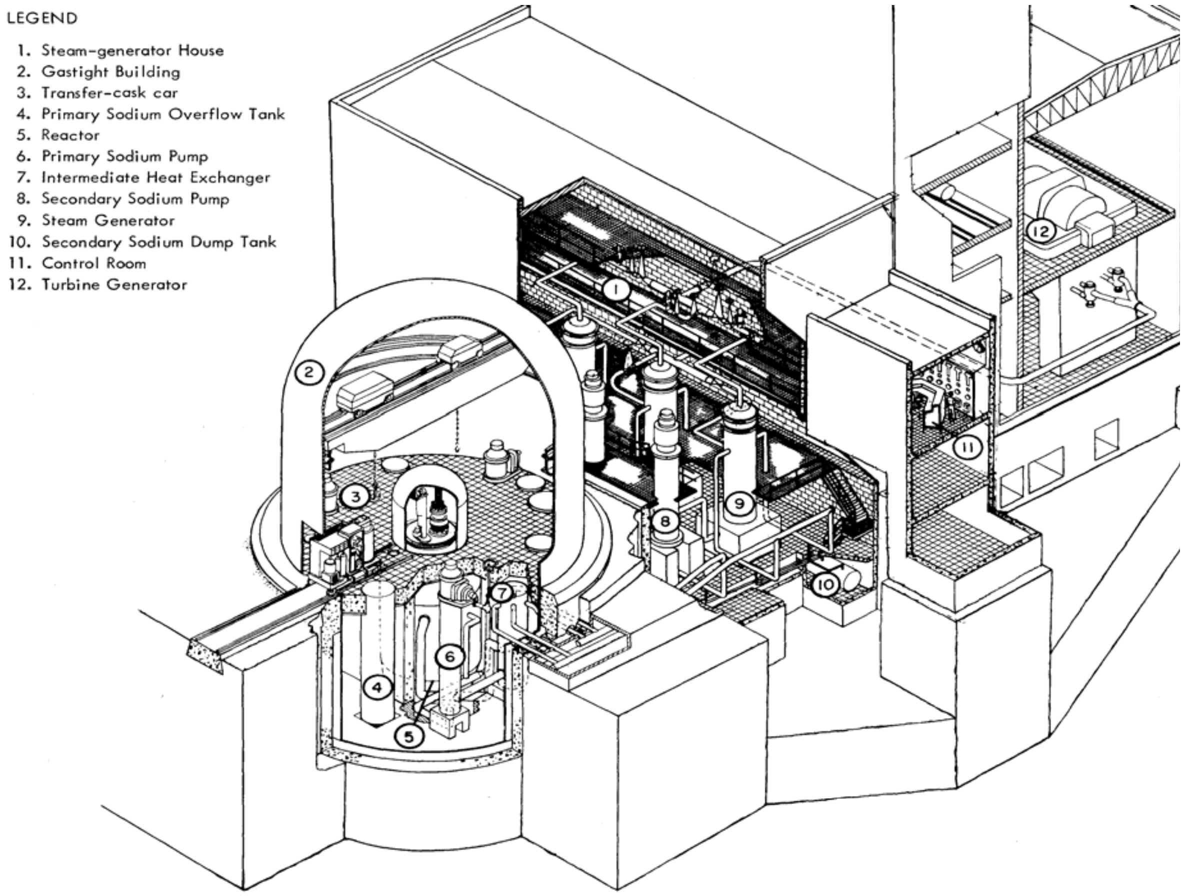
EFFBR had undergone an extensive low power and high power test programme up to 100 MW(th) from 1962 until 1966. In December 1962 a sodium-water reaction took place in the #1 steam generator blowing the ruptutre disk installed for just such a possibility. Examination showed extensive tube bundle damage owing to the the vibration of the tubes against the support structures as well as erosion caused by the sodium water reaction during the period between a reaction and the rupture disk blowout. Investigation showed that the vibration of the tubes at the sodium inlet had been as high as 0.25 in. Baffling and lacing the tubes has been carried out to reduce the vibration to a negligible guantity.

On 5 October 1966, during startup operation of the reactor, fuel melting occurred in the core subassemblies at a power level of 34 MW(th). The reactor was scrammed after the radioactivity level of the argon cover gas had been observed to rise substantially owing to presense of gaseus fission products. A foreign body: one six pieces of zirconium sheet, used to clad a conical flow divider of the meltdown device in the core inlet plenum, had unbolted and blocked the coolant flow in several fuel channels and thus caused the damage. Two yers were needed to define the details of thhe blockage, asses the damage and remove the disloged zirconium piece. The blockage promoted a design shortage -axial coolant inlet port in the nozzle of the fuel subassembly. Several improvement were made: installation of flow guards to prevent coolant blockage, improved control devices etc. After reloading with fresh fuel, reactor was again brought to criticality in July 1970, and reached designed power of 200 MW(th) for the firs time in October 1970. By the end of 1972 it was decided to decommissioning the EFFBR plant because of lack of funding.

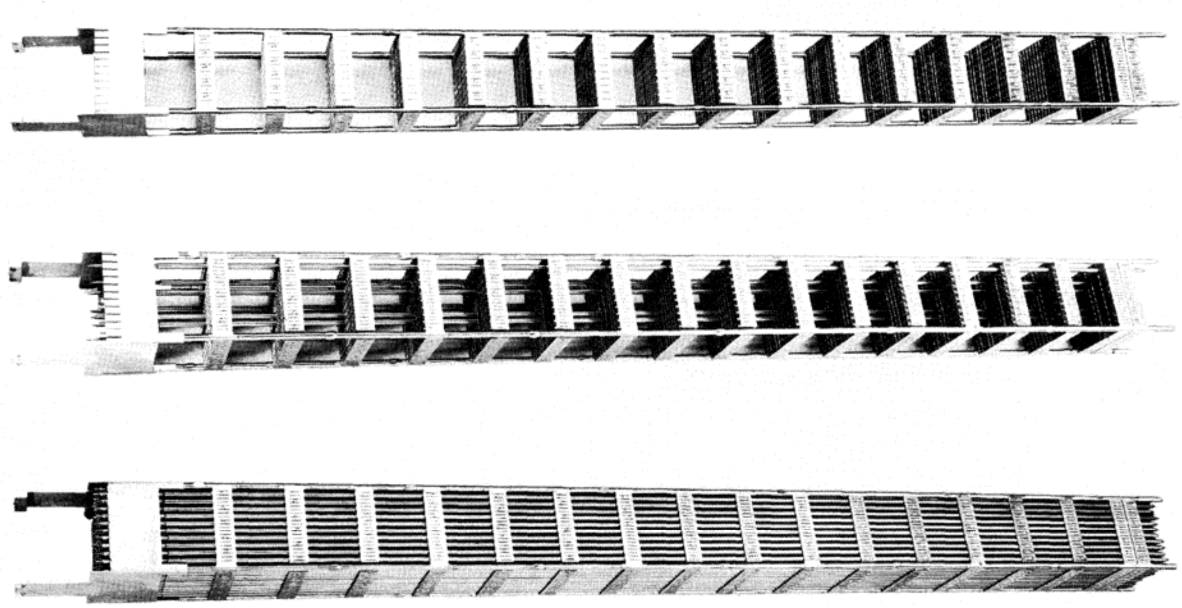
Fermi reactor building.



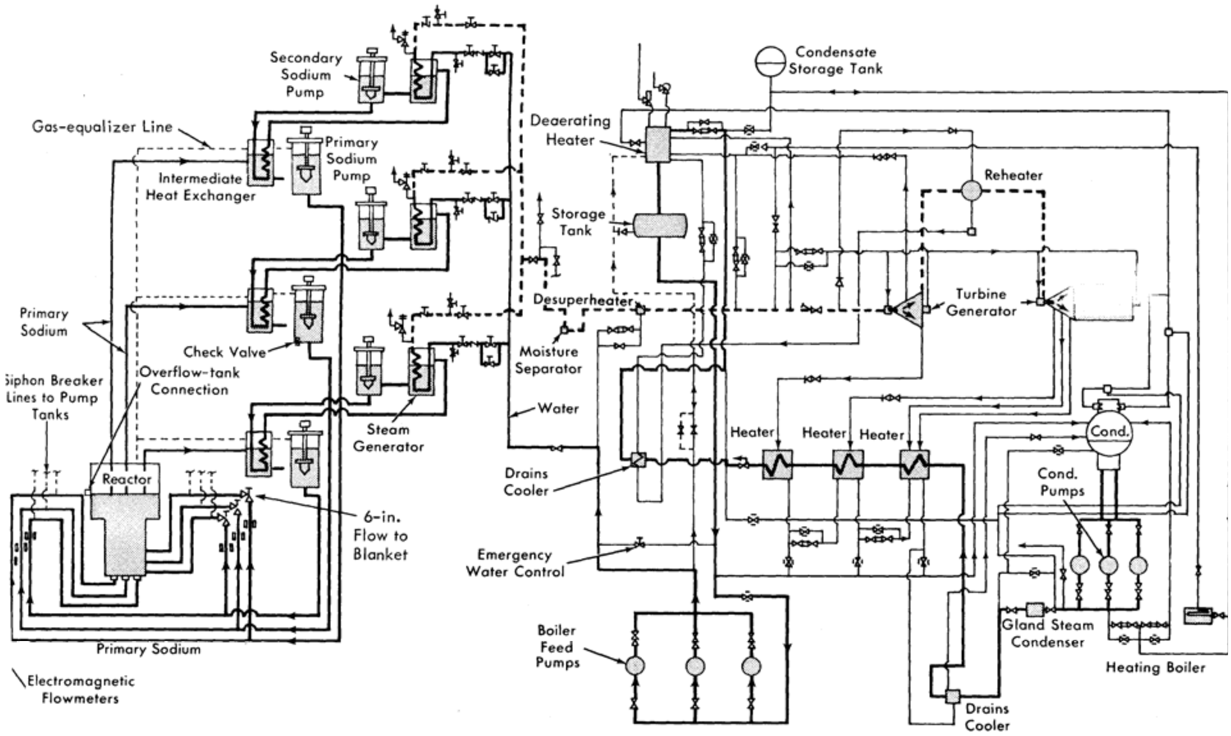
Fermi plant plot plan.



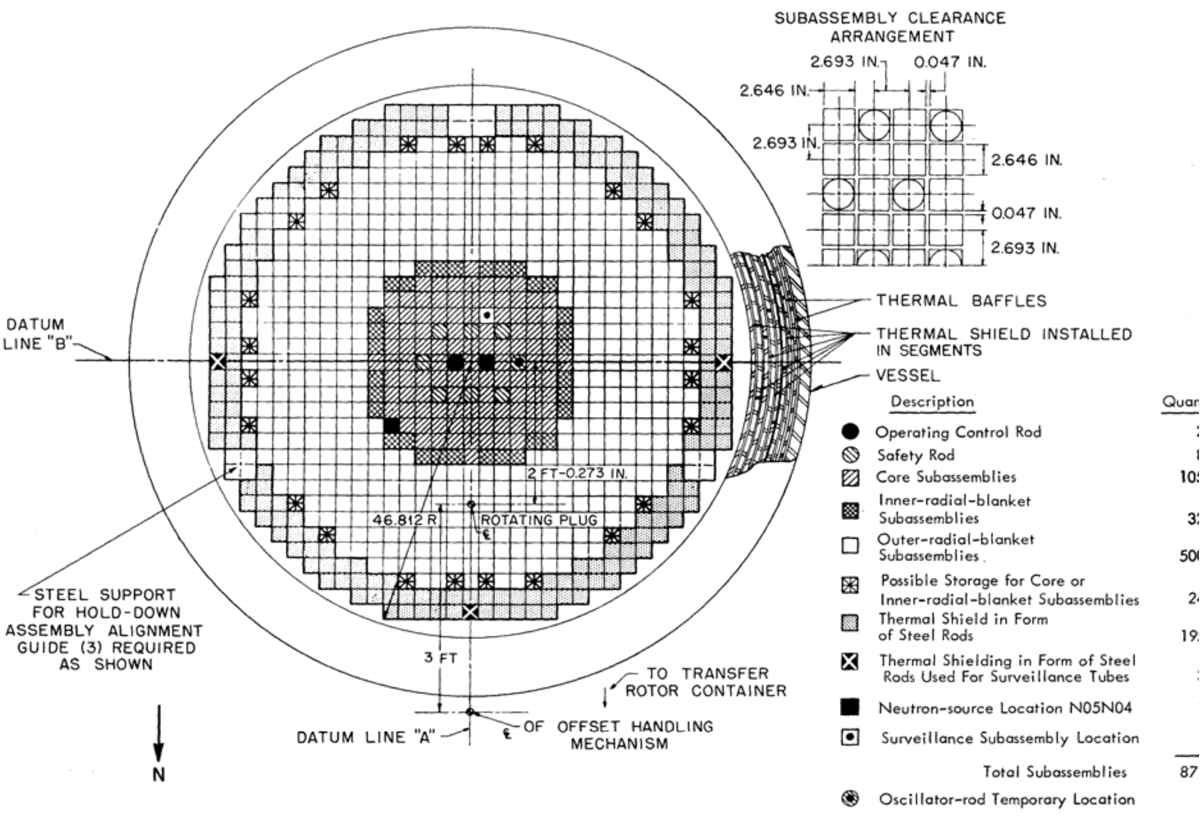
Fermi plant perspective view.



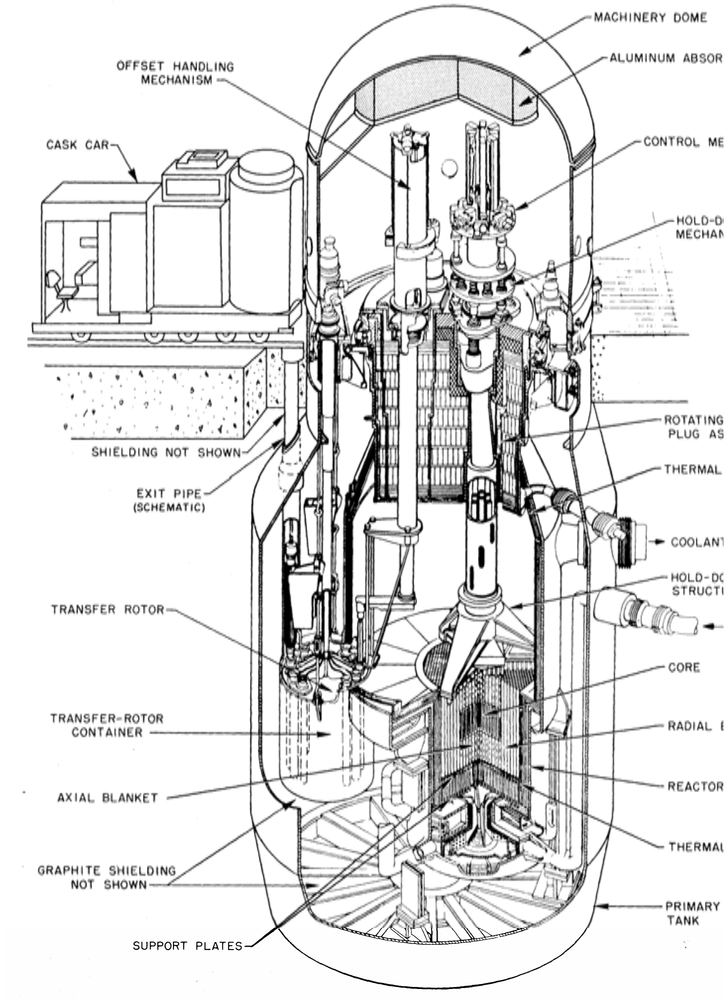
Fermi fuel subassembly elements.



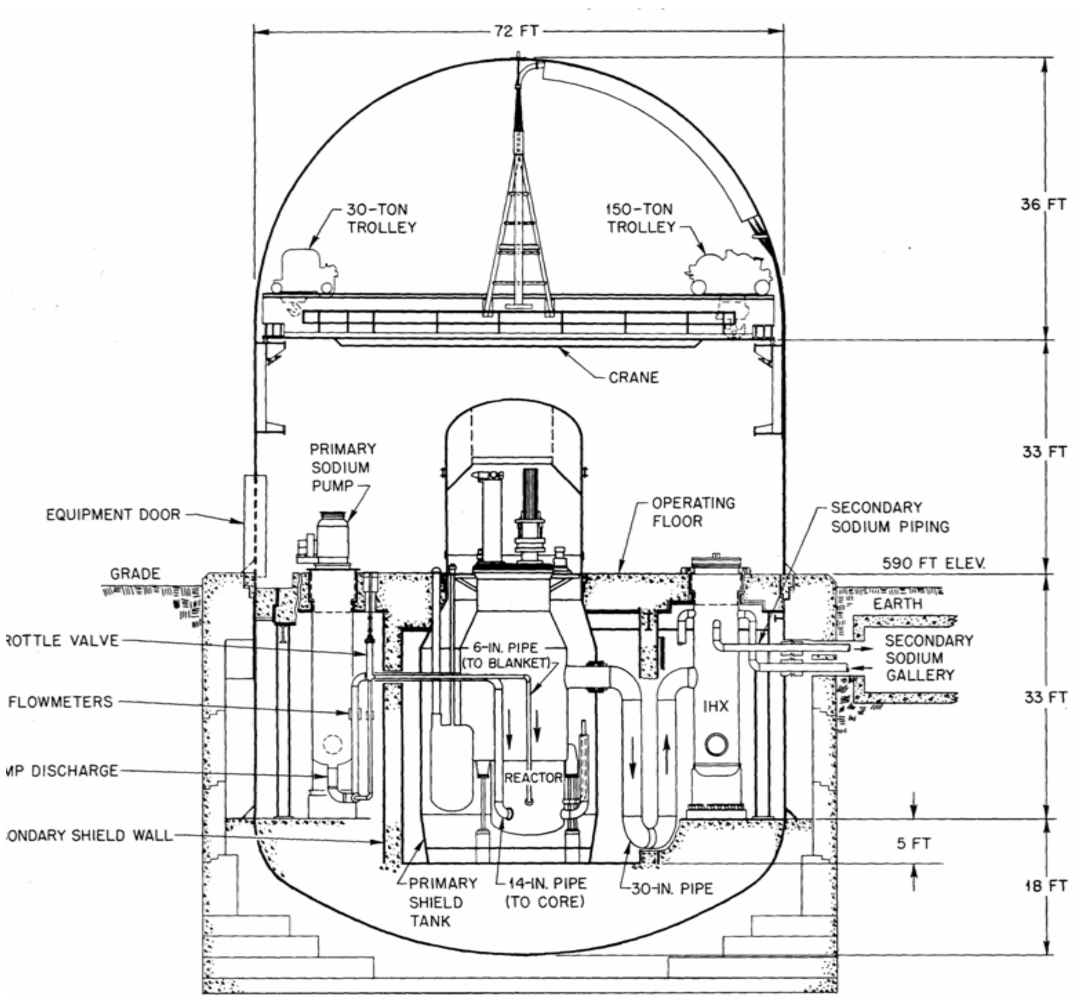
Fermi plant schematic heat transfer and flow diagram.



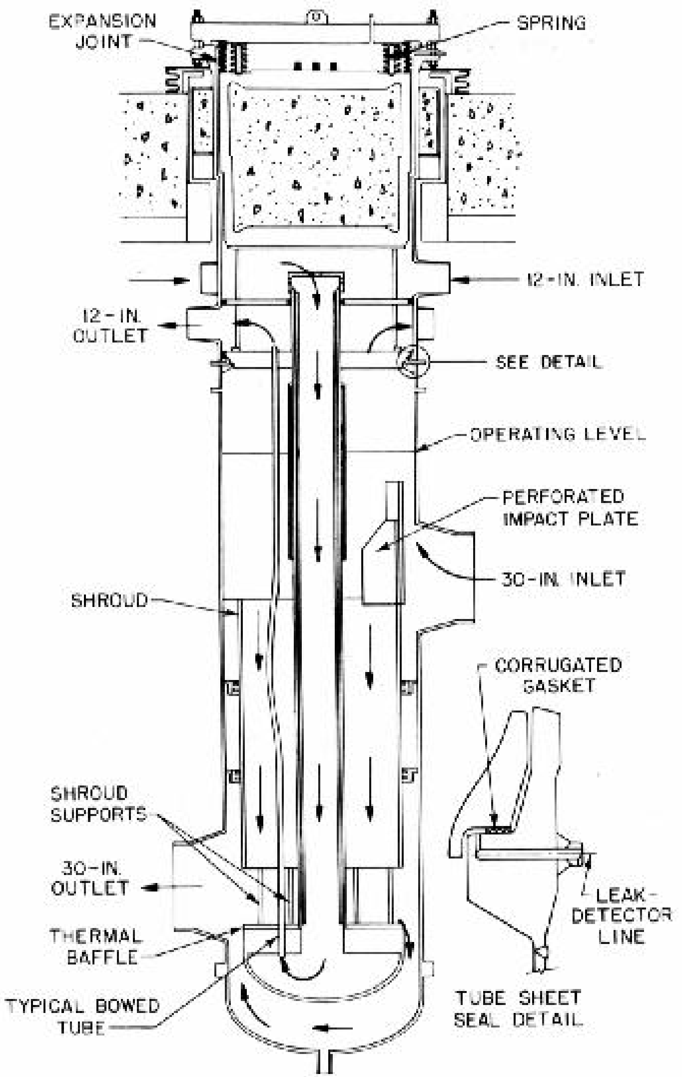
Fermi reactor cross section.



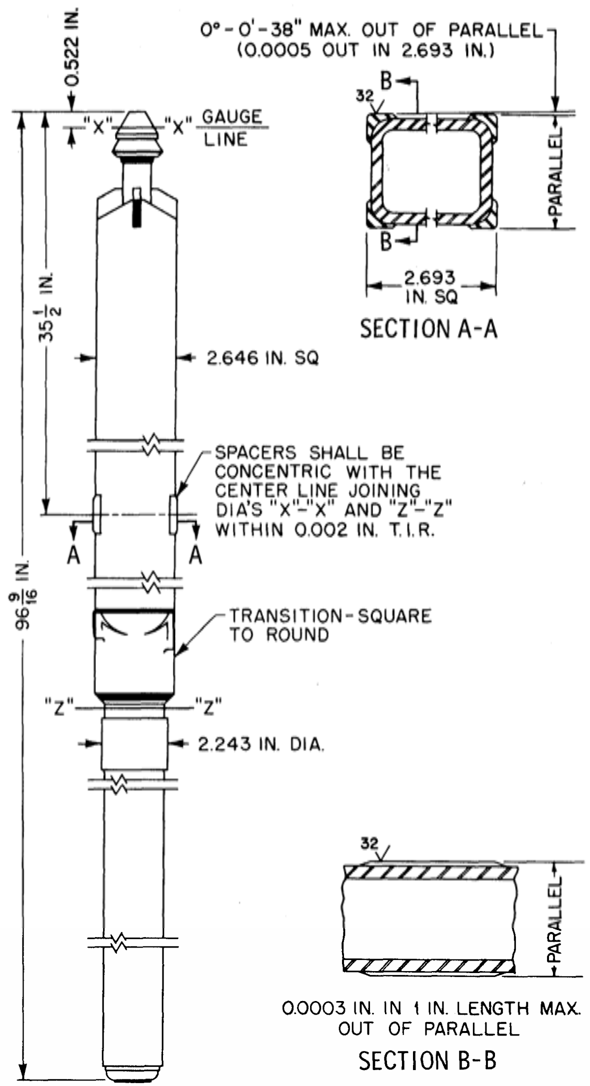
Fermi perspective view of reactor.



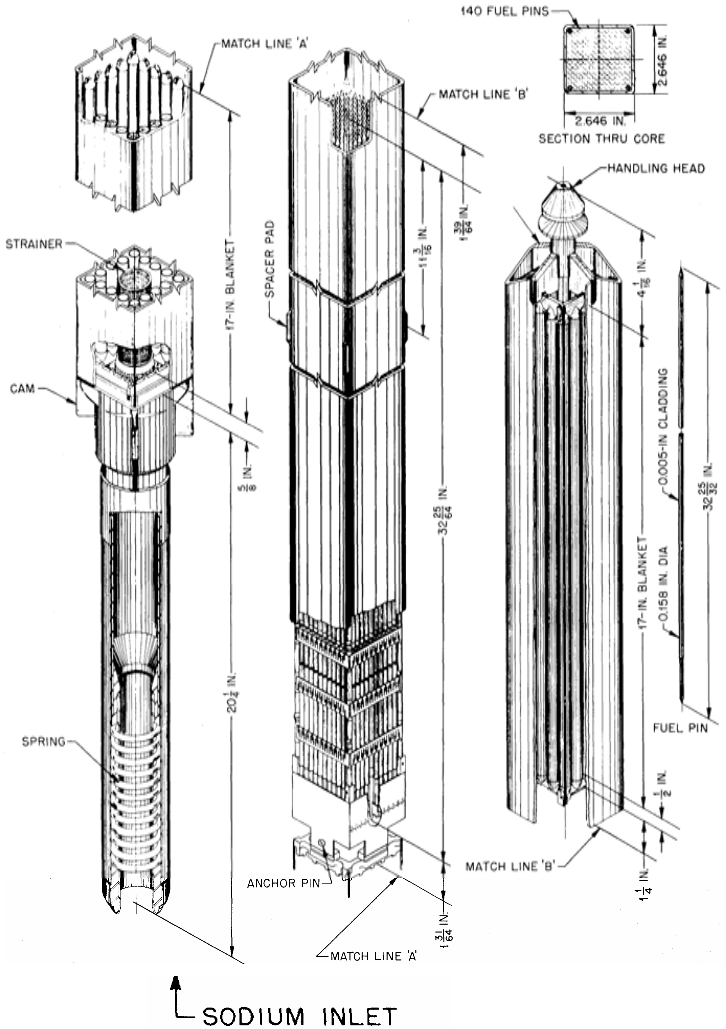
Fermi reactor building cross section.



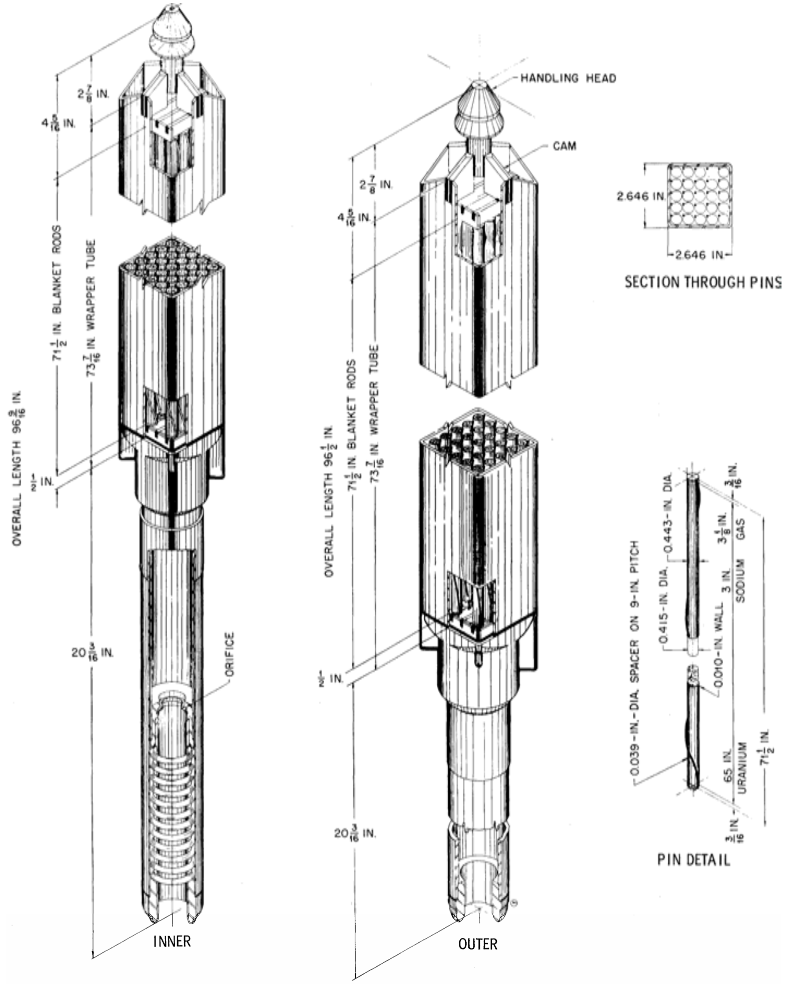
Fermi IHX.



Fermi fuel subassembly external side view (1 of 3).



Fermi fuel subassembly details (2 of 3).



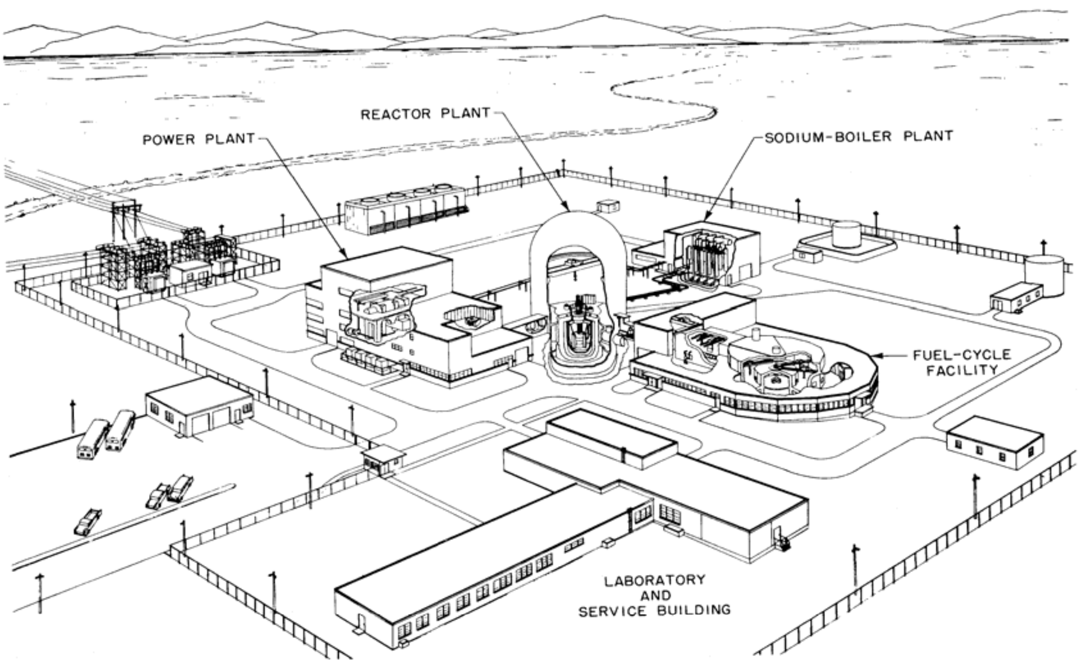
Fermi radial blanket subassemblies (3 of 3).

13.1.4. EBR-II

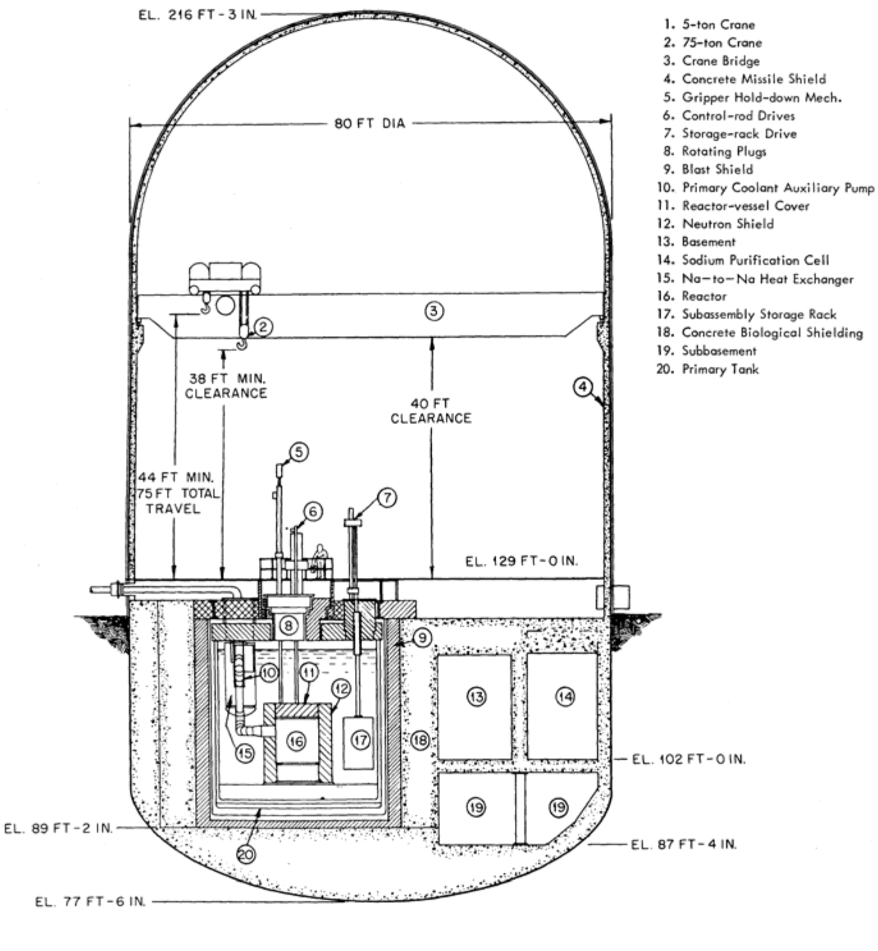
The experimental breeder reactor II (EBR-II), 62.5 MW(th)/20 MW(e) was designed as power plant and to include an integrated fuel reprocessing and refabrication facility in oder to demonstrate the complete closed fuel cycle of FRs. Difficulties with some components delayed wet criticality until November 1963 (plant was constracted in 1961). In April 1963, #1 pump became difficult to rotate and had to be removed. Inspection showed that the pump laburinth was cocked with respect to the shaft center line owing to the tilt of the bottom flange of the shield. The pump bowed owing to the high temperature caused by its rubbing on the aluminium-bronze labyrinth bushing. The shield plug bottom flange was remachined and a new shaft and labyrinth bushing were installed. The ascent to power began in July 1964, and an extensive irradiation test programme for fuels and structural materials was started in 1965. The experiments consisted of various fuel types (oxides, metal, carbides and nitrides) Peak burnus of 19 at.% for MOX fuel and 18.5 at.% for metal fuels have been reached. An integrated fuel cycle was demonstrated. The EBR-II before closed was operated as the integral fast reactor (IFR) prototype, demonstrating important innovations in safety, plant design, fuel design, and actinide recycle. The ability to passively accommodate anticipated transients without scram has resulted in significant benefits related to simplification of the reactor plant, primarily through less reliance on emergency power and by virtue of not requiring the secondary sodium or steam systems to be safety-grade. The uranium-plutonium-zirconium alloy fuel is fundamental to the superior safety and operating characteristics of the reactor.

In January of 1994, the Department of Energy mandated the termination of the Integral Fast Reactor (IFR) Programme, effective as of 1 October 1994. To comply with this decision, Argonne National Laboratory-West (ANL-W) prepared a plan providing detailed requirements to place the EBR-II in a radiologically and industrially safe condition, including removal of all irradiated fuel assemblies from the reactor plant, and removal and stabilization of the primary and secondary sodium used to transfer heat within the reactor plant.

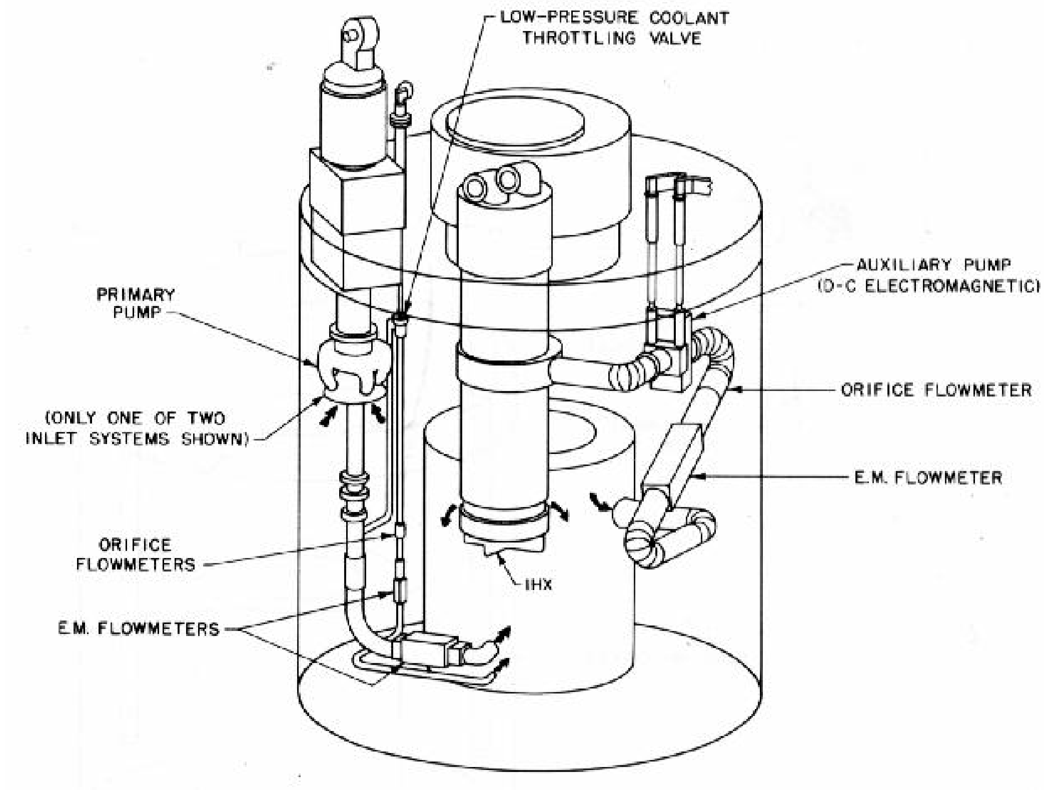
EBR-II perspective view.



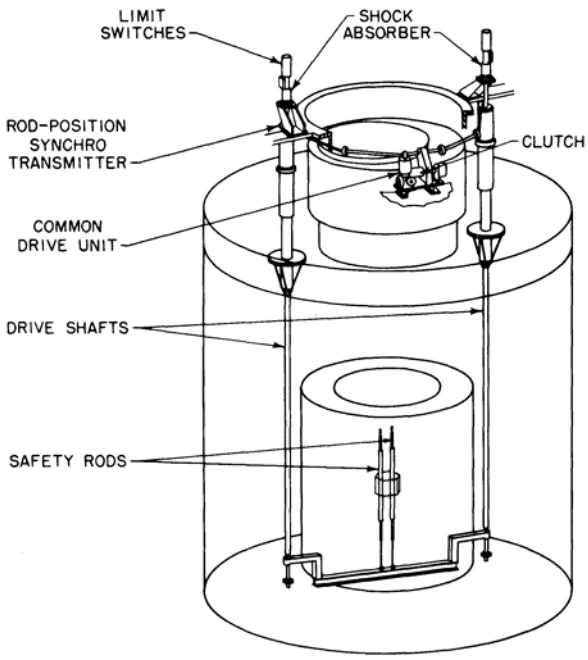
EBR-II reactor overall survey.



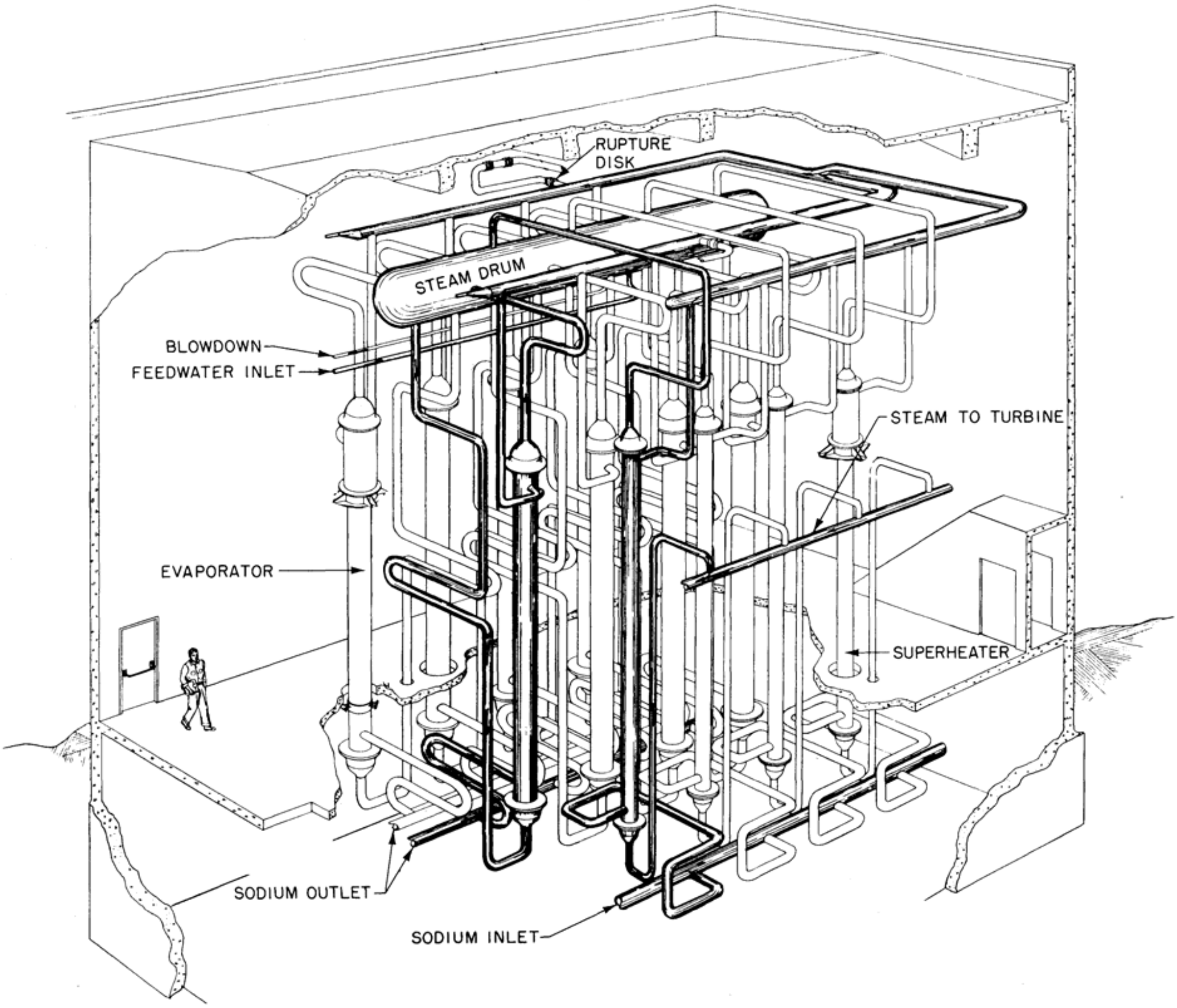
EBR-II vertical cross section.



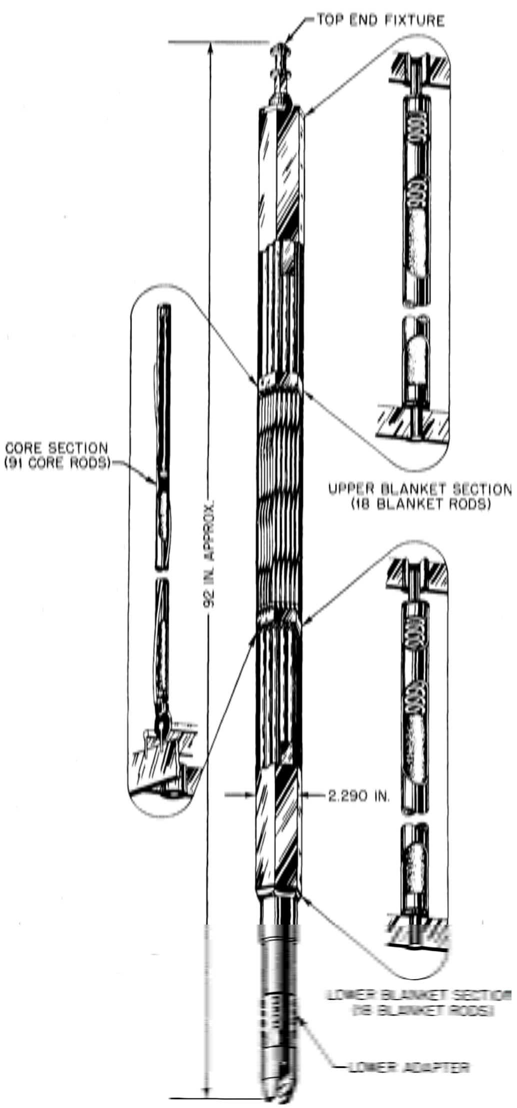
EBR-II primary pipes and equipment.



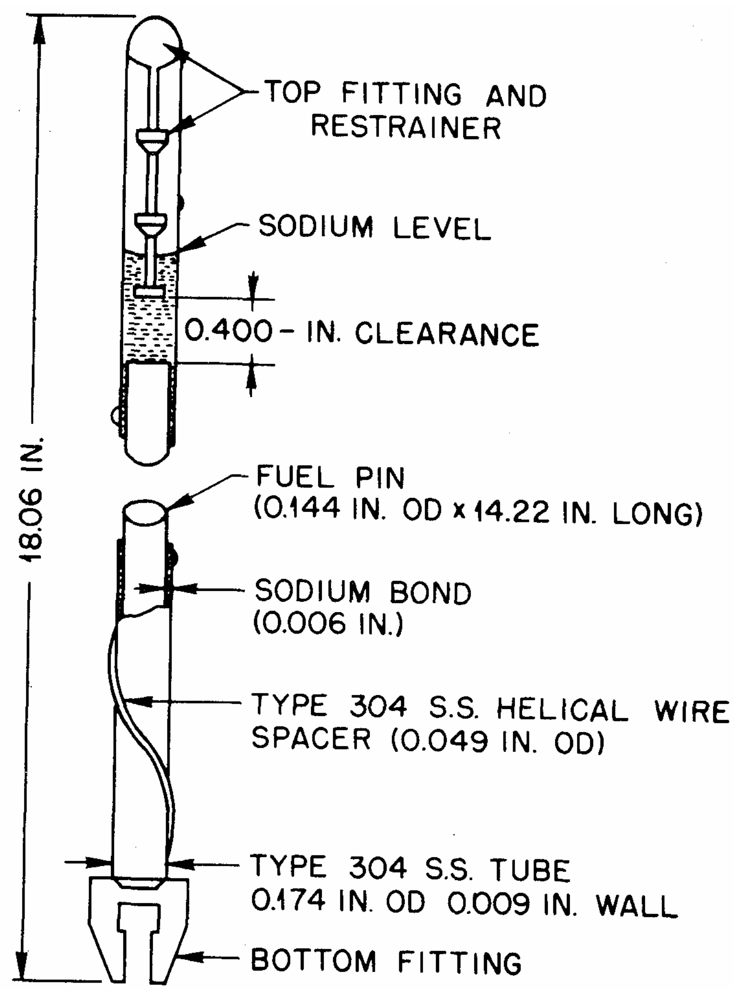
EBR-II safety rod drive system.



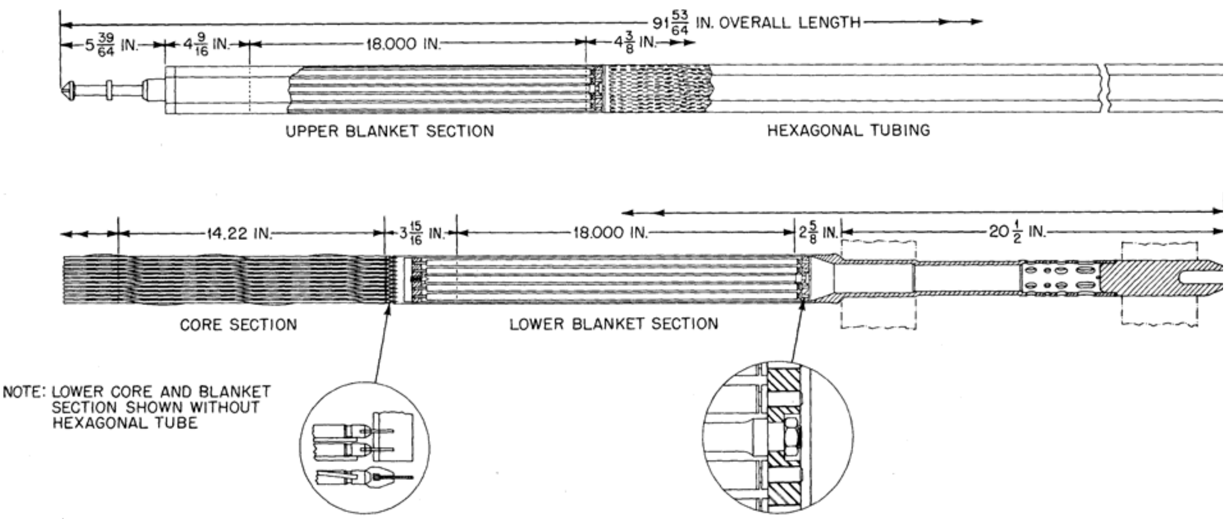
EBR-II steam generator.



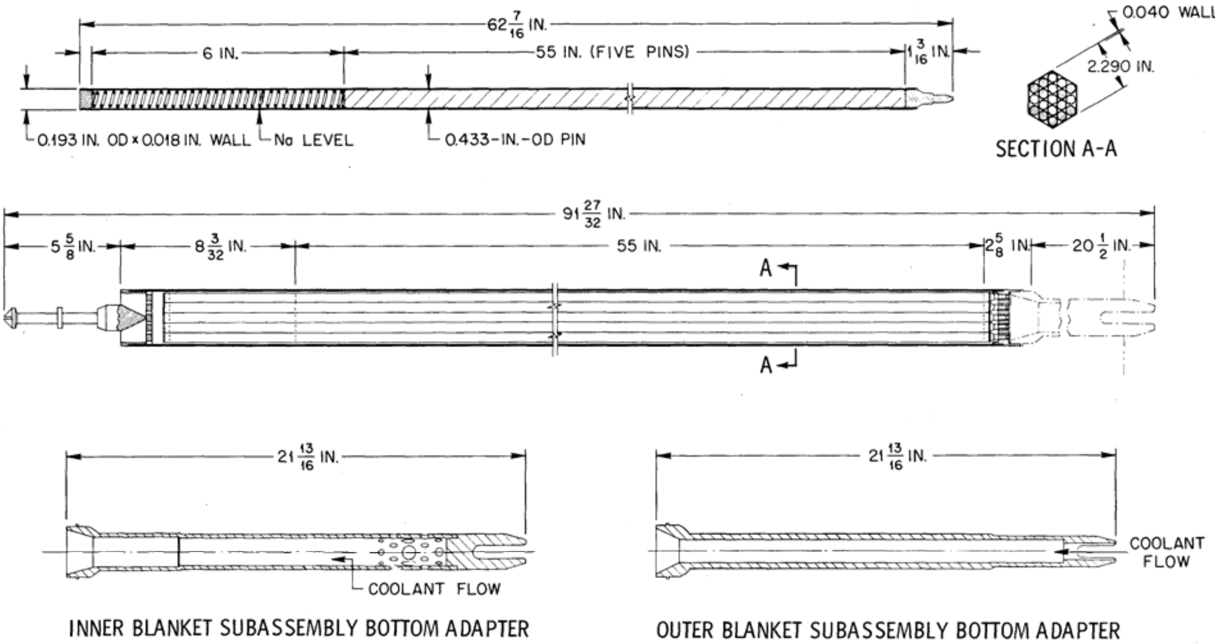
EBR-II fuel subassembly and fuel element (1 of 4).



EBR-II fuel pin design (2 of 4).



EBR-II fuel subassembly details (3 of 4).



EBR-II blanket subassembly details (4 of 4).

13.1.5. Rapsodie

The Rapsodie experimental sodium cooled reactor was the first French fast neutron reactor. The construction was started in 1962 within an association of CEA and EURATOM. The reactor went critical on 28 January 1967, reaching 20 MW (th) power on 17 March 1967. The core and equipment were modified in 1970 to increase the thermal power level to 40 MW (th). The operating parameters were similar to those in large commercial size reactors. During 16 yers of operation ~30 000 ful pins of the driver core were irradiated, of which ~10 000 reached a burnup beyond 10%; 300 irradiation experiments and more than 1 000 tests have been performed. The maximum burnup of the test fuel pins was 27% (173 displacement per atom). In 1971, the irradiations performed in the core revealed a phenomenon of irradiation swelling in the stainless steel of the wrapper and the fuel cladding in the high neutron flux. The Rapsodie results have been extrapolated in the Phénix reactor.

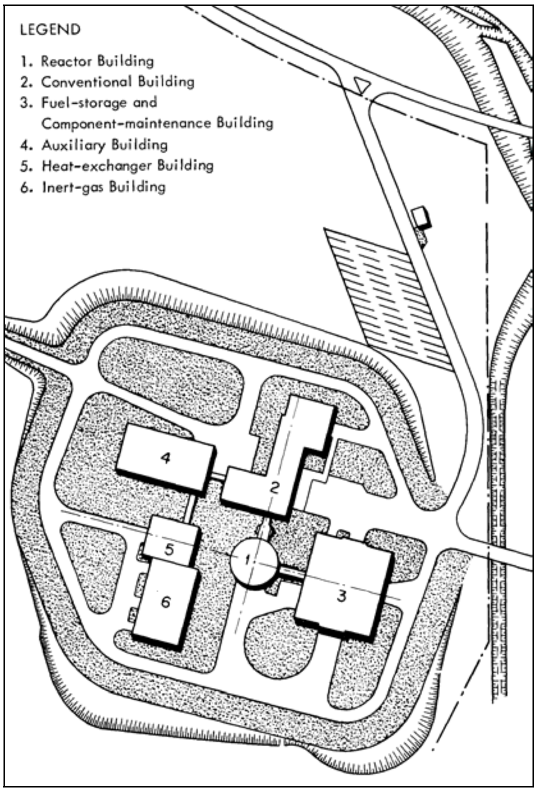
The decision to stop running the reactor was taken after two successive defects were detected in the primary system containment (double envelope of reactor vessel). The first defect, which appeared in 1978, consisted of a sodium micro leak: radioactive sodium aerosols were found in the double wall reactor vessel. Investigations did not find any liquid sodium in the gap nor locate the defect. The reactor was subsequently operated at a reduced power level (~0.6 P_N), which was high enough for irradiation needs but did not cause the leak to reappear. The second defect appeared in 1982 and consisted of a small leak from the nitrogen blanket surrounding the primary system.

Before the final shutdown of the reactor, a series of end-of-life tests were conducted in April 1983. Two series of tests performed on the Rapsodie reactor, the purpose of which was to investigate the serviceability of this reactor's core and of the reactor as a whole under extreme conditions that were characterized by an exceedingly high temperature.

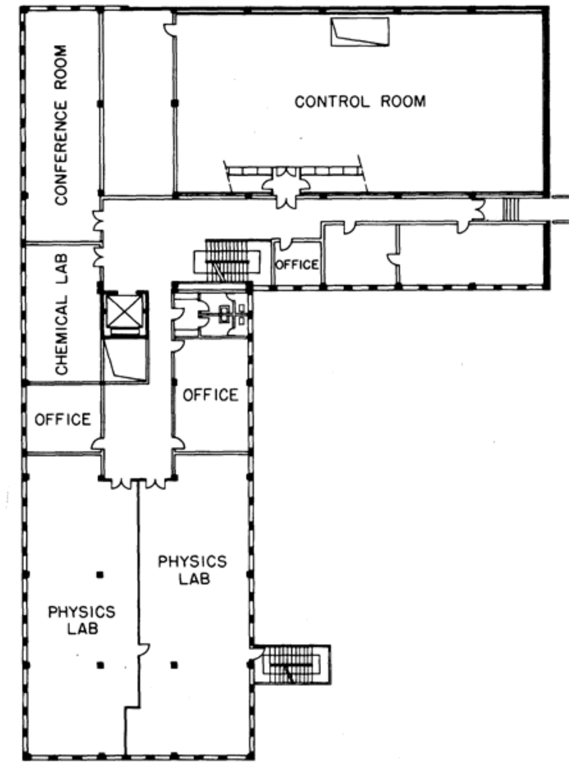
The first series of tests to be performed called for an experimental inquiry into the behavior of fuel elements (FEs) during fuel melting. Over the course of these tests, the fuel pin linear power observed on two test subassemblies reached 1000-1060 W/cm; i.e. two times greater than that normally used in commercial reactors.

The second series of experiments simulated the most serious accident, which consisted of the shutdown of the primary-circuit and secondary-circuit pumps, as well as the ternary-circuit fans, and the non-operation of the safety rods. Here, reactor output reached 21.2 MW (more than 50% of the rated value), while the mean coolant temperatures at the reactor inlet and outlet came to 402 and 507°C, respectively. A comparison of calculation results and experimental data demonstrated that the fuel residing in the core shared a state of coalescence with the FE cladding and expanded with the cladding upon heating-up. It is in such instances precisely that good agreement is reached between the calculation results and the experimental data concerning the coolant temperature at the subassembly outlet.

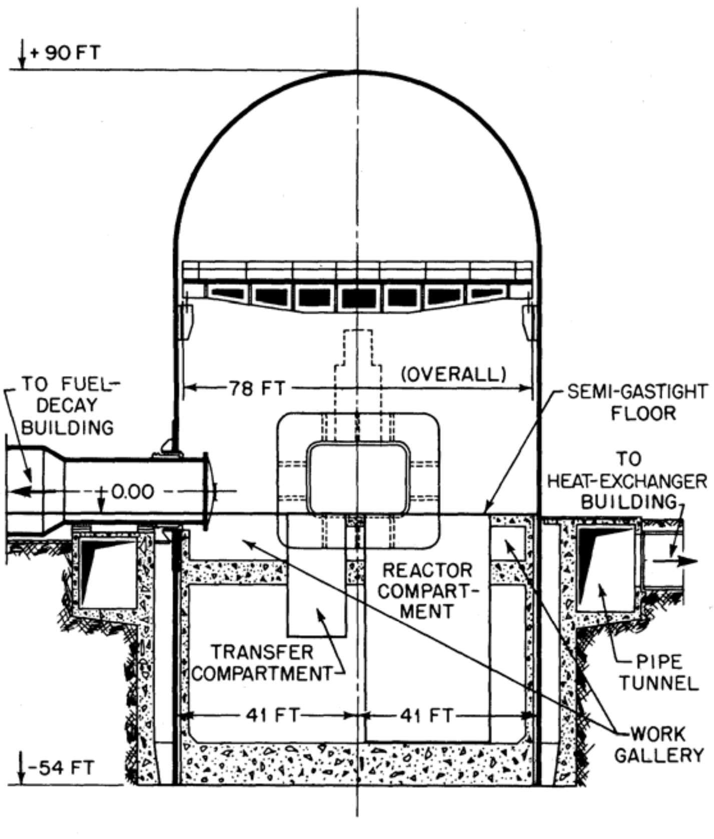
Rapsodie overall survey.



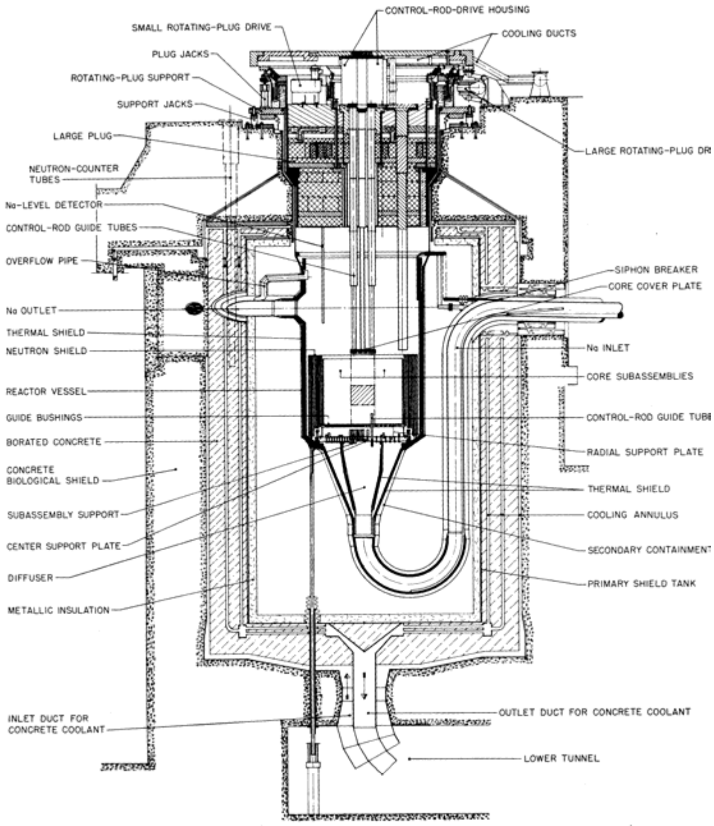
Rapsodie plant plan view.



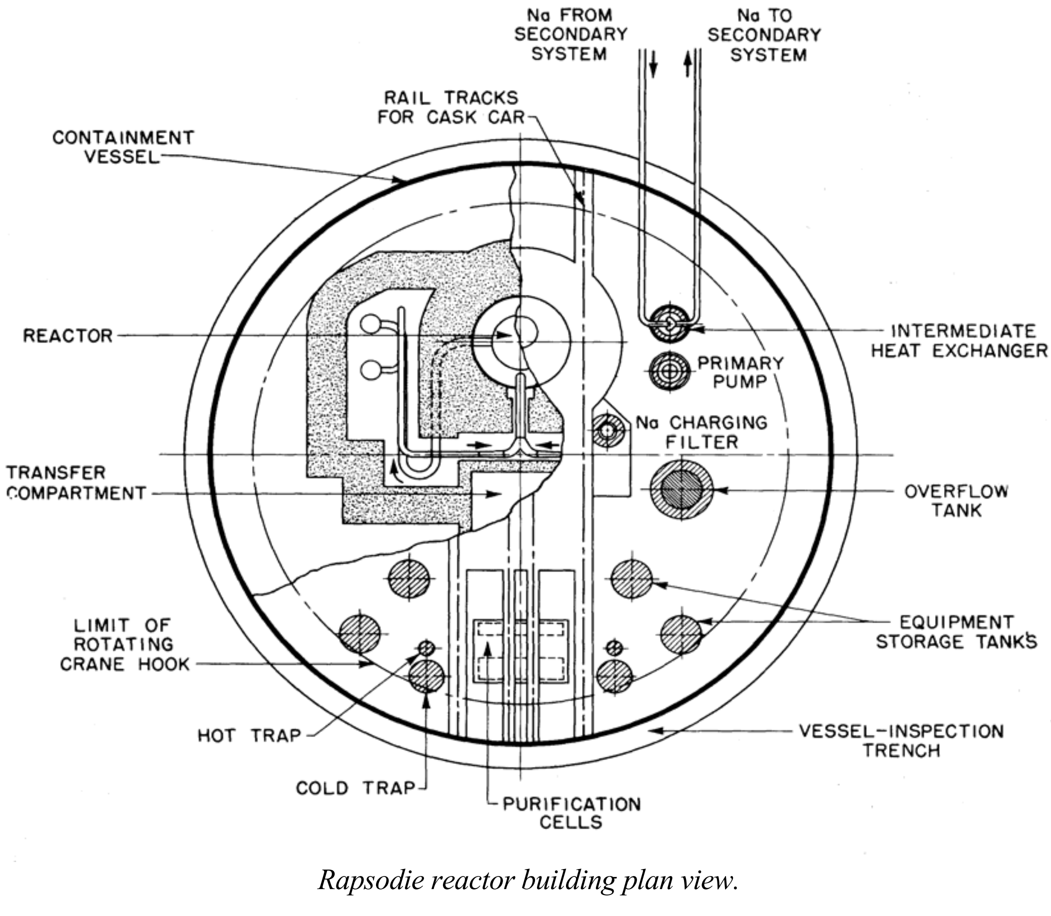
Rapsodie convential building (control room, offices and laboratories) plan view first floor.



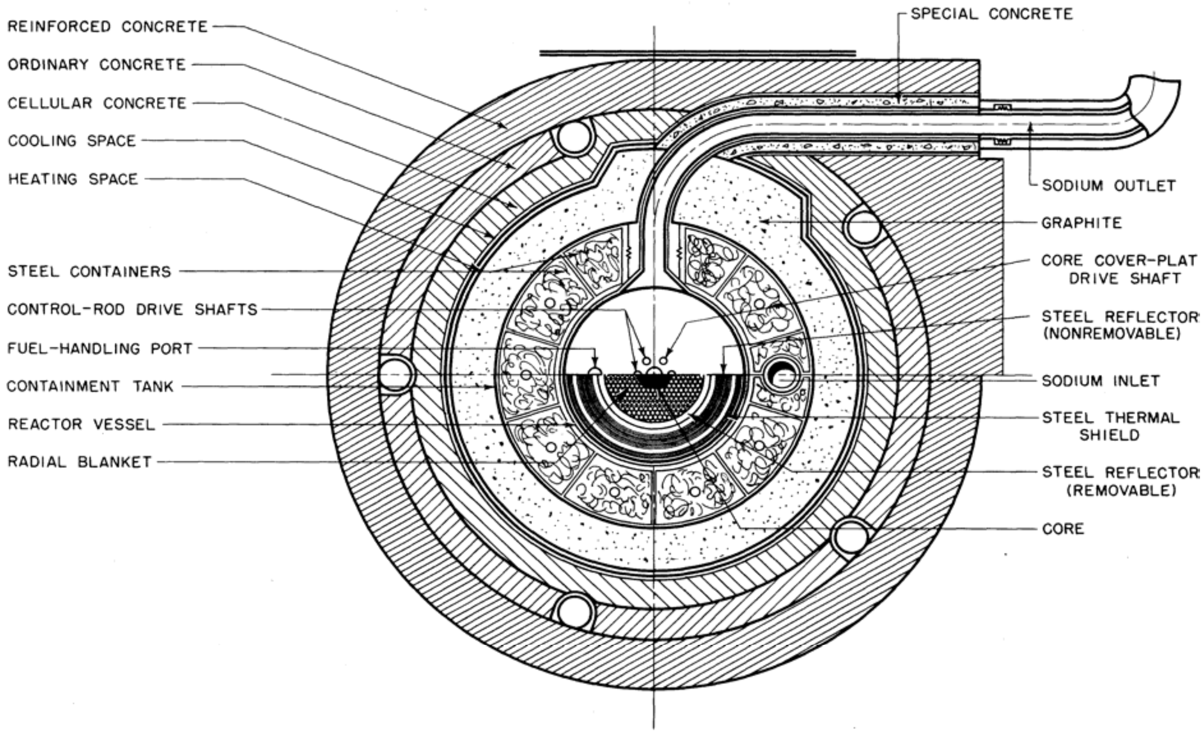
Rapsodie reactor building cross section (1 of 2).



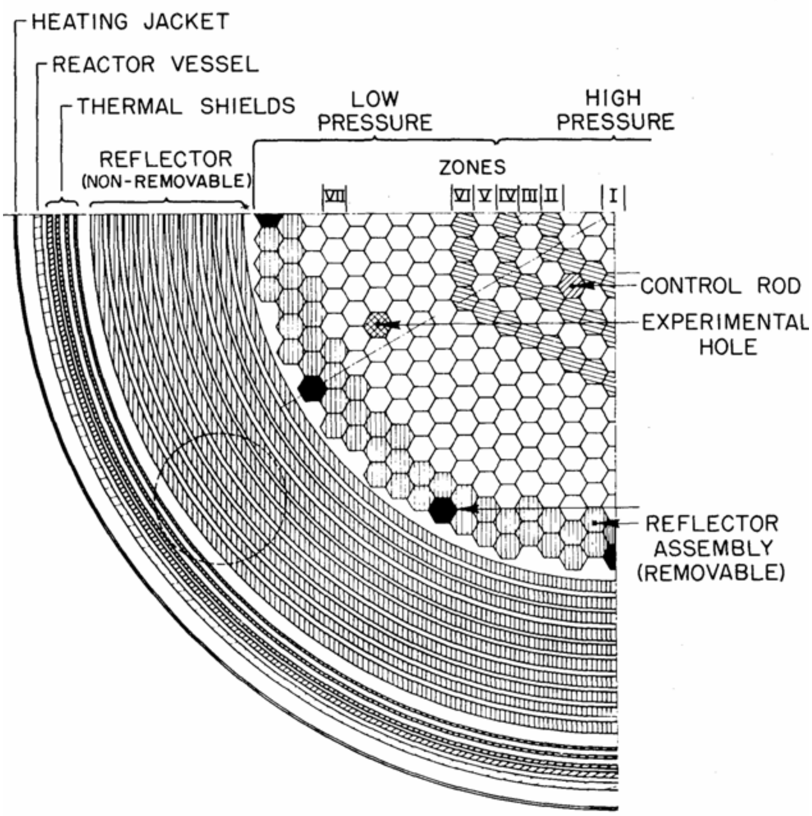
Rapsodie building reactor cross section (2 of 2).



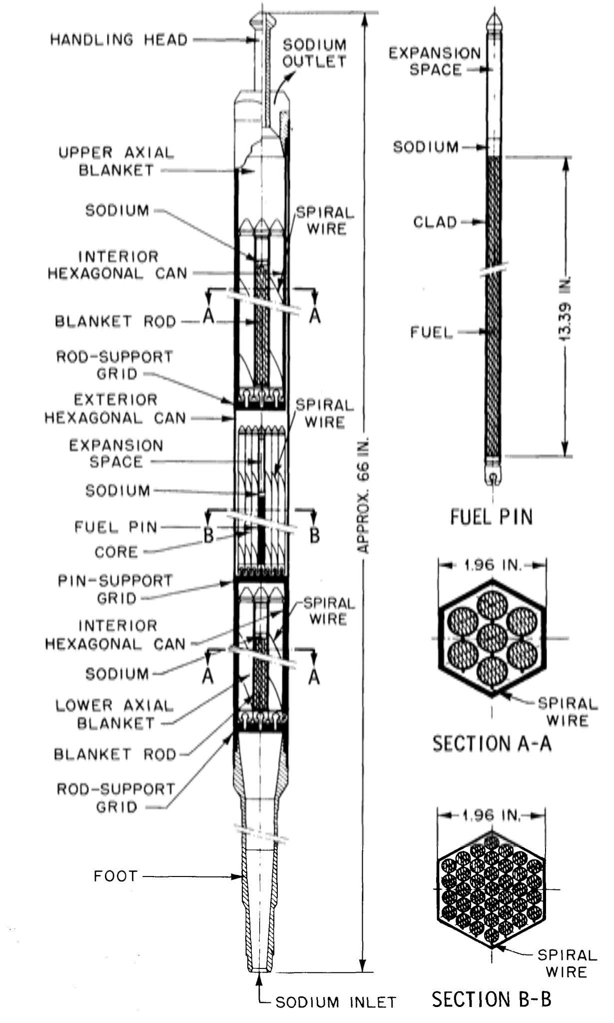
Rapsodie reactor building plan view.



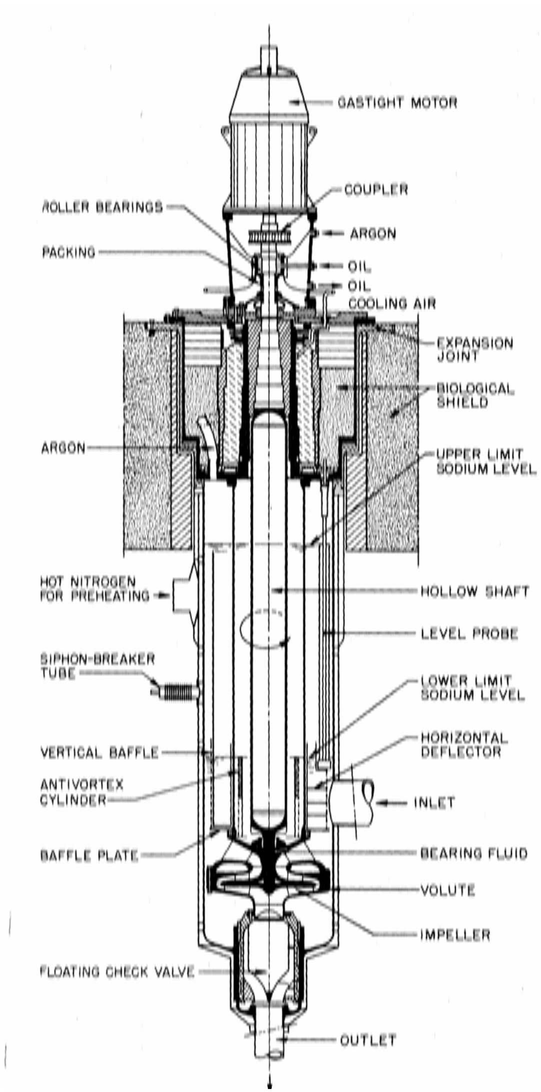
Rapsodie reactor and shield: horizontal cross section (1 of 2).



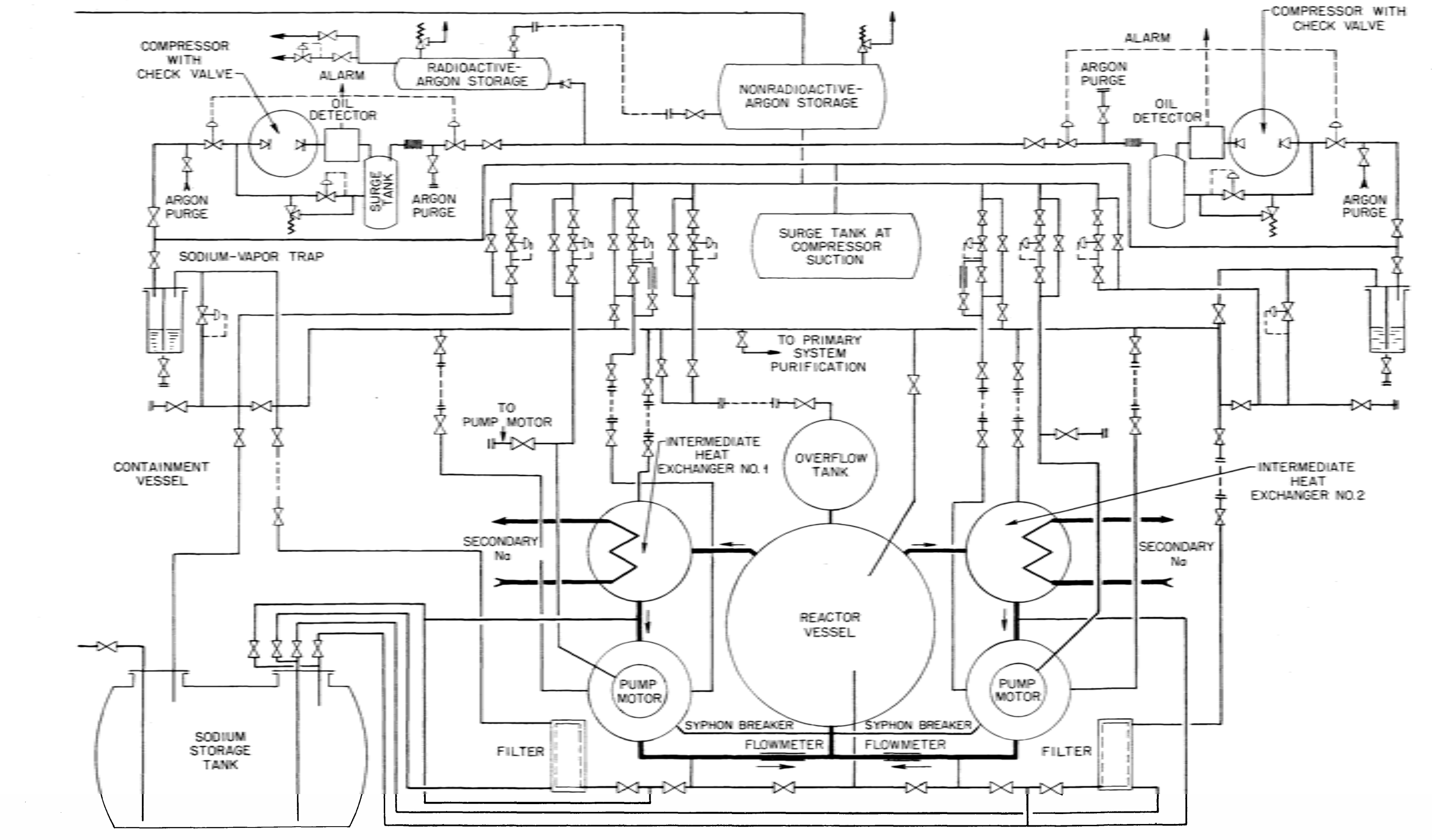
Rapsodie reactor: horizontal cross section (2 of2).



Rapsodie fuel subassembly and fuel element.



Rapsodie primary pump.



Rapsodie primary coolant and inert gas system.

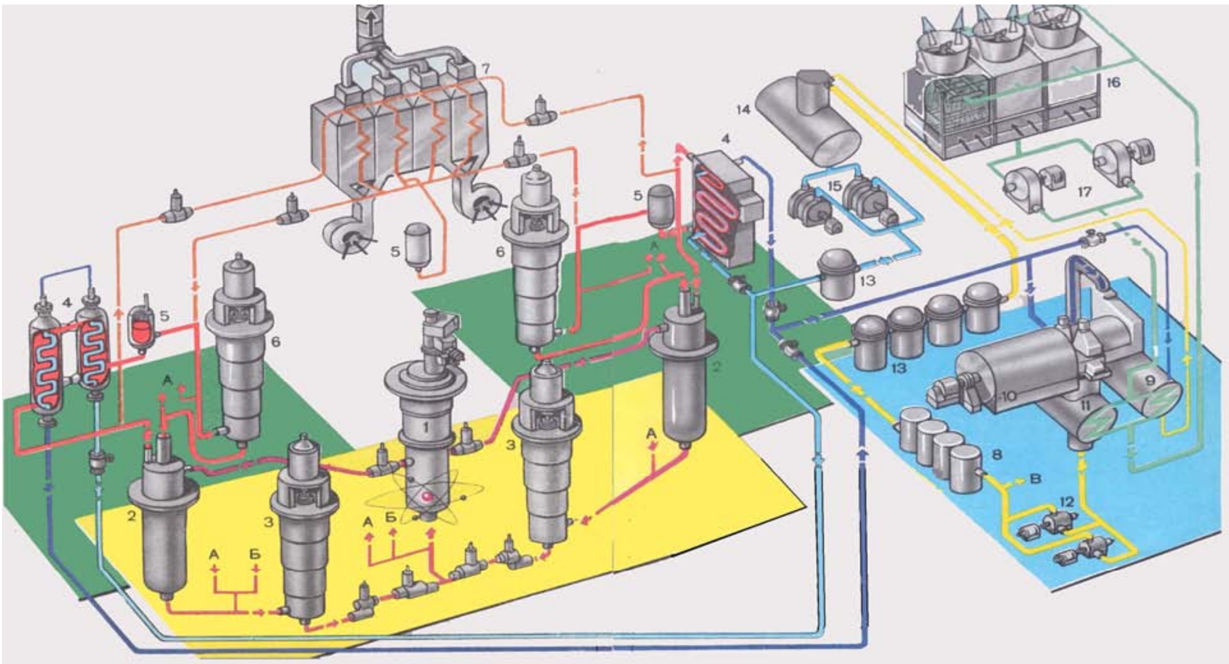
13.1.6. BOR-60

The pricipal goal of BOR-60 (60 MWth, 12 MWe) is to perform wide-range testing of fuels and structural materials for high burnups and the testing of sodium technology and LMFR components, especially steam generators and sodium pumps. Ascent to power started in late 1969, and until the end of 1970 operated with air-cooler. Then one of the steam generators was put into oreration and the turbogenerator was connected to the grid. Power operation has been going on since 1971.

The experiments consisted of various fuel types (oxides, metal, carbides and nitrides). A record high burnup level of about 35 at.% has been successfully reached with an experimental MOX subassembly in BOR-60 while a lot of standard fuel pins have attained burnt levels of 25–30 at.%.

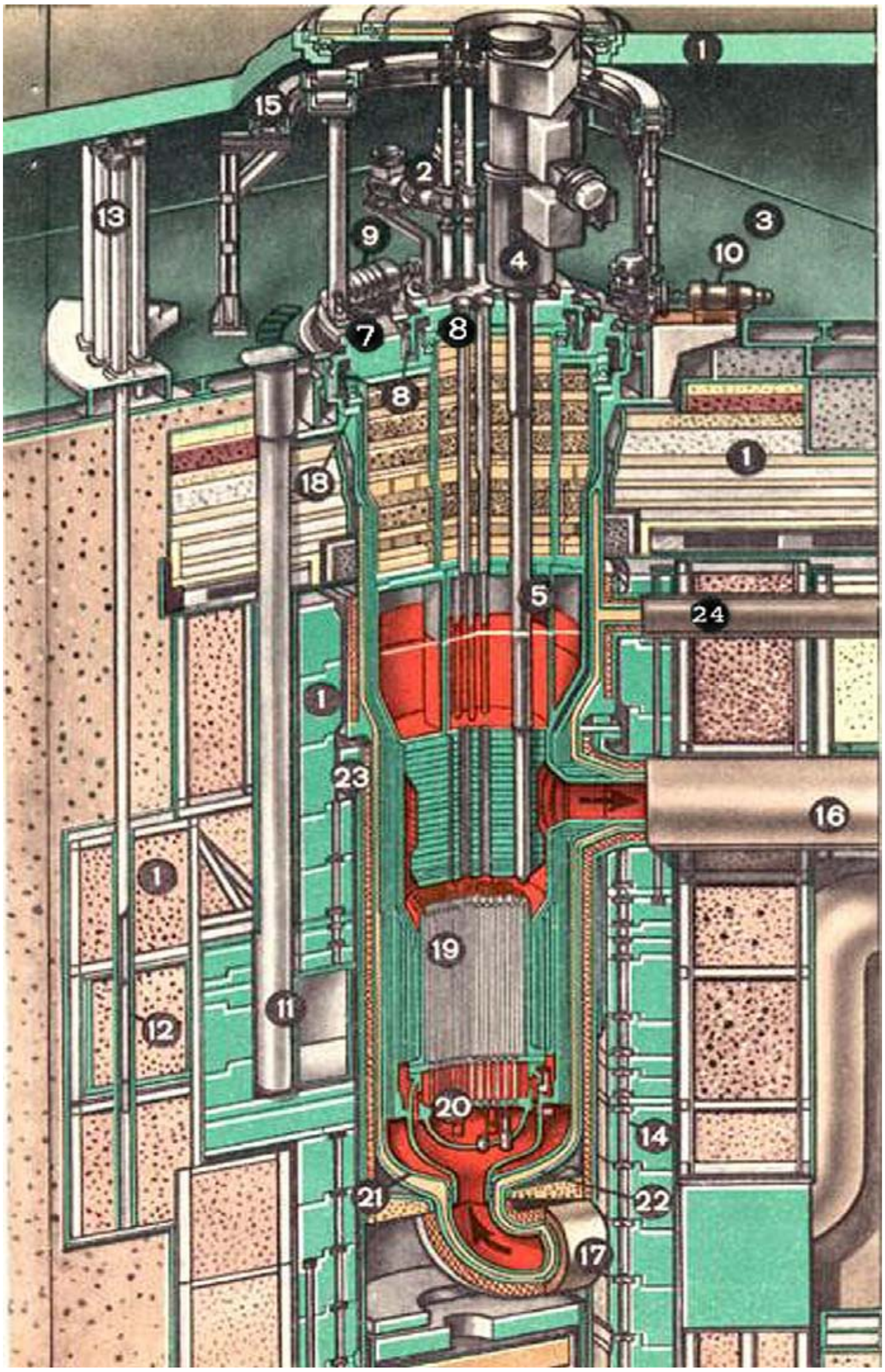
Five different type once through steam generators including those for BN-600 and BN-350 were tested at the BOR-60 plant. The second loop of the secondary circuit is operated with an electromagnetic pump; its operating life exceeded 100 000 hours.

Present activities in the fast reactor technology area in Russian Federation include design of the BOR-60 experimental reactor modification, including its replacement by the sodium cooled BOR-60M plant.



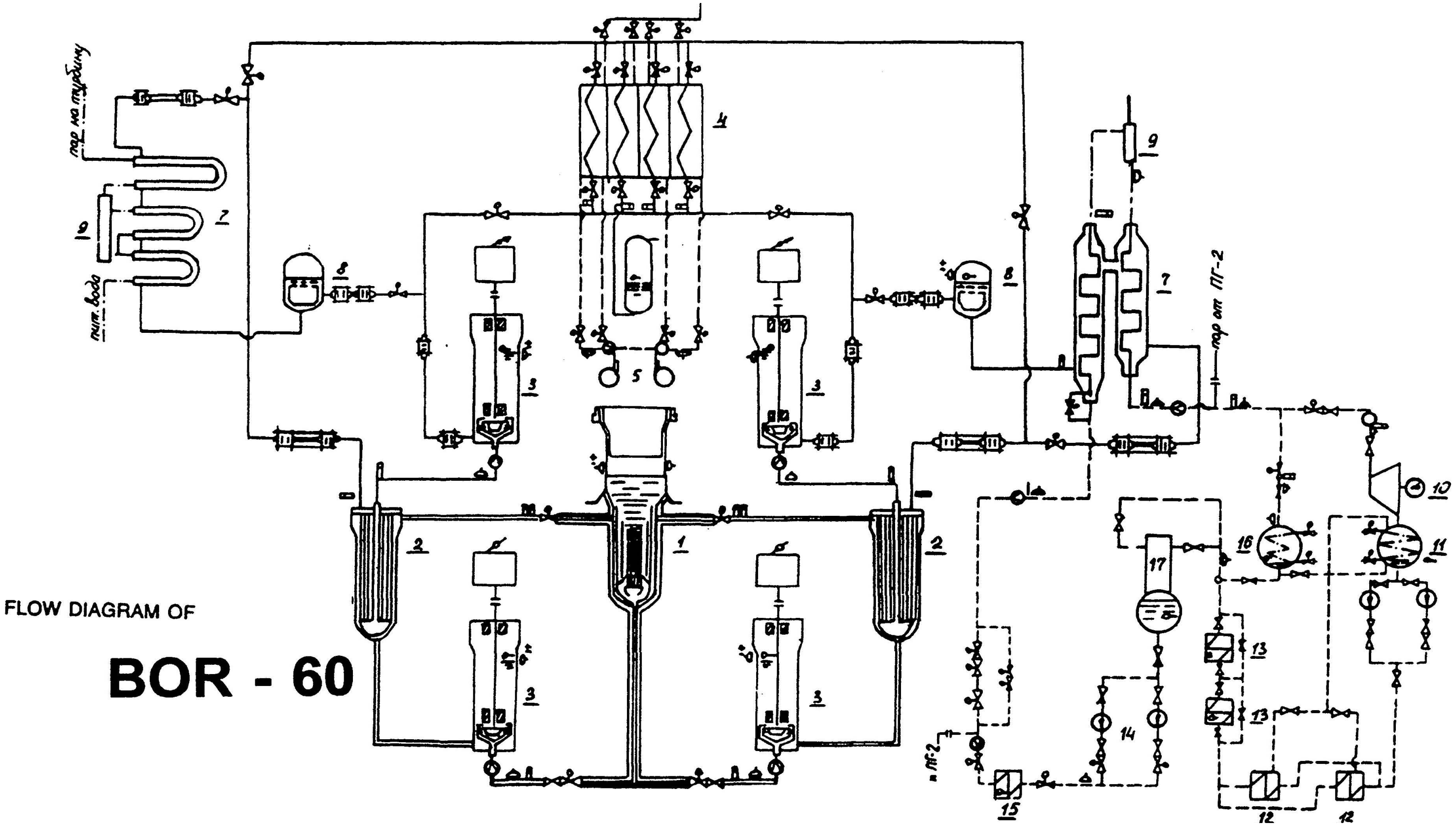
1-reactor, 2-intermediate heat exchanger, 3-primary pump, 4-steam generator, 5-buffer tank, 6-secondary pump, 7-sodium-air heat exchanger, starting capacitor, 8-water purification system, 9-starting condenser, 10-turbogenerator, 11-turbine condenser, 12-condensate pump, 13-recuperative heat exchanger, 14-deaerator, 15-feed-pump, 16-blower cooling tower, 17-cooling tower circulation pump. A-to sodium purification system, Б-to sodium γ-spectrometer loop, B-makeup water

BOR-60 facility axonometric sketch.



1-biological shield, 2-driving and control rood gear, 3-reactor pit, 4-junction cylinder, 5-reloading channel, 6-small rotating plug, 7-large rotating plug, 8-plug sealing, 9-small rotating plug gear, 10-large rotating plug gear, 11-external irradiation channel, 12-ionization chamber, 13-ionization chamber gear, 14-shield cooling channels, 15-power supply, 16-exit socket, 17-head socket, 18-basket flange, 19-core and steel screen subassemblies, 20-head collector, 21-frame, 22-casing, 23-reactor support, 24-gas socket

BOR-60 reactor vertical cross section (2 of 2).



1-reactor, 2-IHX Na/Na, 3-pump, 4-HX Na/air, 5-ventilator, 6-expansion tank, 7-SG, 8-expansion tank SG, 9-separator, 10-turbine, 11-condenser, 12 -heater, 13-low pressure heater, 14-pump, 15-high pressure heater, 16-condenser, 17-deareator

BOR-60 plant flow diagram.

13.1.7. KNK-II

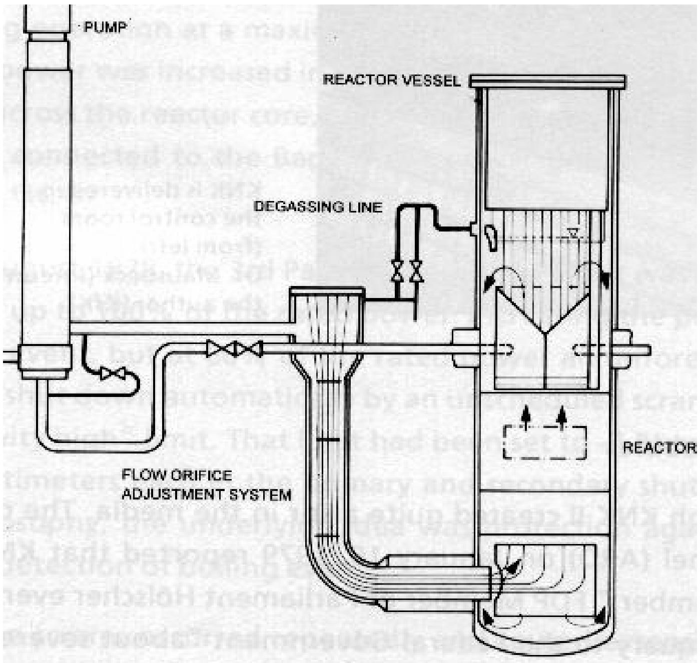
KNK-II (Kompalte Natriumgekuhlte Kernreaktoranlage) was reconstructed from 1975 to 1977, after having been operated with a thermal reactor core with a ZrH_2 moderator (KNK-I) between 1972 and 1974. Full power (58 MWth, 20 MWe) operation started in March 1979.

KNK-II was built and has been operated to serve as the nation's first fast flux irradiation facility, to gain operating experience with a liquid metal cooled fast reactor system and to conduct an extensive test programme in fast reactor environment.

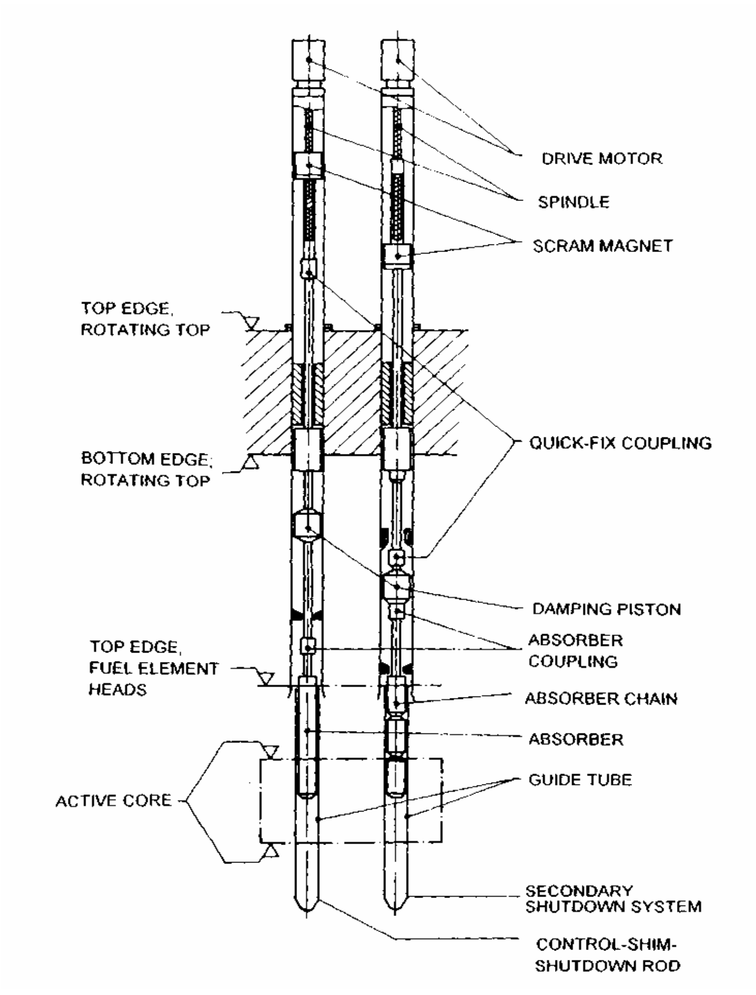
The KNK-II core was a two-zone core, the test zone of which was equipped with MOX fuel surrounded by a drive zone and served as a test bed for the fuel elements of the SNR-300 reactor. For running these elements with equivalent power per unit rodlength, the reactor core has been subdivided into a test zone and a driver zone which differ greatly with respect to fuel element power levels. It shoulb be pointed out, that only the fuel elements in the test zone cotained MOX fuel. A maximum burnup of 100 000 MWd/t was reached with the first KNK-II core.

The operation of KNK had been impaired by the unforesin impact of gas bubbles entrained in the sodium coolant. There were scrams via 'negative reactivity high' at about 60% design power in 1978/79. (Reactivity was one of three parameters whose signals were used to detect coolant flow disturbances in fuel elements). Additional experiments helped to detect a vent line as the main sourse of gas entering the sodium. Actually this line was served to ensure decay heat removal by natural convection in a certain type of accident. The amount of gas entrained was a function of the flow and, hence, the reactor power. For this reason, throttle valves were installed in the vent line. Minor quantities of gas were also introduced into the system via some other routes. The gas collected at certain points at the pumps until it was entrained towards the reactor core, depending on flow conditions in the pipelines. Measures have been taken to deflect the gas bubbles by design modifications at the grid plate insert of the fuel elements so as to make them move towards the reflector elements, which they can pass without affecting reactor operation. In this way bubble problem has been remived for good.

A difficult problem in operation was posed by sticking in the shutdown systems of KNK-II. In December 1986, a control rod of the primary shutdown unit for the first time was found to stick while the reactor was shutdown. The cause was found to be sodium aerosols plated out during prior handling steps, when the rod actuating equipment had not been swept with gas. This blockage in the primary shutdown system was caused by depositions in the rod actuating equipment in a phase in which the cover gas quality had been insufficient.



KNK-II primary system.



Schematic representation of the shutdown rods in the KNK-II shutdown systems.

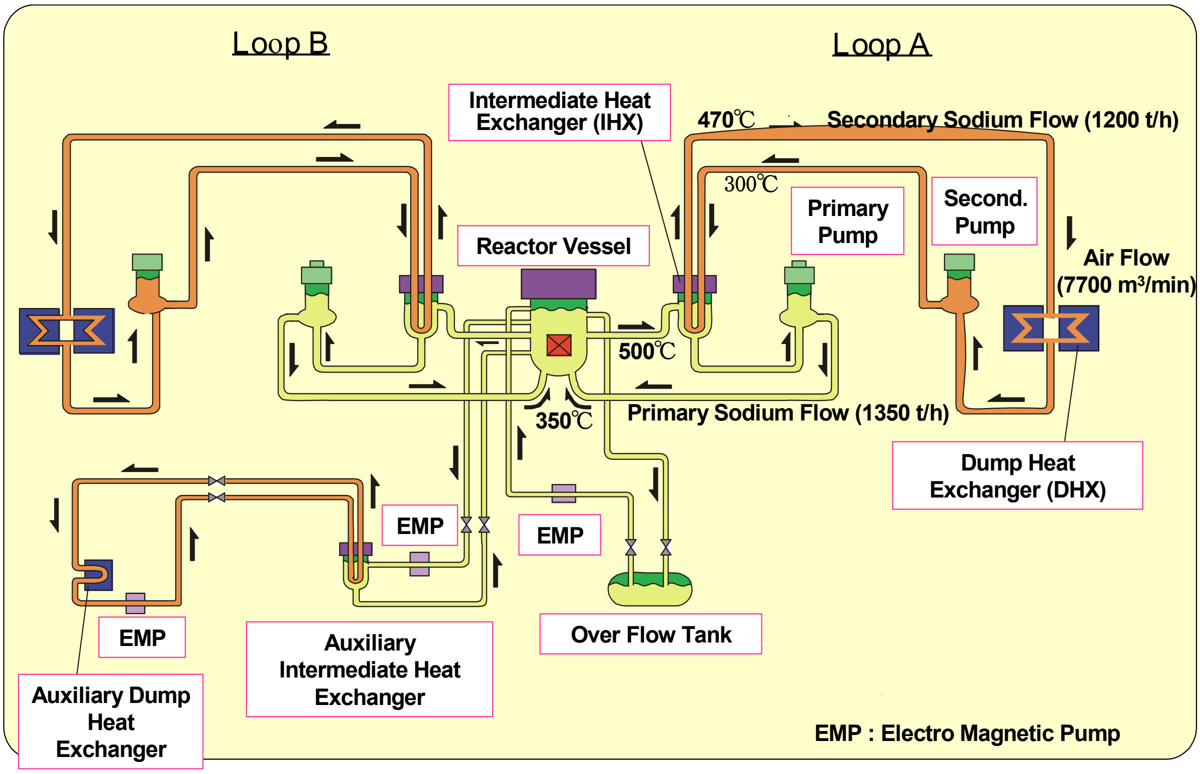
13.1.8. JOYO

Since July 1979, JOYO has been operating with the MARK I core at a 75 MW(th) power and the maximum burnup reached was 40 000 MWd/t.

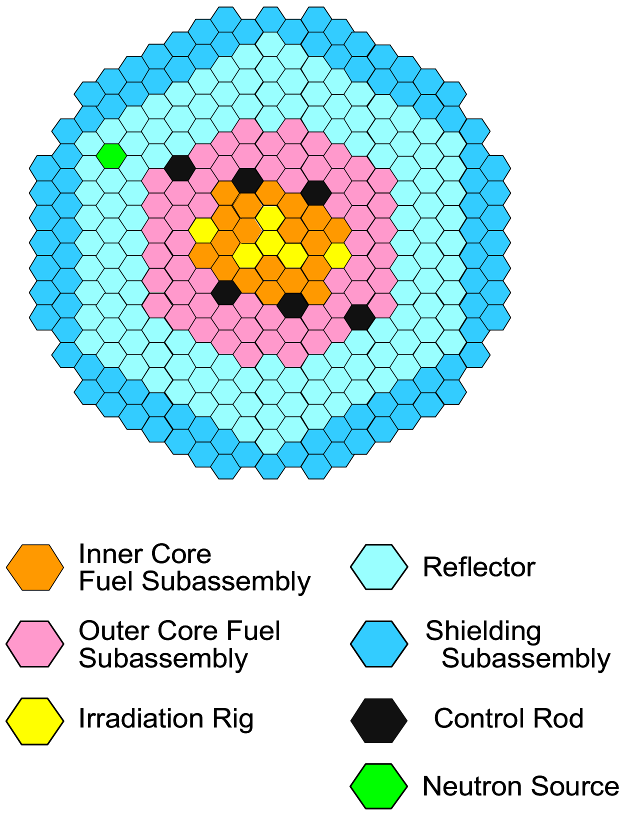
Since August 1983, plant has been operating with the MARK II core on a 100 MW(th) power level.The main objectives of programme were: the test irradiation of fuels and structural material development, the acquisition of operation and maintenance data for Monju, and the development of preventive maintenance technology using plant detection technoloques. The JOYO reactor has successfully completed and tested the plant and core modifications for the MK-III upgrade programme (the main IHX, the main dump heat exchanger and motors of the secondary pump have been replaed to improve a heat removal capacity), and rated power operation was started in 2004. The upgraded MK-III core provides a significantly enhanced irradiation testing capability compared to the MK-II core. Initial critically of the MK-III core was achieved on July 2003, which was followed by the successful operational demonstration up to the rated power of 140 MW(th). Functional and performance testing verified the design parameters. The utilization plan for future fuels and materials developments and safety testing in the JOYO MK-III core has been developed.

The experimental fast reactor JOYO has shown excellent performance for more than 26 years; 64 000 pins with solid pellets have been irradiated in JOYO with a maximum burnup level of around 15 at.%.

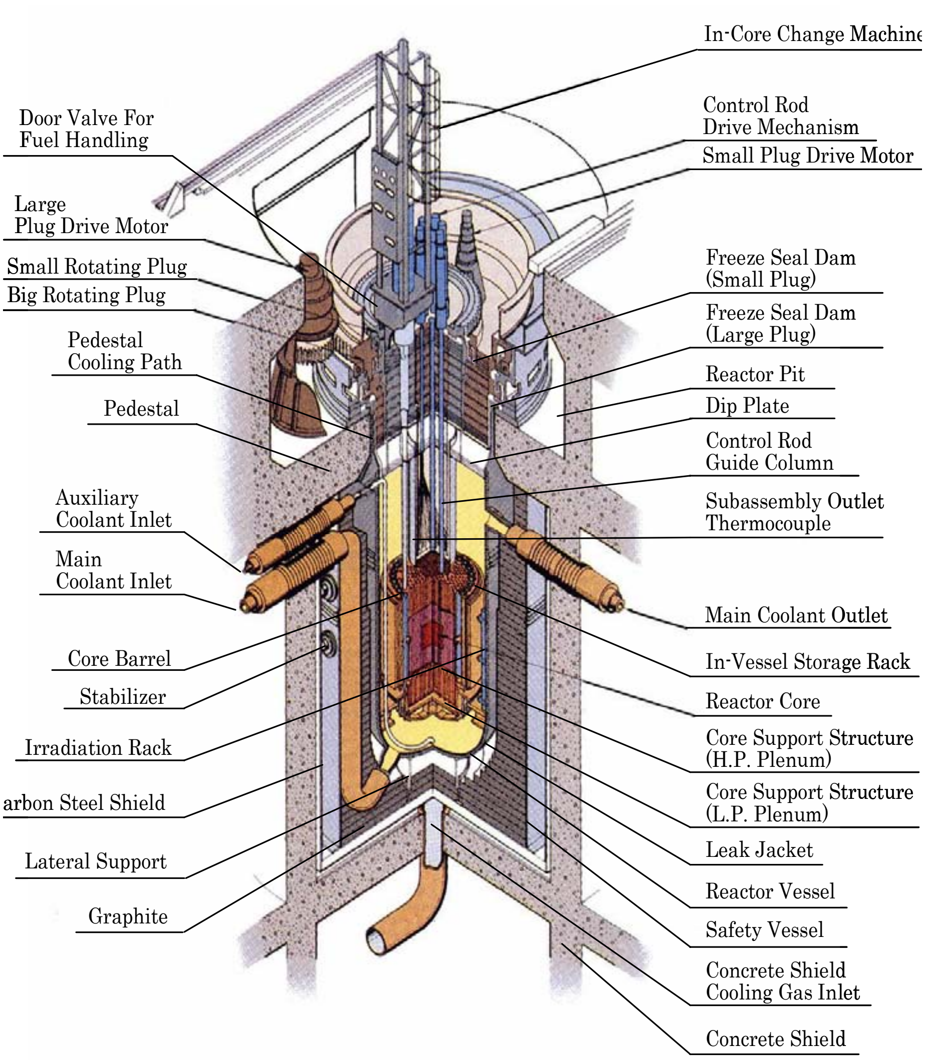
JOYO overall survey.



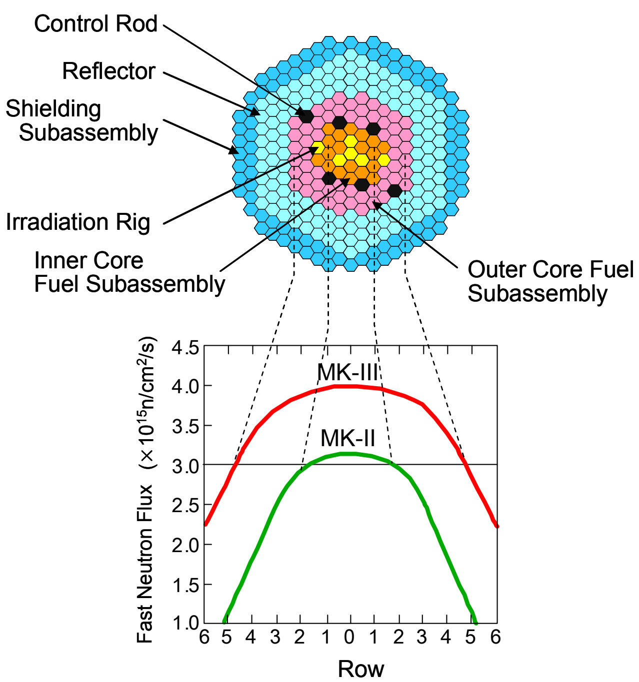
JOYO reactor cooling system.



JOYO reactor core.



JOYO reactor system.



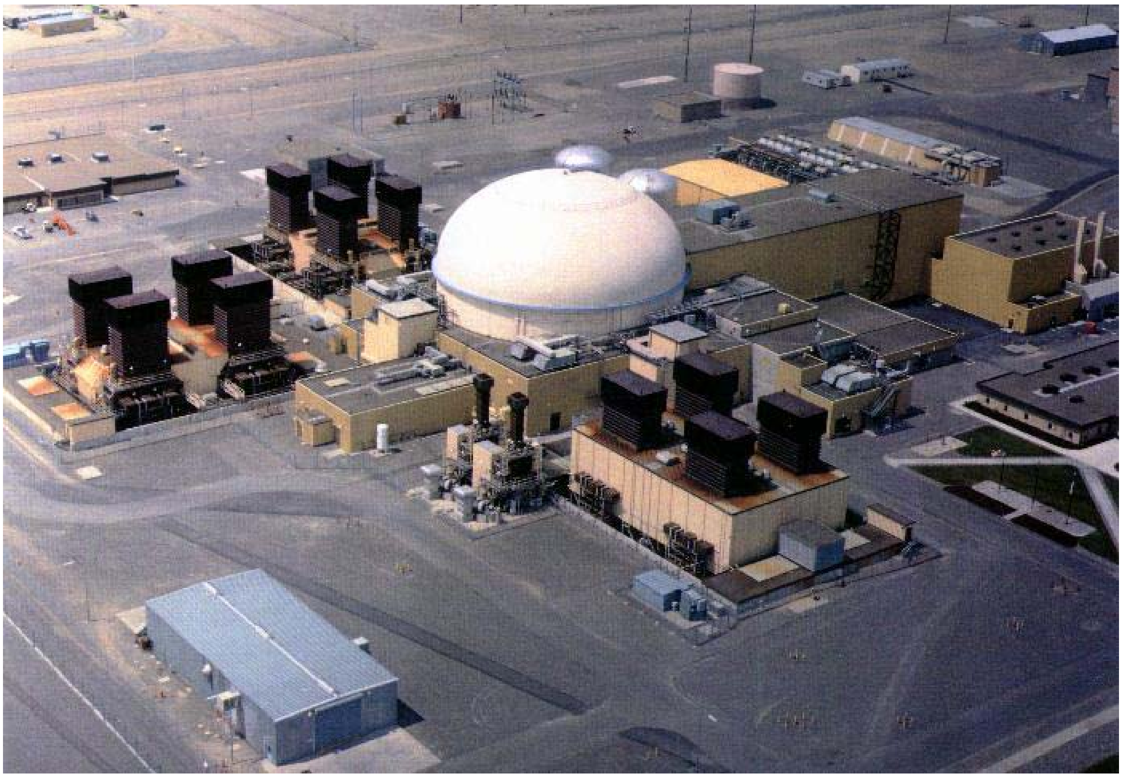
JOYO fast neutron flux distribution.

13.1.9. FFTF

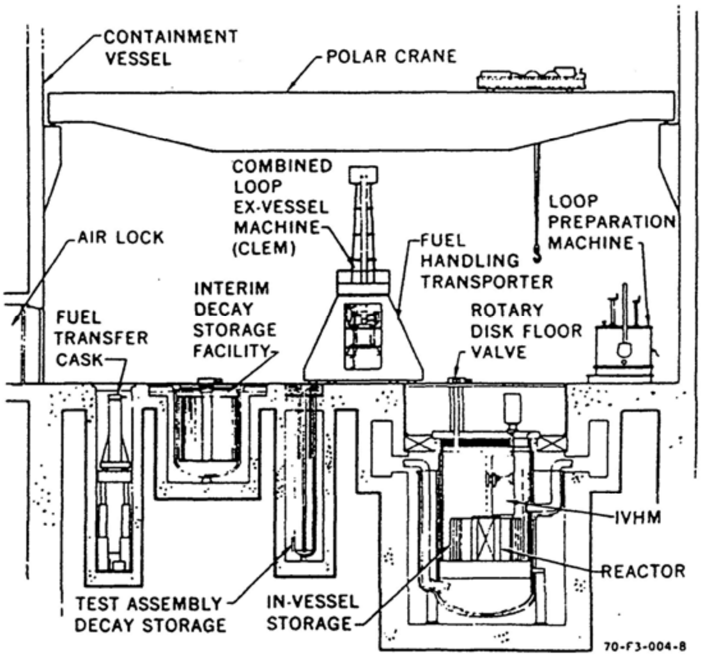
The fast flux test facility (FFTF) was a 400 MW(th) sodium cooled fast reactor specifically designed for development and testing of fast breeder reactor fuels, materials, and components. The reactor was a loop-type plant with three parallel heat transport system loops. The plant has neither steam generators nor blanket assemblies for fissile breeding, consistent with its role as a test reactor. The FFTF was equipped with a great deal of instrumentation. Each core assembly was provided with instruments for measurement of sodium flow rates and sodium outlet temperature. Three instrument trees, one of which serves each of the three core sectors, provide outlet instrumentation for all fuel assemblies, control and safety assemblies, and selected reflector assemblies. In addition, 8 of the 73 core positions were equipped for full in-core instrumentation. Two of these eight positions were available for closed-loop facilities.

In these closed test-loops components inserted in the reactor core, the coolant, instrumentation and heat transfer systems were completely separated from the main FFTF core, permitting the testing of fuels and materials over a wide range of temperatures in a controlled environment independent of the main reactor coolant system. The open loop test positions and integral components of the reactor core for testing large quantities of candidate fuel pins and assemblies were cooled by the reactor primary coolant system.

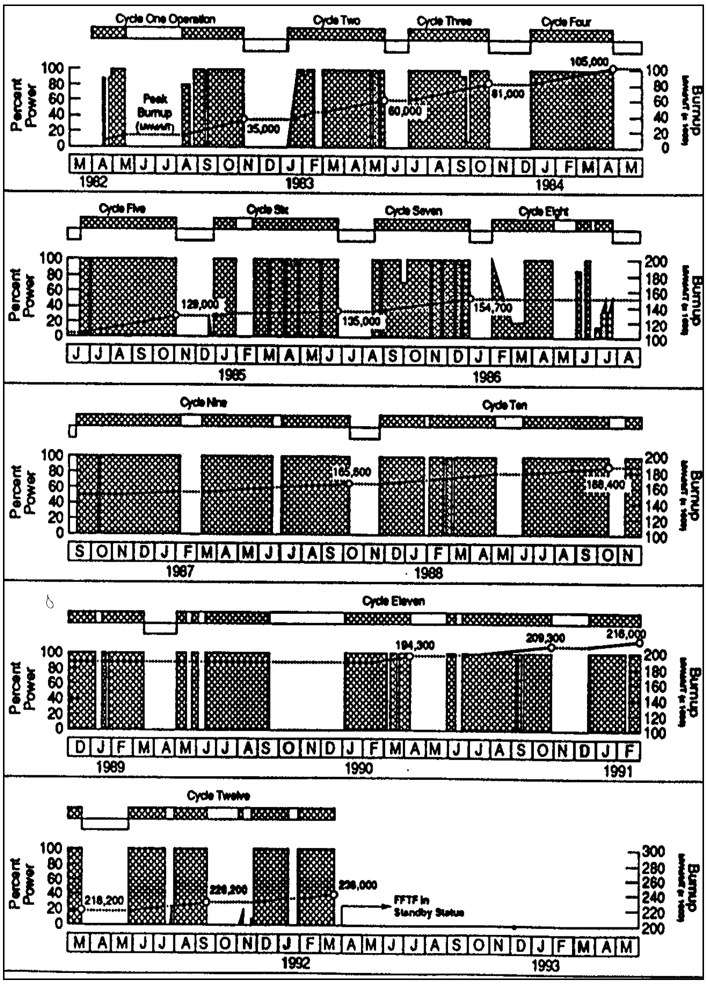
The FFTF began its power ascent in November 1980. In December 1980 full power of 400 MW(th) was reached. A series of natural circulation tests proved that the FFTF loop-type system could be operated safely under conditions of long-term decay heat removal by natural convection without any sodium pumps working. Nine core demonstration experiment for fuel assemblies, including lead tests, continued irradiation until the reactor was shut down in March 1992. A lead test assembly reached a world's best fuel assembly burnup of 238 MWd/kg. The highest burnup assembly reached a burnup of 221 MWd/kg. It was agreed to process a hot channel lead test for post irradiation examination by PNC. All nine assemblies have achieved their current exposures without operational difficulty. The possibility of future DOE missions along with collaborative international programmes for the FFTF had been evaluated. The plant was in steady state hot standby conditions for a long time and was shutdown in 2000.



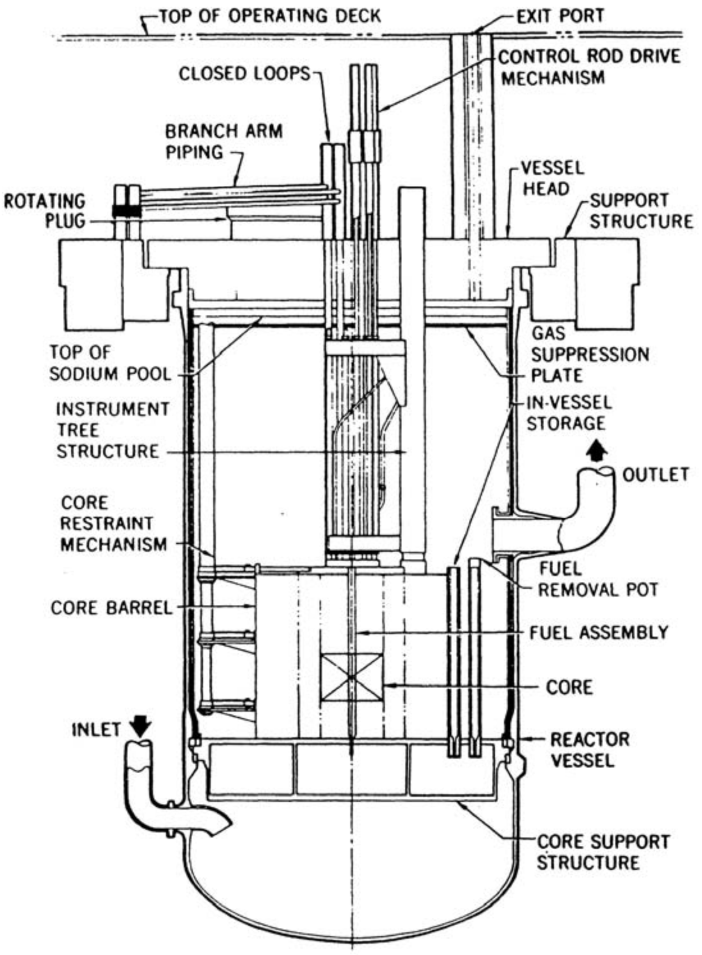
FFTF overall survey.



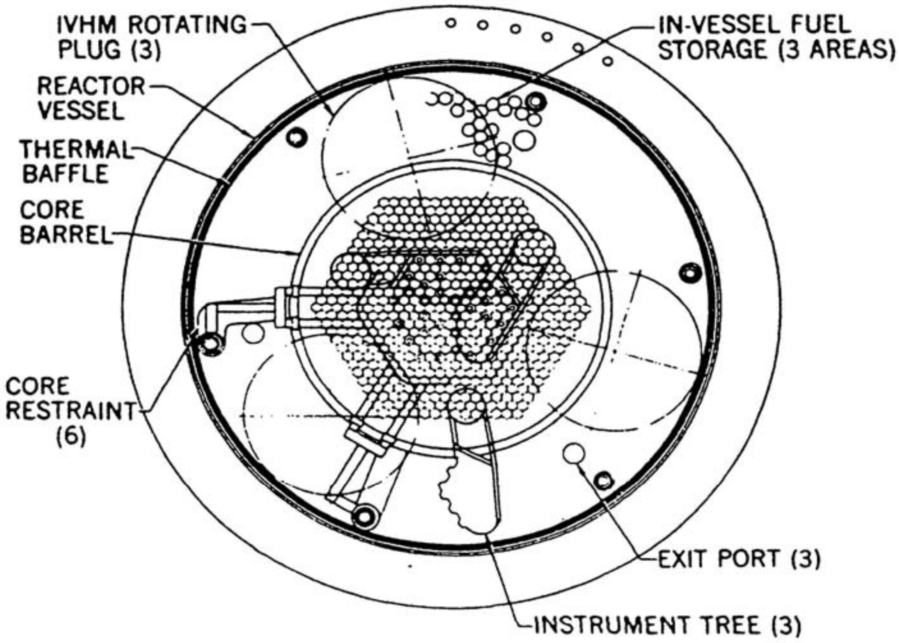
FFT plant elevation.



FFTF operating and fuel burnup histogram.



FFTF reactor elevation.



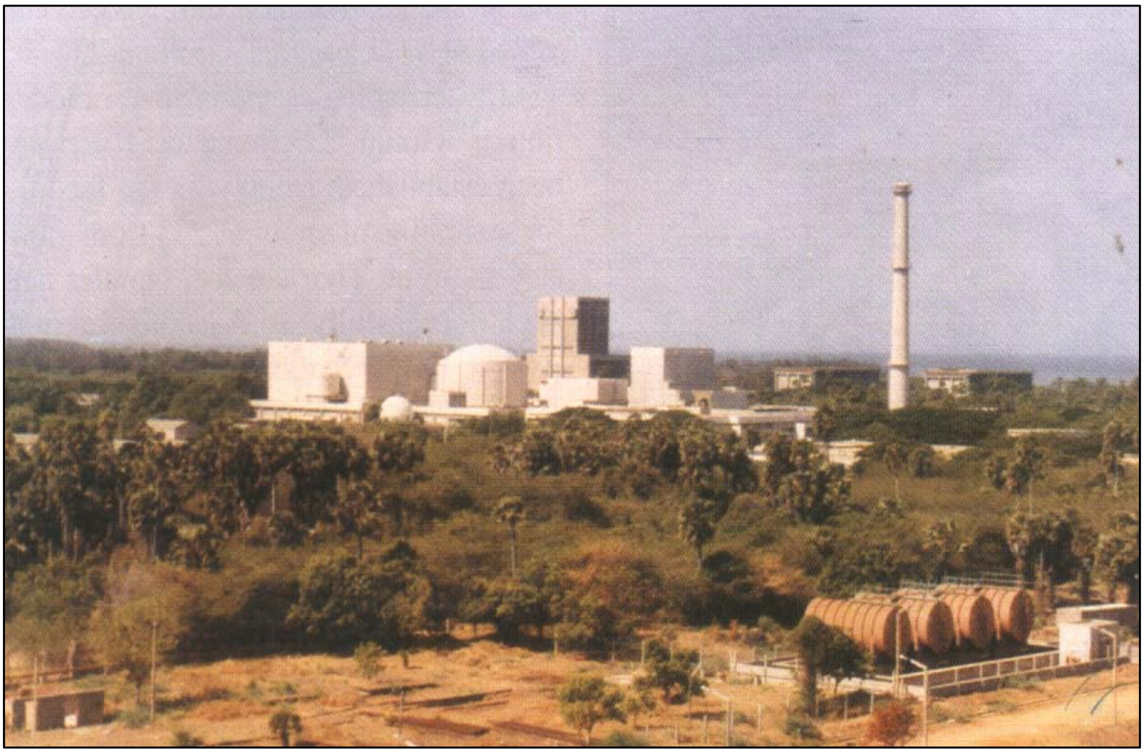
FFTF reactor plan view.

13.1.10. FBTR

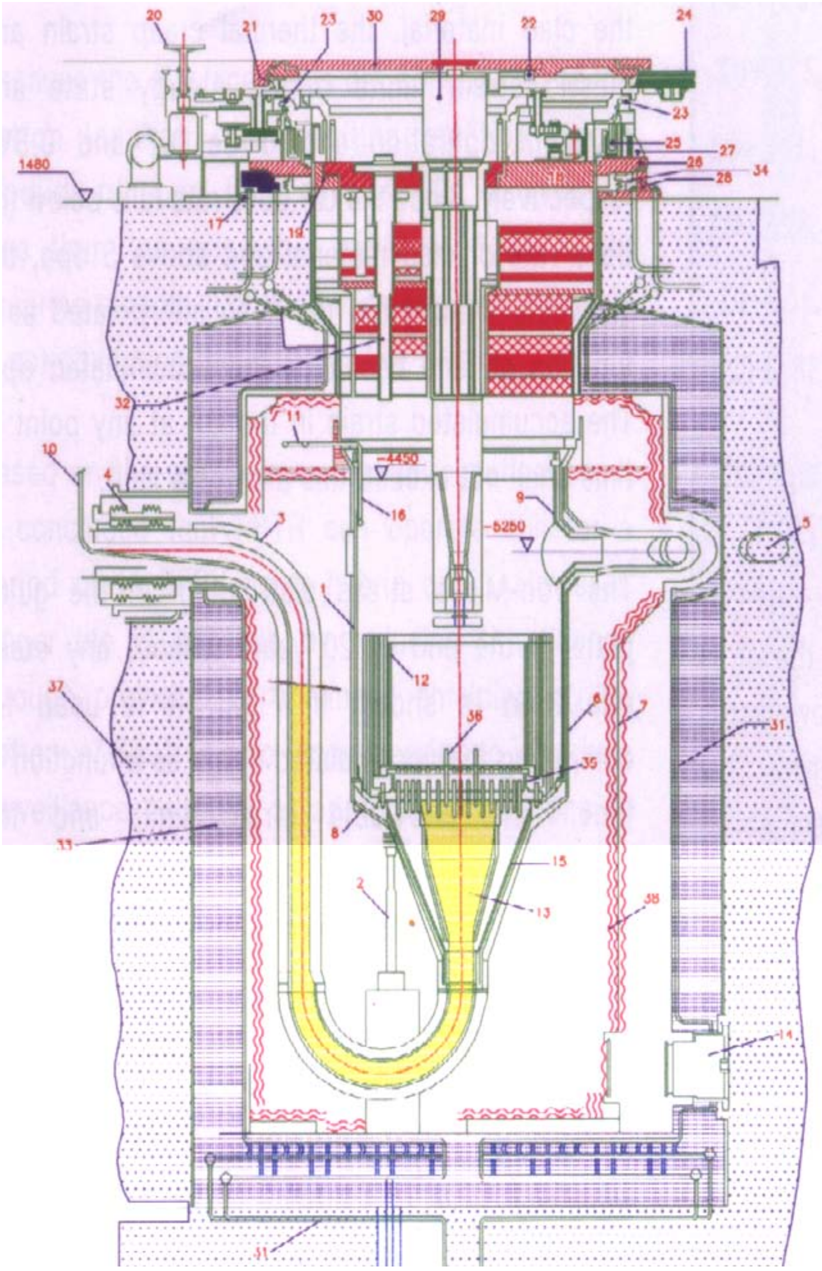
The Indian fast reactor development programme is built based on the experience accumulated with the small-size [40 MW(th)/13 MW(e)] fast breeder test reactor (FBTR) located at Kalpakkam, which is operational since 1985.

Important works including PFBR shielding experiments, testing of transfer arm in air, boron enrichment, post-irradiation examination of FBTR fuel after 125 GWd/t burnup, structural integrity testing, and reprocessing of carbide fuel are being carried out.

Development of technology of low doubling time fuels and structural materials capable of sustaining high neutron fluence has already been initiated and work is going on satisfactorily.



FBTR overall survey.



1) reactor vesssel
2) displacement measuring device
3) sodium inlet pipe
4) compensating bellows
5) clad rupture detection pipe
6) double envelope of reactor vessel
7) steel vessel
8) supporting bracket for double envelope
9) thermal shields
10) fill & drain pipe
11) purified sodium return pipe
12) neutron shields
13) diffuser
14) man hole
15) thermal shields
16) siphon break pipe
17) rest plate on concrete
18) large rotatable plug
19) small rotatble plug
20) large rotatable plug drive
21) casing for moving cable guide
22) detachable connections for small rotatable plug
23) large plug bearing
24) cable entry on block pile
25) large plug liquid metal seal
26) support plate
27) upper bracket
28) lower bracket
29) control plug
30) anti explosion floor
31) biological shield cooling pipes
32) guel handling canal
33) borated concrete
34) ss bellows
35) grid plate assembly
36) control rod guide sleeve
37) structural concrete
38) thermal insulation

FBTR reactor assembly.

3.1.11. PEC

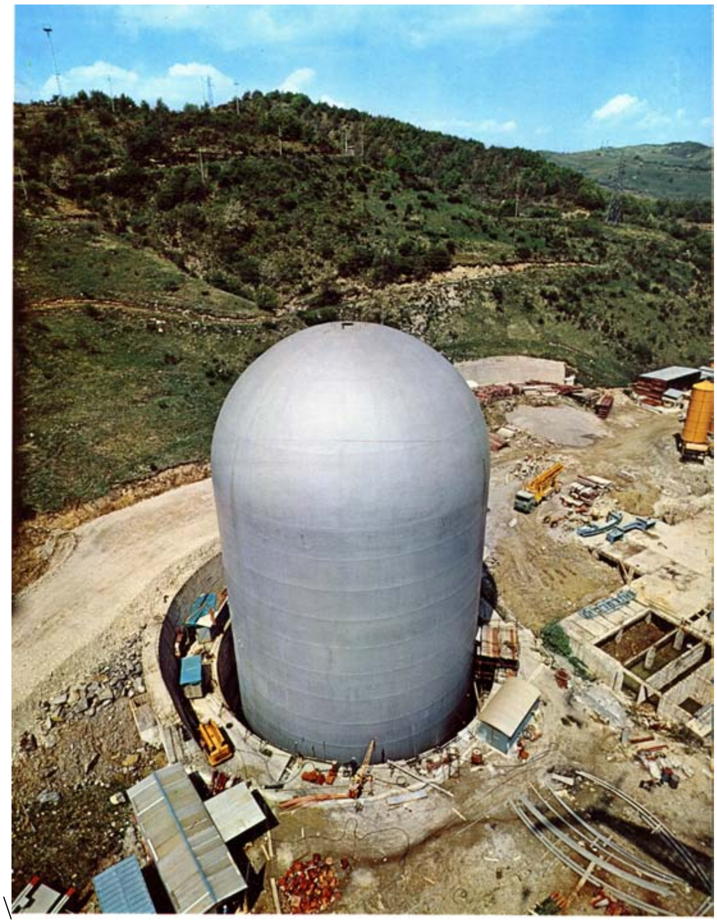
PEC (Prove per Elementi di Combustibile) - fuel element testing facility, history:

ENEA (CNEN) defined conceptual plant design:

- 1974 Authorization of plant construction;
- 1976 Beginning of civil engineering;
- 1981 completion of most of the experimental loops to test core element models and the test channel prototype;
- 1983 Placement of the grid inside the reactor tank; the total progress of completion of the plant was 45% with design 86% complete, supply 30%, and civil work 61%, whils assembly had just begun;
- 1987 The Italian Government after a referendum concerning the use of nuclear energy in Italy finally decided to stop the PEC plant construction.

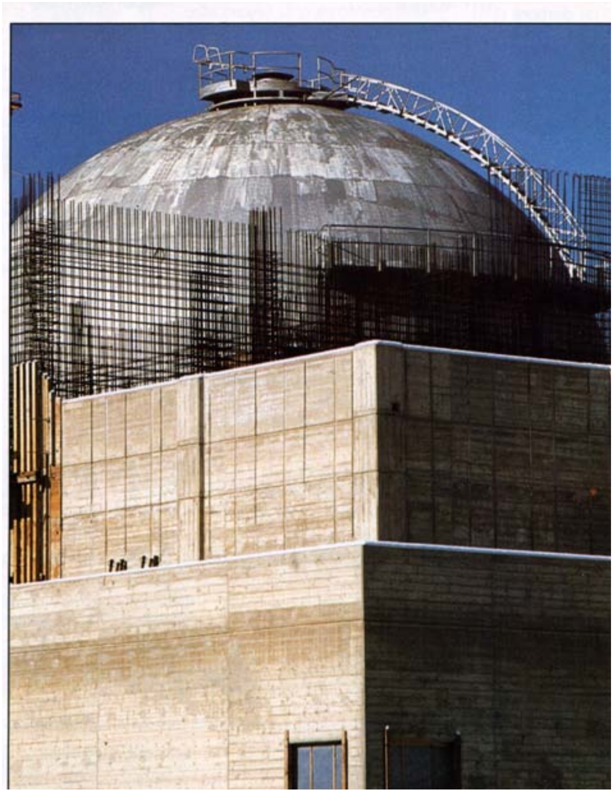
The PEC reactor [power output: 123 MW(th)/0 MW(el)] was of semi-integrated type (integrated intermediate heat exchangers and primary pumps) and was cooled by two sodium primary and secondary circuits. A test channel, hydraulically and thermally insulated from the core, was located at the core center, corresponding to the seven central positions. The maximum power of the experimental element inside the test channel was 3 MW(th).

PEC reactor plant: the site of construction (1 of 2).

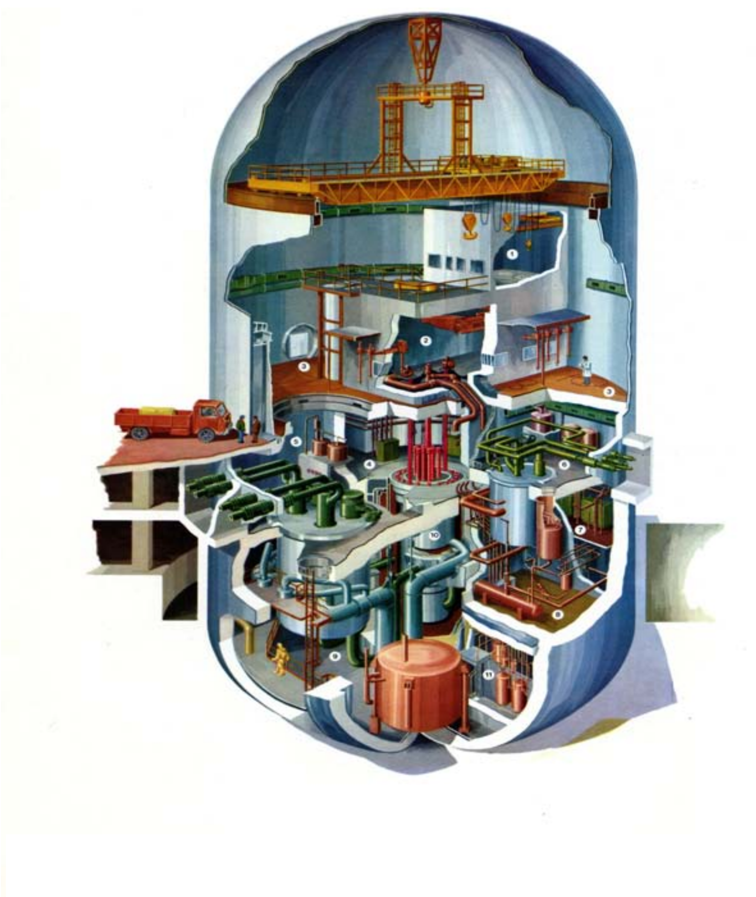


PEC reactor plant: the site of construction (2 of 2).

PEC under construction, 1984.



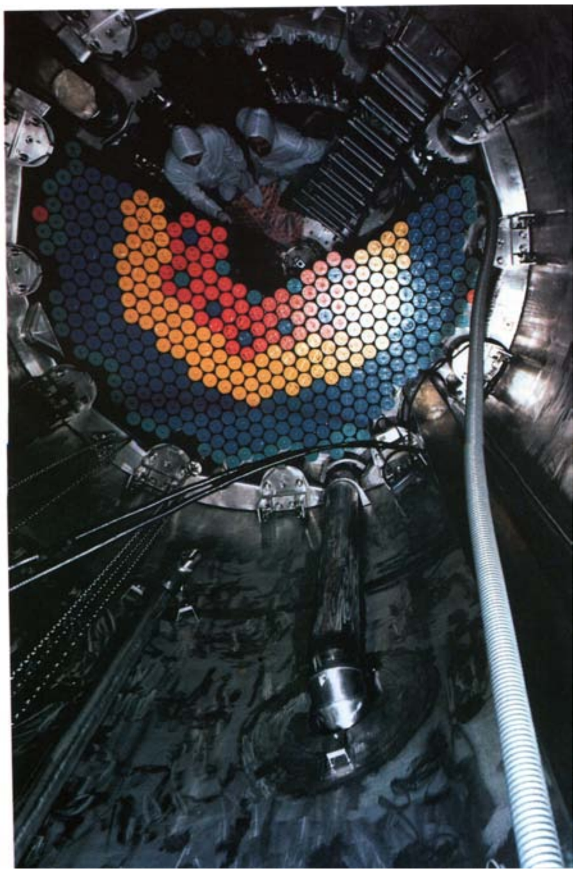
PEC under construction building.



1, 2, 3, 4, 5, 6, 7, 8-reactor auxiliary and and test channel systems and equipment, 9-integrated intermediate heat exchangers and primary pumps block, 10-reactor

PEC reactor plant perspective view.

PEC montage.



PEC reactor central zone.

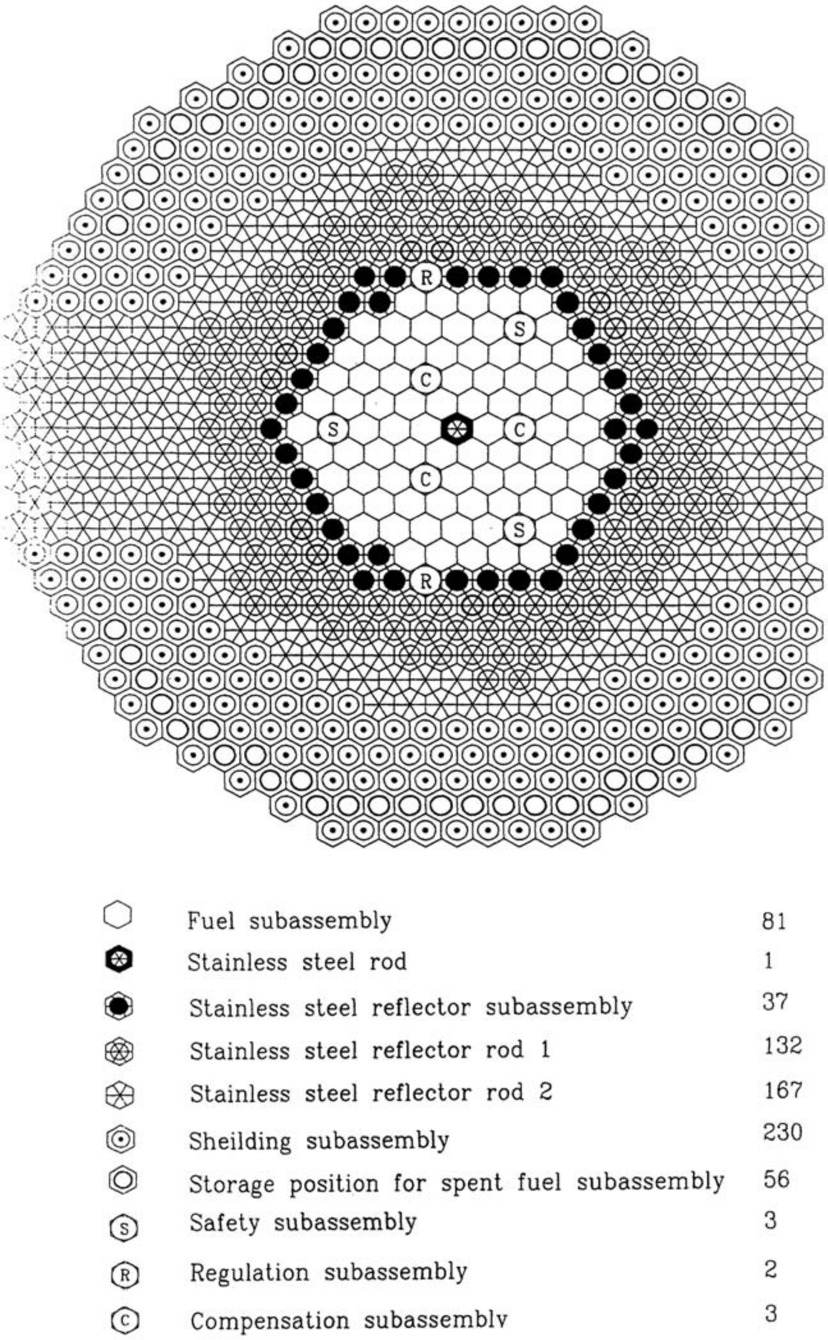
3.1.12. CEFR

The 65 MW(th)/25 MW(e) China experimental fast reactor (CEFR) is under construction. This is the first step in the Chinese fast reactor engineering development.

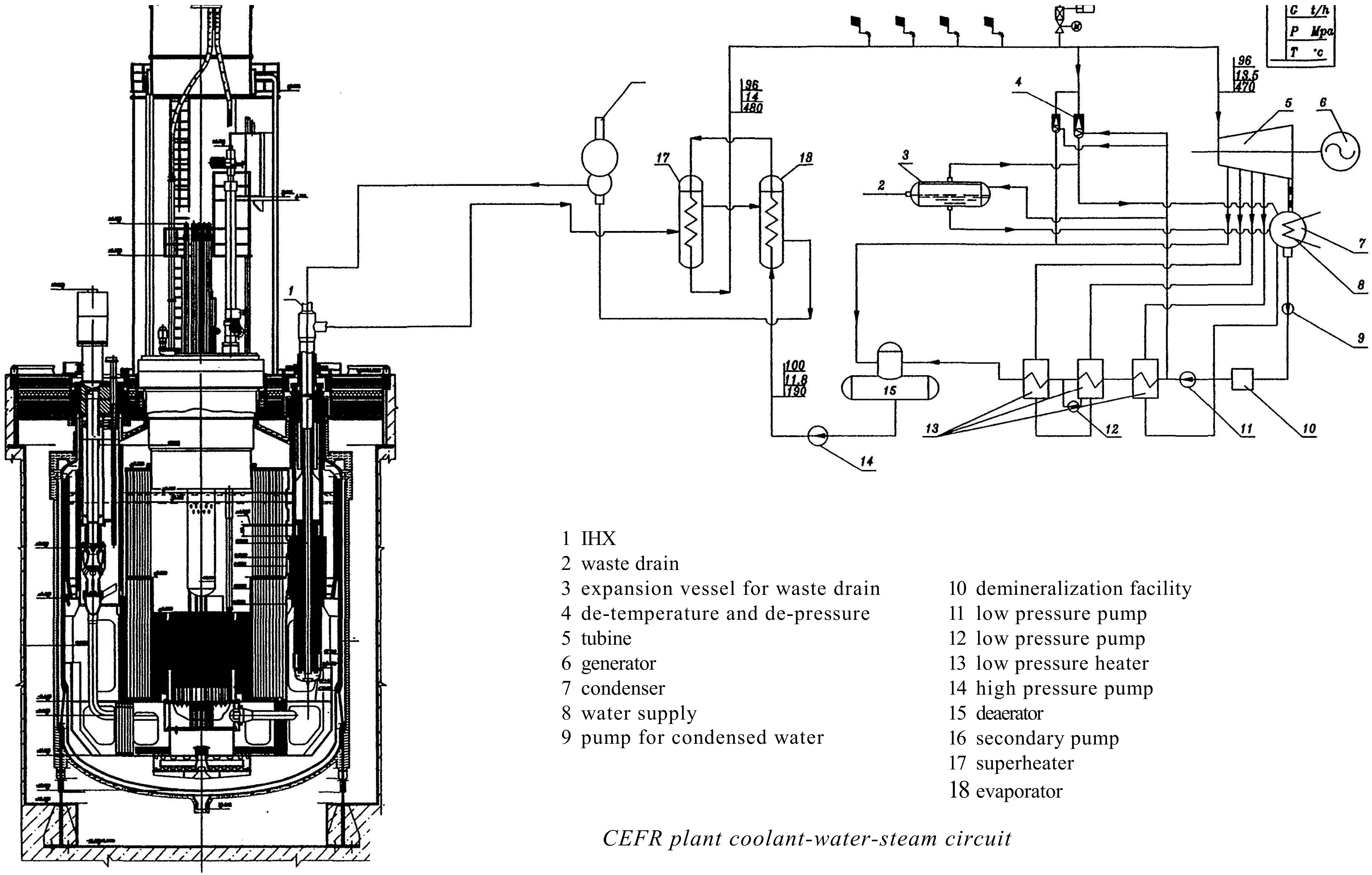
Ninety percent of the concrete constructions, including the main CEFR building, have been completed: hundreds components have been installed in the building. First criticality is foreseen in 2008 being evaluated taking as reference for the CPFR.

As a second step in the Chinese fast reactor technology development effort, a 600 MW(e) China prototype fast reactor (CPFR) is presently under consideration. The role of minor actinide transmutation is also being evaluated taking as reference for the CPFR.

China experimental fast reactor under construction, 2003/2004.



CEFR reactor core.



1 IHX
2 waste drain
3 expansion vessel for waste drain
4 de-temperature and de-pressure
5 tubine
6 generator
7 condenser
8 water supply
9 pump for condensed water
10 demineralization facility
11 low pressure pump
12 low pressure pump
13 low pressure heater
14 high pressure pump
15 deaerator
16 secondary pump
17 superheater
18 evaporator

CEFR plant coolant-water-steam circuit

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13.2. Demonstration or prototype fast reactors

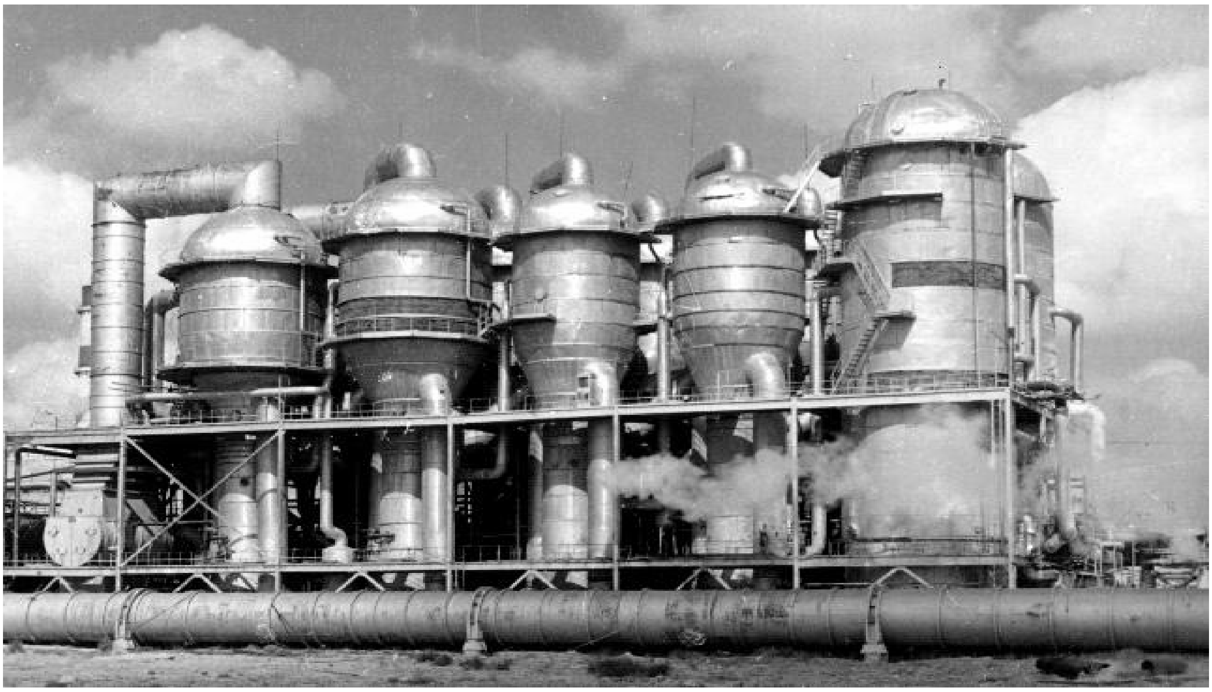
13.2.1. BN-350

The BN-350 plant history :

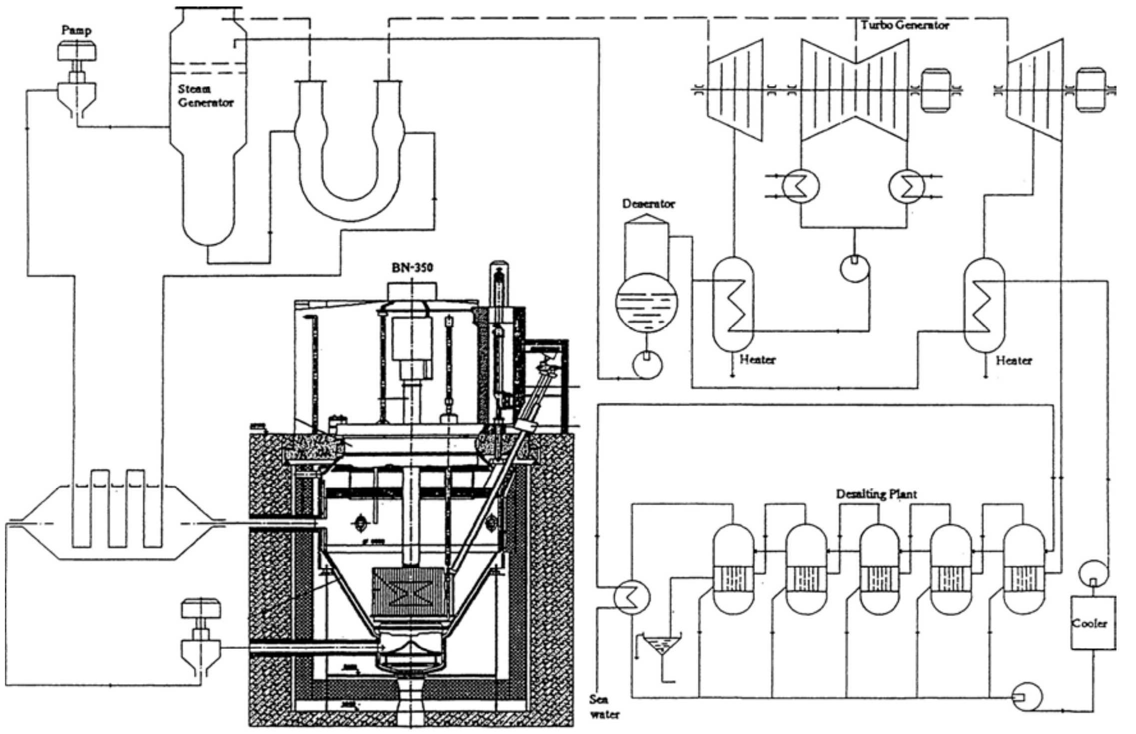
- 1965–1971: construction period;
- 29 November 1972:first criticality of the reactor;
- 16 July 1973: power startup of the reactor. The extended start up was due to loss of integrity events in four evaporators (detected by the appearance of hydrogen in the gas plenum) when the steam generators (SGs) were filled with water;
- end of 1973–February 1975: SGs repair;
- 1973–1975: operation at power levels up to 300 MW(th);
- from March 1975: operation at 650–750 MW(th) for electrical power generation [150 MW(e)] and sea water desalination (100 000 tons of desalinated water per day);
- from January 1996 to June 1998: operation at 420 MW(th), 50 MW(e), producing 45 000 tons of distilled water per day;
- April 1999: final shutdown.

For more than twenty-five years, the operation of the BN-350 reactor has promoted the exploration of the new industrial region of Kazakhstan, which is rather rich in natural resources.

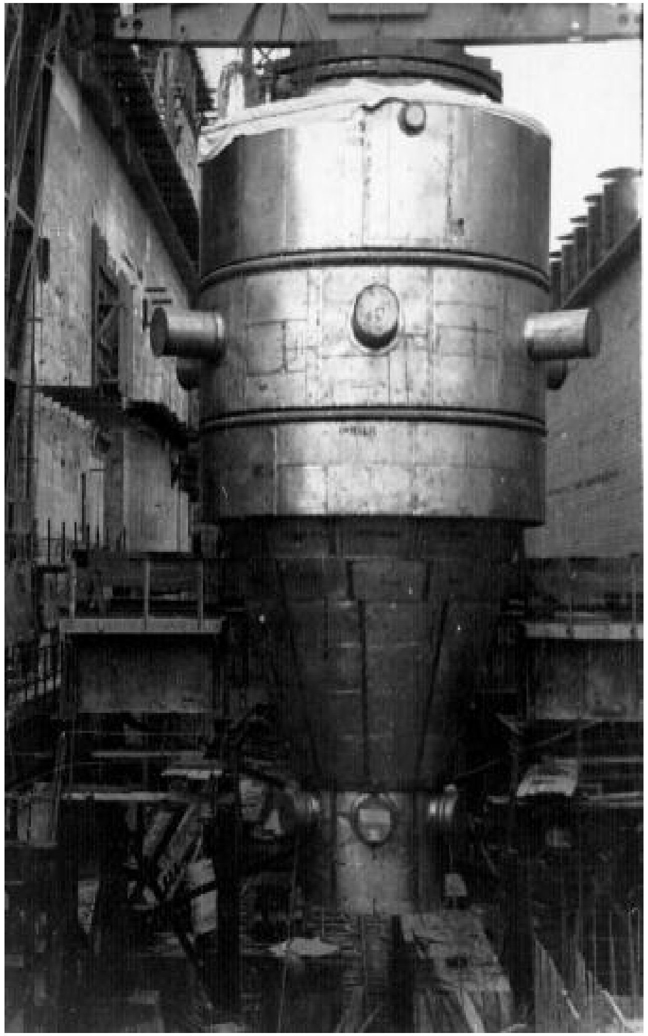
BN-350 nuclear power plant - a fresh water source in the Kazakhstan desert: overall survey.



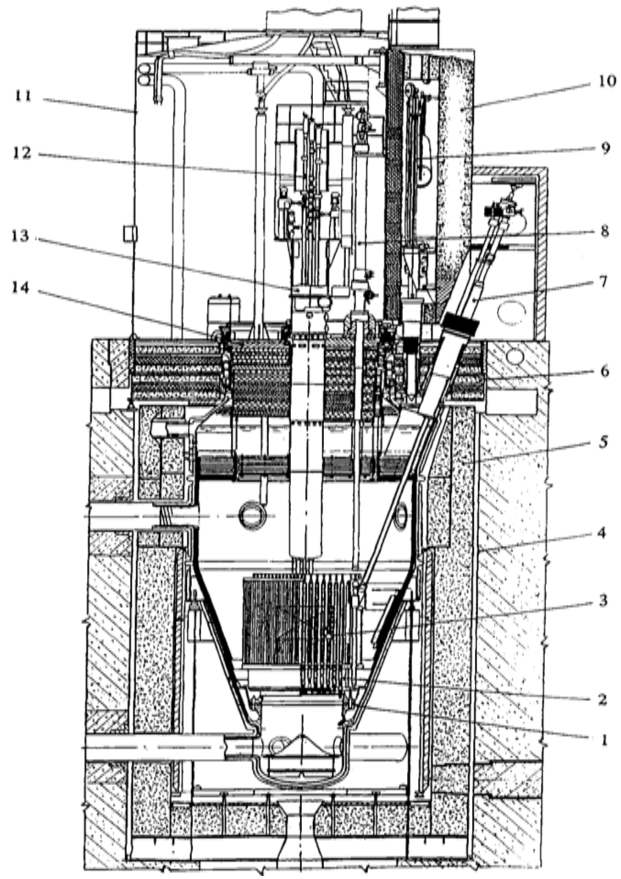
BN-350 nuclear desalting complex [~100 000 tons per day fresh water for a large city Aktau (Kazakhstan)].



BN-350 schematic diagram of the nuclear desalting complex.

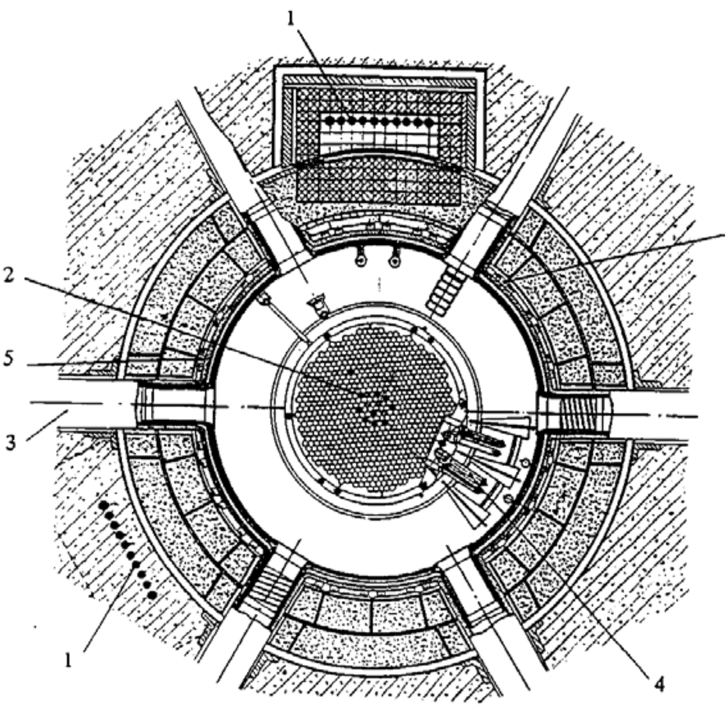


BN-350 reactor vessel (reactor montage).



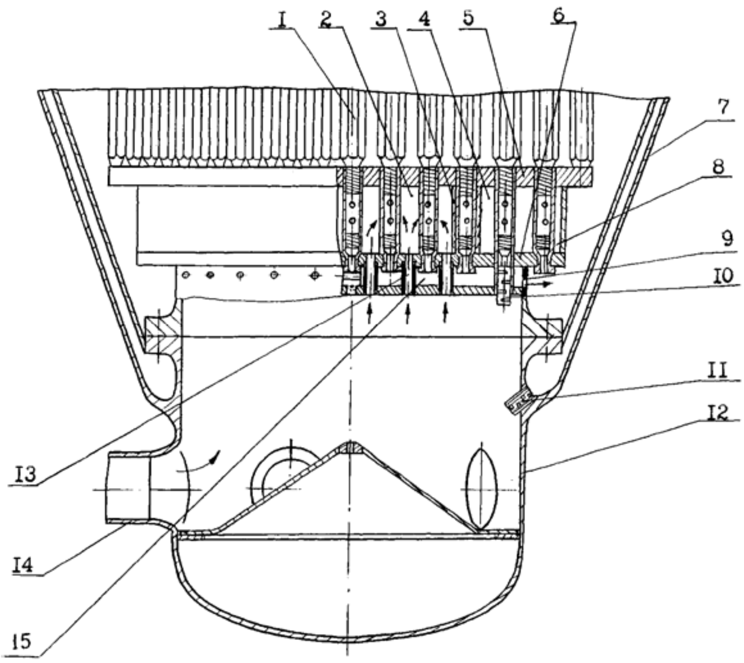
1-reactor vessel, 2-core diagrid, 3-reactor core, 4-reactor well liner, 5-lateral shield, 6-upper-stationary shield, 7-elevator, 8-refuelling mechanism, 9-FAa transfer mechanism, 10-fuel transfer cell, 11-protective dome, 12-control rod drive mechanism, 13-above core structure, 14-rotating plugs

BN-350 reactor assembly.



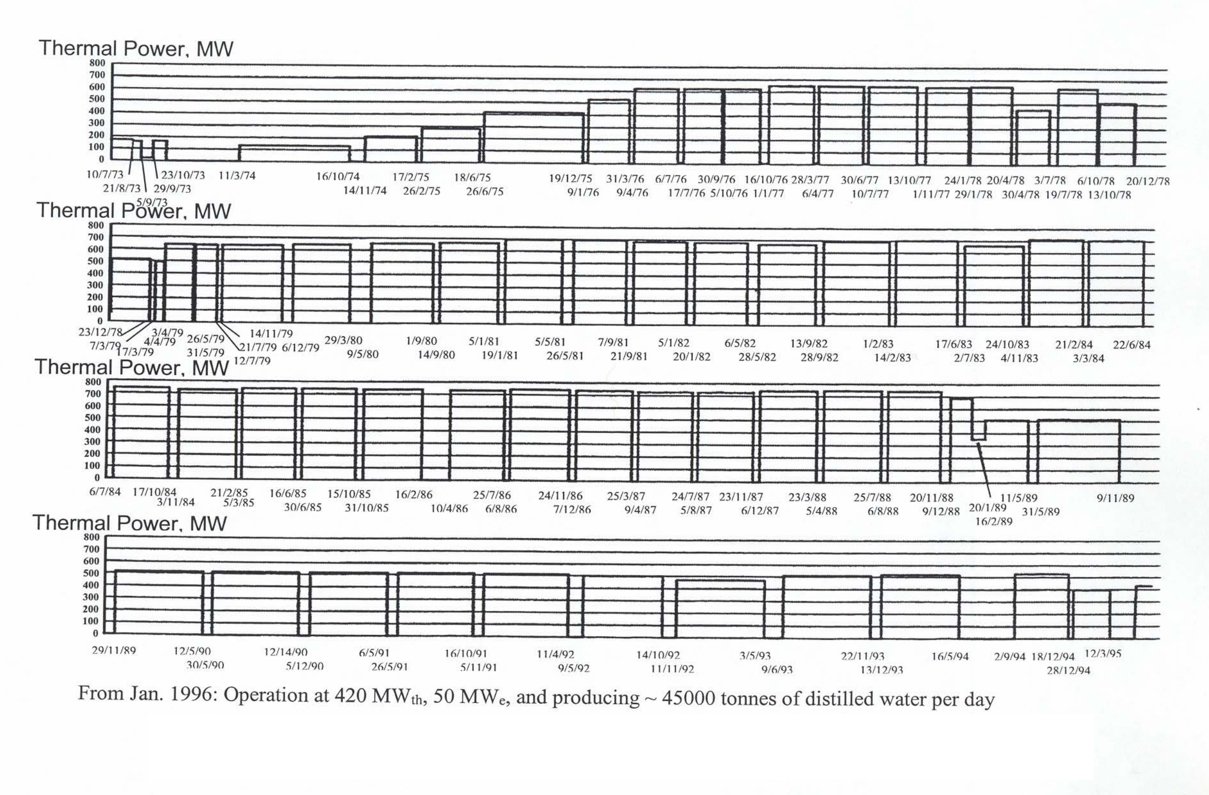
1-set of ionization chambers, 2-reactor core, 3-sodium outlet pipe, 4-elevator, 5-channels for additional ionization chambers

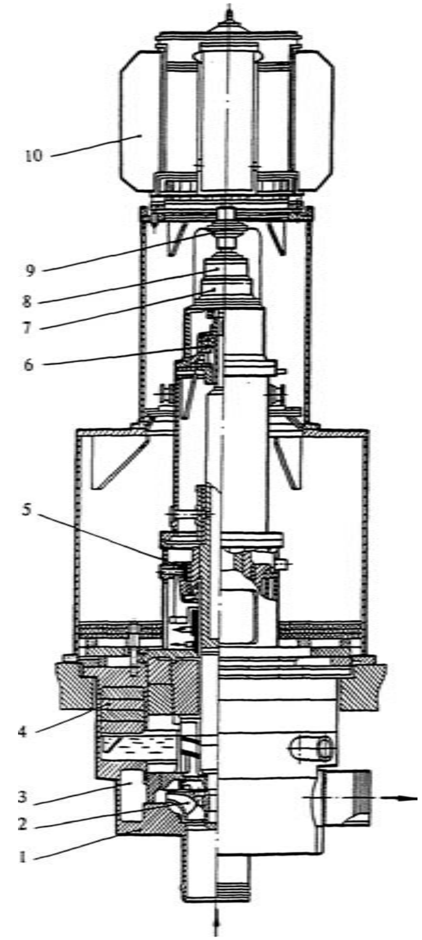
Reactor plan view (cross section).



1-fuel subassembly, 2-low pressure plenum, 3-partition, 4-low pressure plenum, 5-upper plate of the pressure plenum, 6-lower plate of the pressure plenum, 7-reactor vessel, l8-collector of sodium flowing from the lower spring sealing of the fuel subassemblies, 9-collector draining orifices, 10-low pressure plenum throttle, 11-throttle for the reactor vessel cooling sodium flow, 12-reactor inlet sodium collector, 13-high pressure plenum inlet orifices, 14-high pressure pipe socket, 15-low pressure collector

Elevation of the BN-350 diagrid and pressure plenum.

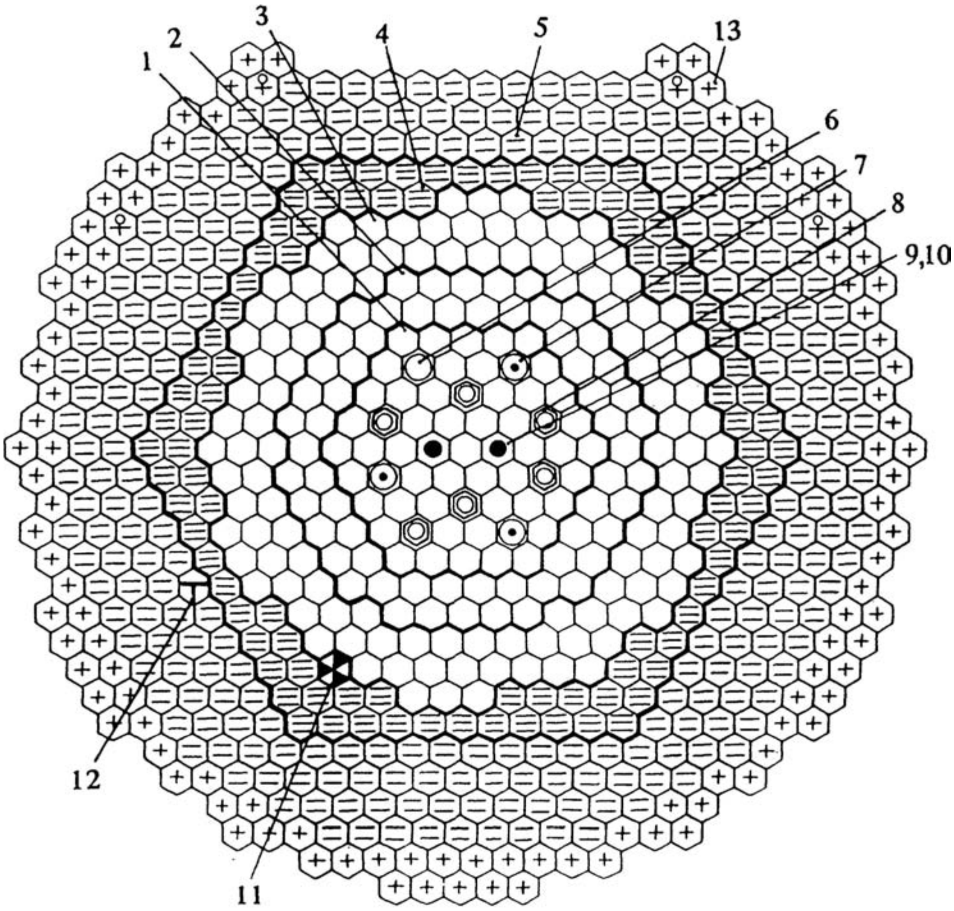




1-casing, 2-impeller, 3-pressure header, 4-biological shield, 5-radial bearing, 6-radial-thrust bearing, 7-repair seal, 8-face seal, 9-coupling, 10-motor

BN-350 specified power histogram (the gap between vertical bars: reactor shatdown for refuelling).

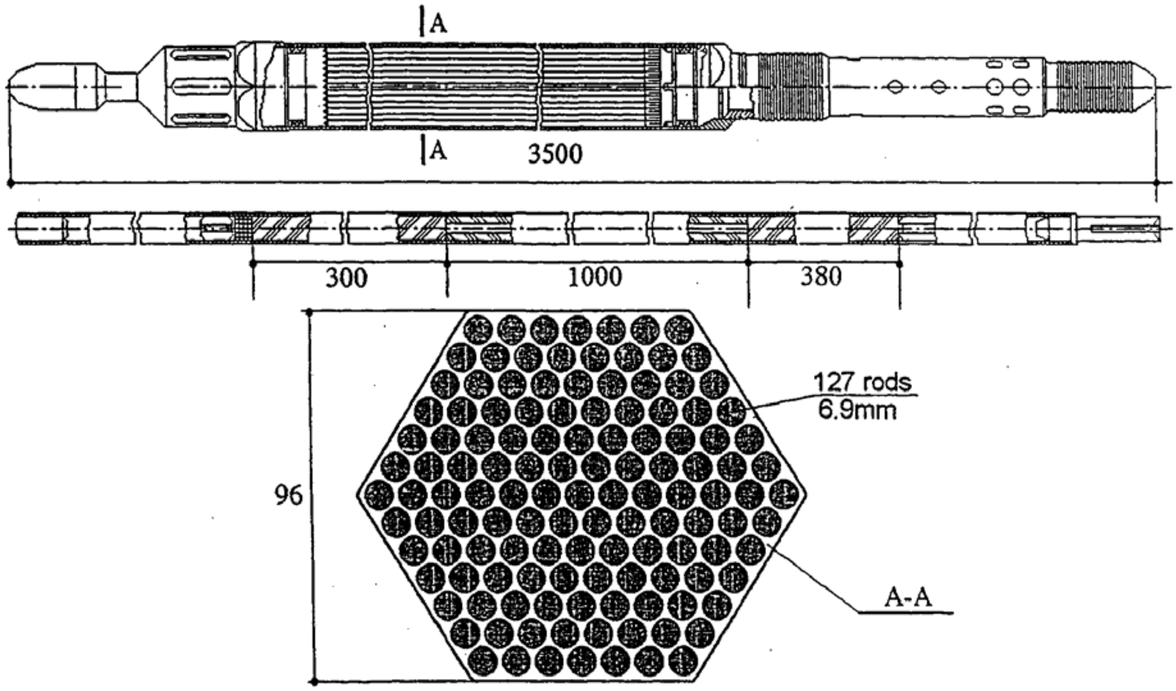
BN -350 reactor primary pump.



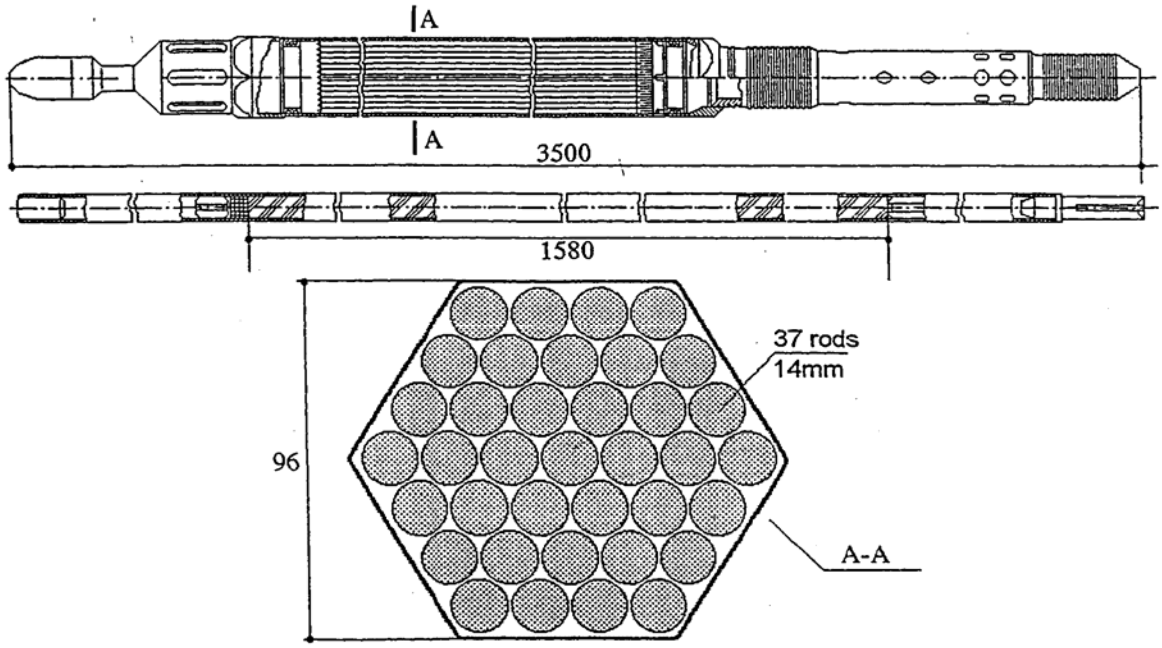
1-low enrichment fuel assemblies (FAs), 2-medium 1 enrichment FAs, 3-high enrichment FAs, 4-inner blanket FAs, 5-outer blanket FAs, 6-temperature effect compensator rod, 7-emerg protection rod and its guiding sleeve, 8-reactivity compensation rod and guiding sleeve, 9, 10-automatic control rod, 11-neutron source, 12-technological assembly, 13-core FAs in-reactor storage

BN-350 core and blanket layout[2].

[2] During the initial period of the reactor operation until, when the first design core (fuel rod of 6.1 mm OD) was used, large number of fuel failures (loss of clad integrity events-design/calculation error) occurred Therefore the second design of core fuel assembly was developed with fuel rods of 6.9 mm OD. This advanced core provided for increased fuel burn up and more reliable operation of the fuel rods, mainly due to the following improvements: (i) the gas plenum height in the fuel rod was increased at the expense of integration in one clad tube (6.9×0.4 mm) of core and axial blankets material (fissile and fertile) and reduction of the lower blanket height; (ii) the fuel assembly duct material Cr18Ni10Ti (austenitic steel) was replaced by stabilized austenitic steel Cr16Ni11Mo3 in a heat-treated state; (iii) the coolant pressure in the middle plane inside the duct was diminished by approximately 35% resulting in a decrease in duct deformation by radiation-induced creep; iv) the power distribution over the core radius was flattened by the incorporation of a medium fuel enrichment (21%) zone between the existing core zones with “low” (17%) and “high” (26%) enrichment of fuel, resulting in a decrease of the fuel rod specific heat rating.

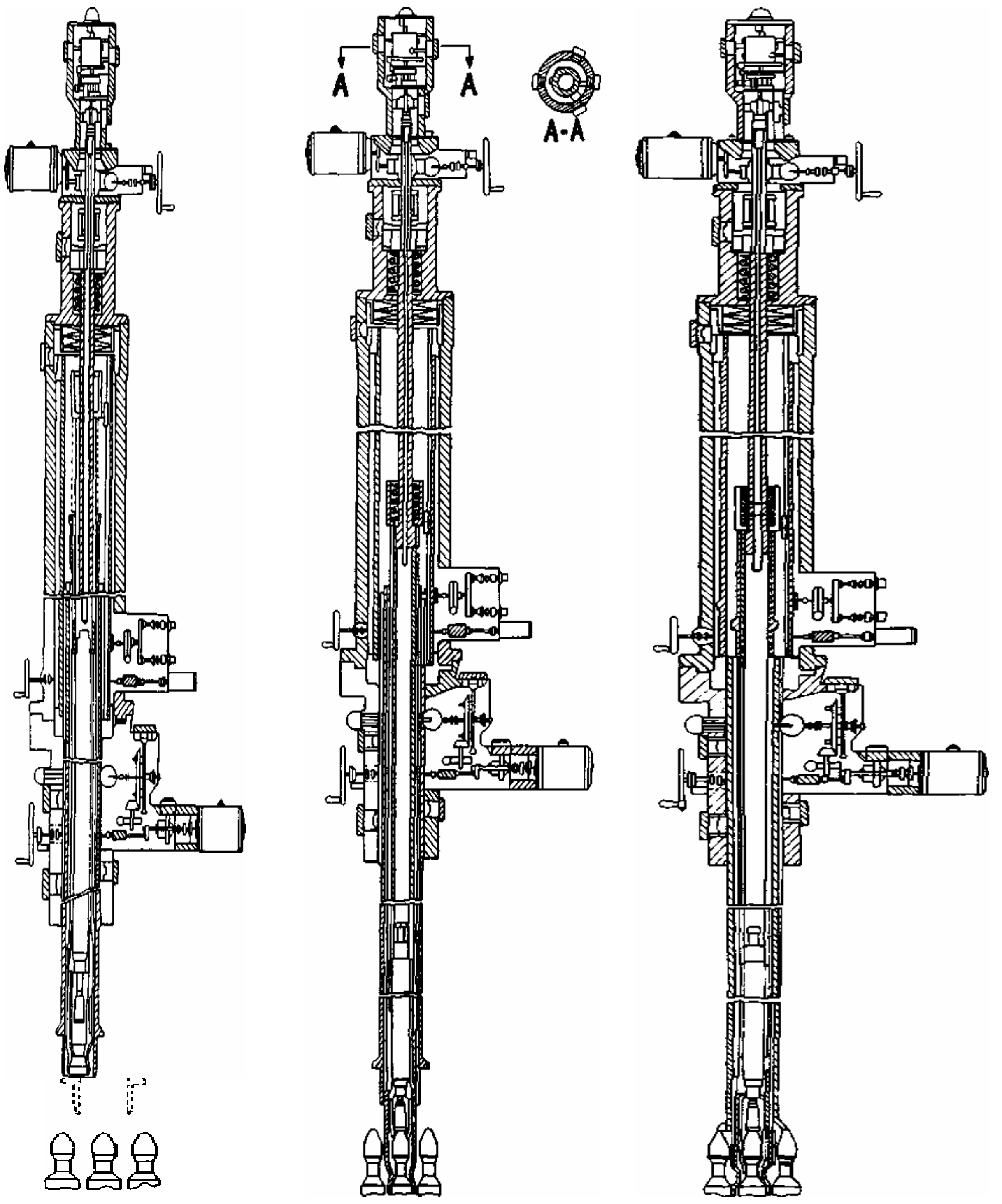


a)

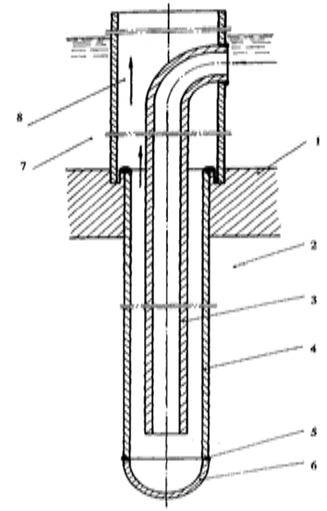


b)

BN-350 active zone and blanke assemblies and rods.

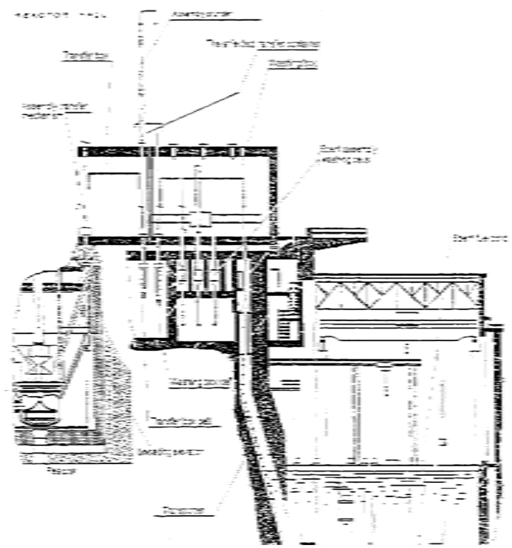


BN-350 refuelling mechanism-mode of operation.



1-tube sheet, sodium, 3-downcomer tube, 4-heated outer tube, 5-lower weld seam, 6-bottom of Field tube[3], 7-boiler water, 8-steam-water mixture outlet

BN-350 evaporator re-entrant tube-location of leaks.



BN-350 spent subassemblies unloading scheme principle[4].

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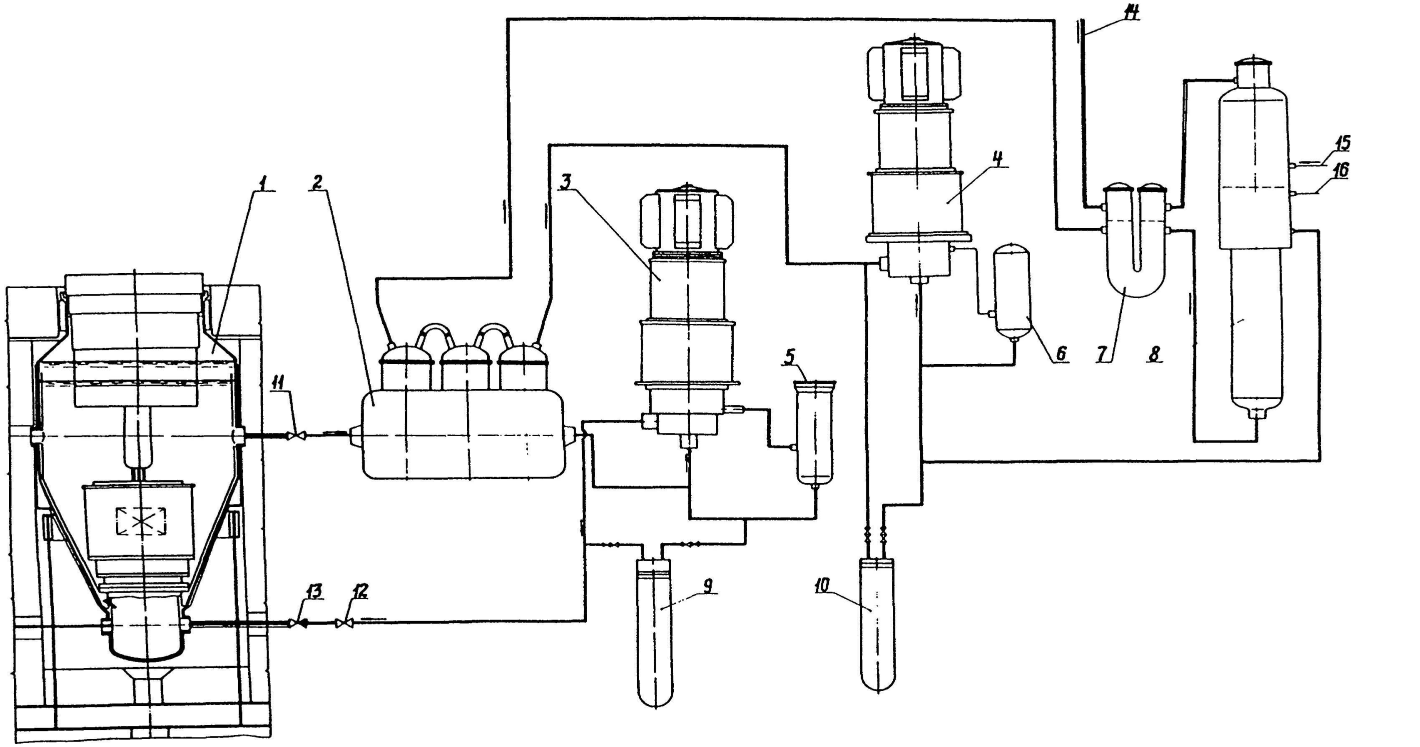
[3] In the BN-350 reactor, there was an incident (1976) causing the fuel storage drum failure. The cover (plug) of the storage drum included concrete filler. In the course of heating, vapor of crystallization water from the concrete penetrated into sodium-potassium alloy, filling the drum, and, upon interaction with this alloy, chilled the drum. BN-350 personnel developed special technology to dissolve the formed conglomeration using water-oil emulsion, and as a result of its implementation, fuel subassemblies stored in the drum were set free and placed in the water pool. A special lead-shielded transfer container was designed and manufactured for transporting spent fuel assemblies from the transfer cell to the washing cell

[4] The initial period of reactor plant operation was characterized by unreliable operation of the SGs. Numerous leaks occurred in the re-entrant evaporator tubes. Metallographic examination of a great number of tubes showed the presence of microcracks in the tube-to-bottom weld joints. Mechanical deformation of the tube bottoms during cold stamping were acknowledged as the most probable cause of the microcracks. Growth of the microcracks could occur under the effect of internal stresses arising during welding the bottoms to the tubes and under cyclic thermal loads during evaporator operation. Outer tubes of 32×2 mm (OD×wall thickness) were replaced by 33×3 mm tubes with machined bottoms.



1-reactor, 2-intermediate heat exchanger, 3-reactor coolant pump, 4-secondary coolant pump, 5, 6-pump leakage drain tanks, 7-steam superheater, 8-evaporator, 9, 10-filter-traps, 11-ND 600 gate valve, 12-ND 500 gate valve, 13-check valve, 14-main steam line, 15-feed water, 16 gas system line

BN-350 schematic flow diagram of sodium circuits.

13.2.2. Phénix

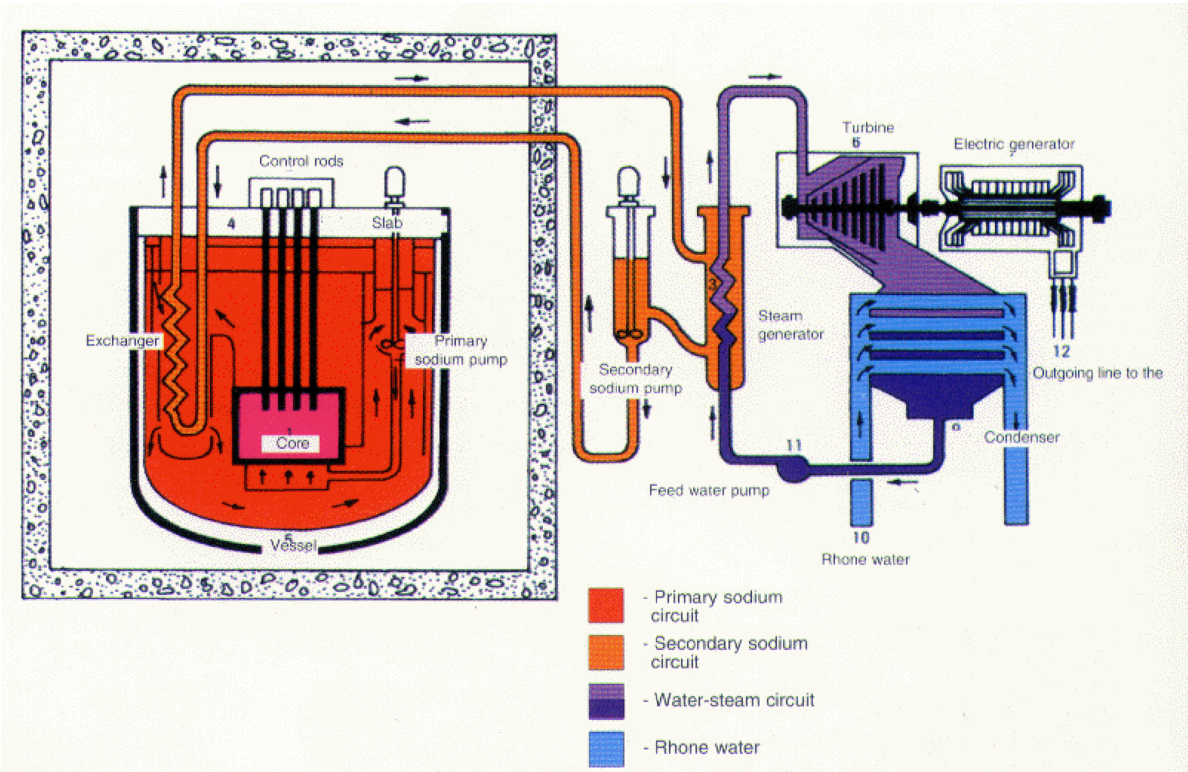
The reactor plant Phénix with 255 MW(e) [(565 MW(th)] nominal power rating, was firstly connected to the electricity grid on 13 December 1973; the nominal power was reached on 12 March 1974, 18 days ahead of plan.

The NPP was generally operated at the power tolerated by the reactor and equipment, with comparatively high load factor. Phenix has currently provided about 100 000 hours of grid-connected operation representing 3 900 equivalent full power days at operating temperatures of 560°C for the reactor hot structures. The plant has achieved the objectives of demonstration of fast breeder reactor technology which were set at the time of construction. The Phénix reactor has operated with a gross thermal efficiency of 45%.

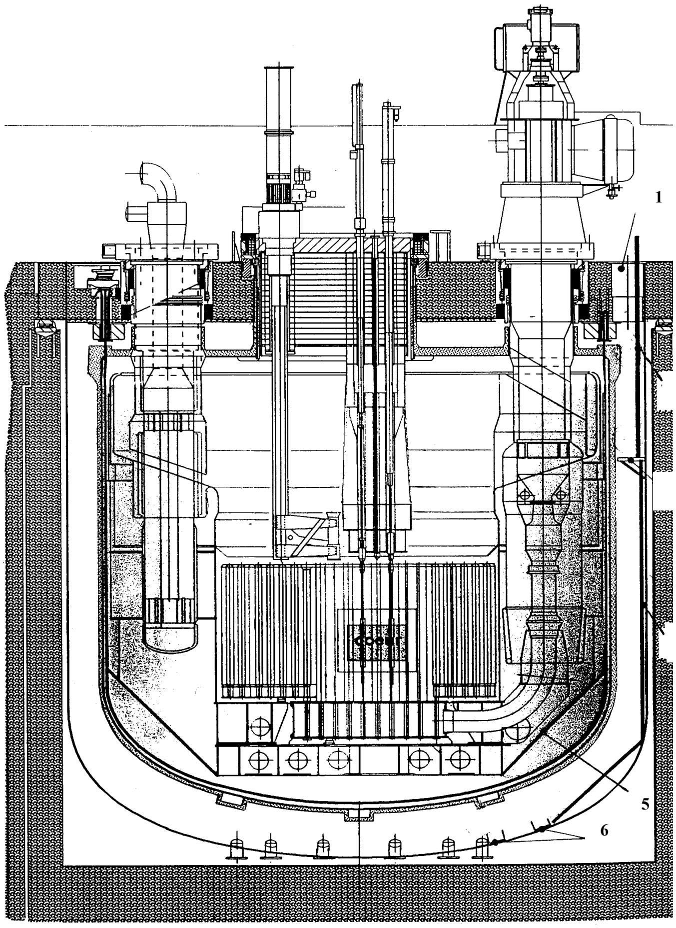
From 1992, the role of Phénix as an irradiation facility has been emphasized, particularly in support of the CEA R&D programme in the context of line 1 of the 30 December 1991 law on long-lived radioactive waste management. This programme was further strengthened in 1998 to compensate for the shutdown of Super-Phénix. It involves transmutation of minor actinides and long-lived fission products. Since 1993, the reactor power has been limited to 350 MW(th) [145 MW(e)] on two secondary loop operations

Phénix overall survey.

Phénix power plant.



Phénix power plant flow sheet.



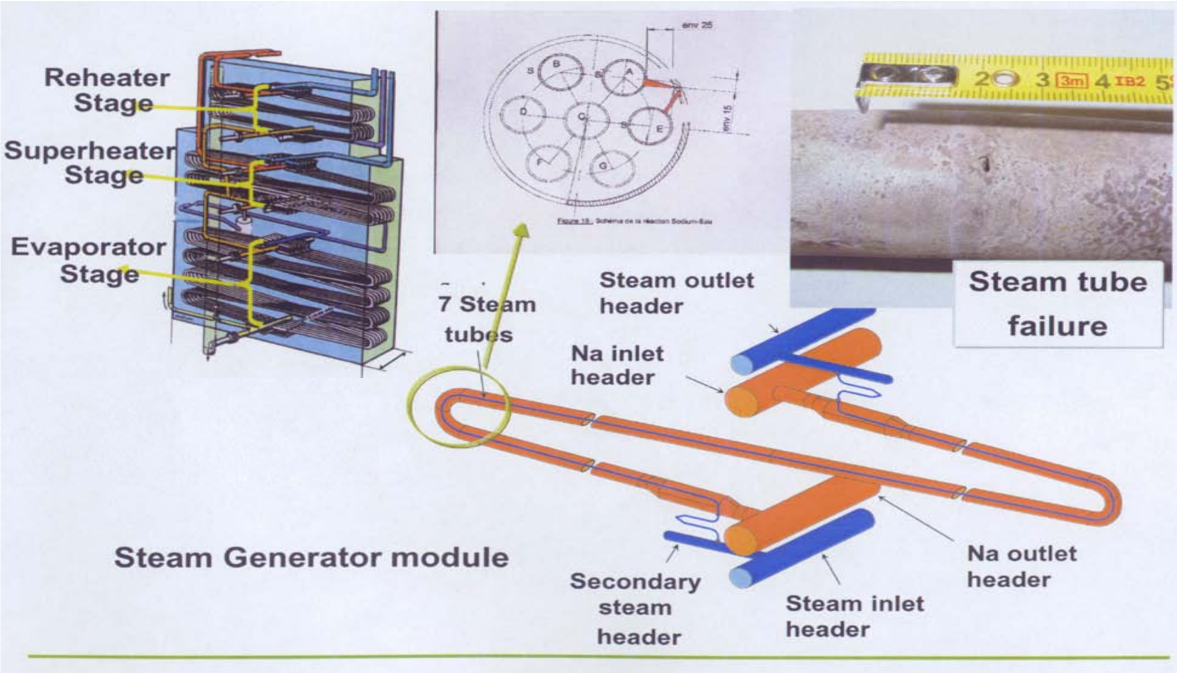
1-manhole (Ǿ = 500 mm), 2-movable ladder, 3-catwalk, 4-fixed ladder, 5-conical skirt, 6-cable tracks

Elevation through Phénix primary circuit.

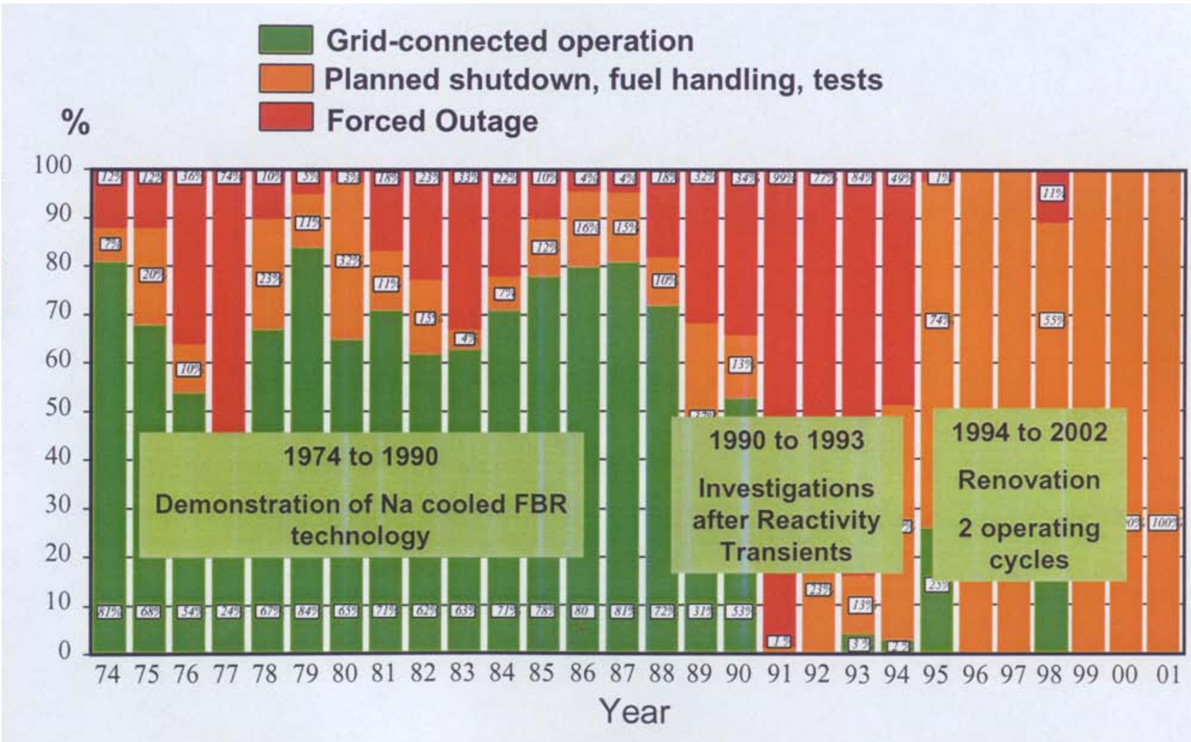
Main events	74	75	76	77	78	82	83	84	86	88	89	90	98	00	03
IHX secondary circuit sodium leaks			X X	X	X			X X		X			X	X	
Steam generator leaks		X[1] X[1]	X[1] X[1]			X[2] X[2]	X[2] X[2]								X[2]
Secondary circuit main pipe sodium leaks	X	X X	X						X X	X					X[3] X[4]
Negative reactivity shutdowns			X		X						X X X		X		
Grid-connected operation time, %	81	68	54	24	67	62	63	71	80	72	31	Investigation after reactivity transient, renovation, test and operation			

X[1]-water leaks into the evaporator box space through the subheader's shell wall;
X[2]- sodium-water reaction;
X[3]-leak in the bellow of the sodium purification system valve;
X[4]-leak in the electromagnetic pump of the steam generator hydrogen detection circuit.

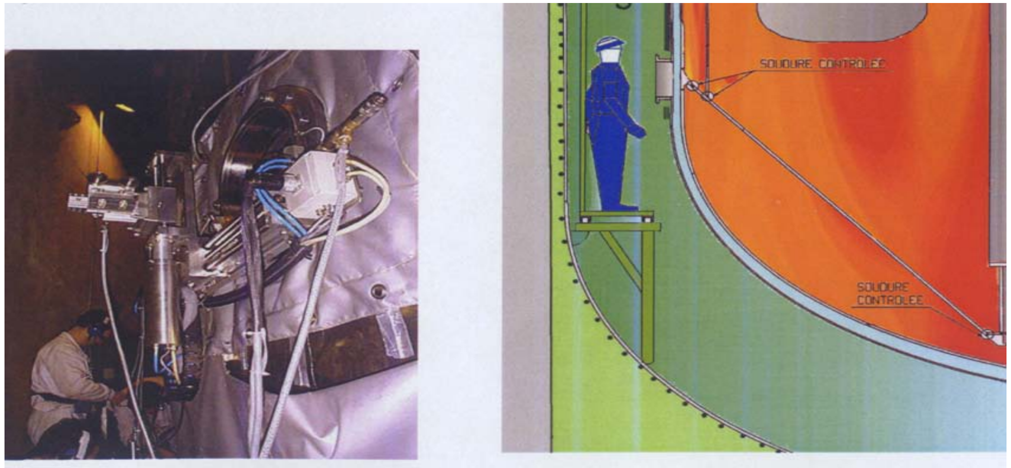
Phénix main events and the grid-connected operation time in the relevant years.



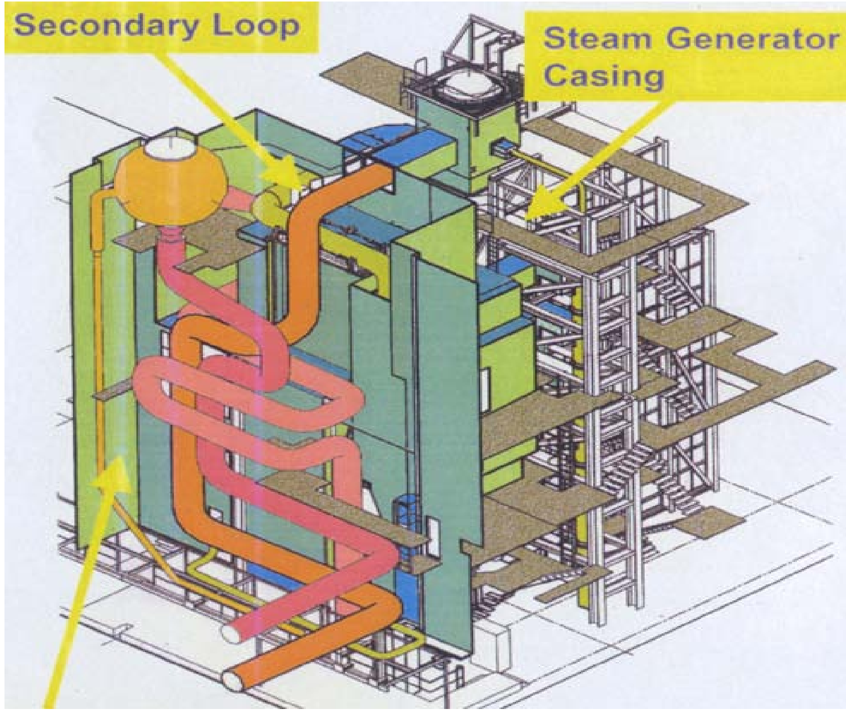
Phénix SG tube failure, steam into sodium leak (2003).



Phénix operating histogram.



Phénix reactor conical skirt welds ultrasonic inspection.



Sodium zone partitioning

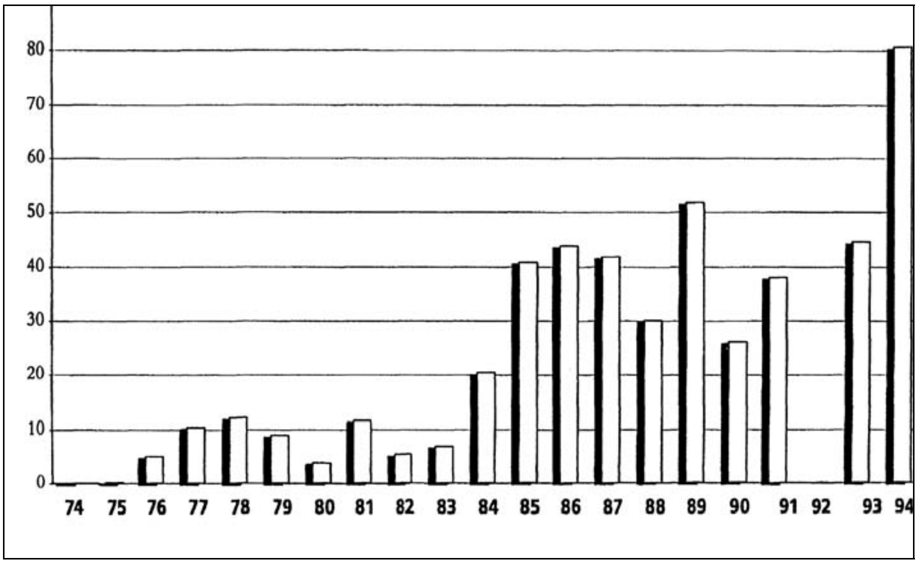
Protection of the Phénix steam generator building against large sodium fires.

13.2.3. PFR

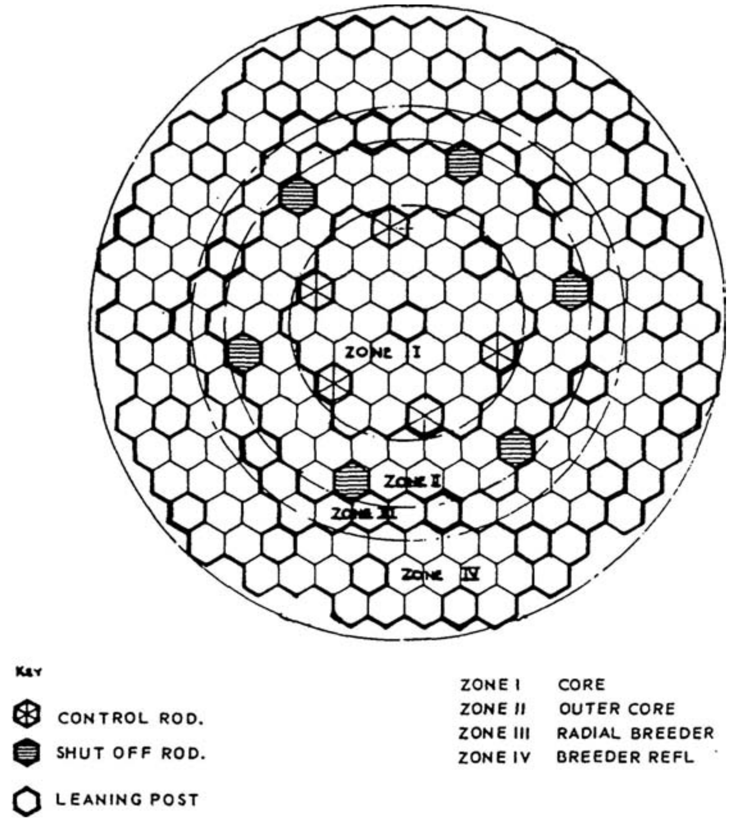
The approach to criticality began in February 1974 and was achieved in March 1974. Physics parameters for the core and for the reactivity effectiveness of, and interaction between the control and shut-off rods agreed with prediction within the expected uncertainties. The hot dynamic test was completed in June 1974.

The operating history of the PFR power plant can be divided into two phases. For the first ten years electrical output was limited, mainly because of a series of leaks in the steam generator units, and the highest load factor in any year was 12%. After 1984, with the steam generator weld problems dealt with, plant performance improved and in the final year of operation the load factor was about 57%. In 1985 PFR was able to operate, for the first time since the commissioning period, with a full set of steam generator units. In the second decade of operation there was one major outage. In this period, until 1991, the reactor and primary circuit equipment were responsible for only a very small fraction of unplanned outage time. On 25 June 1991, a leakage of oil from a bearing of one of the primary pumps into the primary sodium led to interruption of reactor operation for 18 months. PFR was started up for the last time on 14 January 1994.

PFR overall survey.

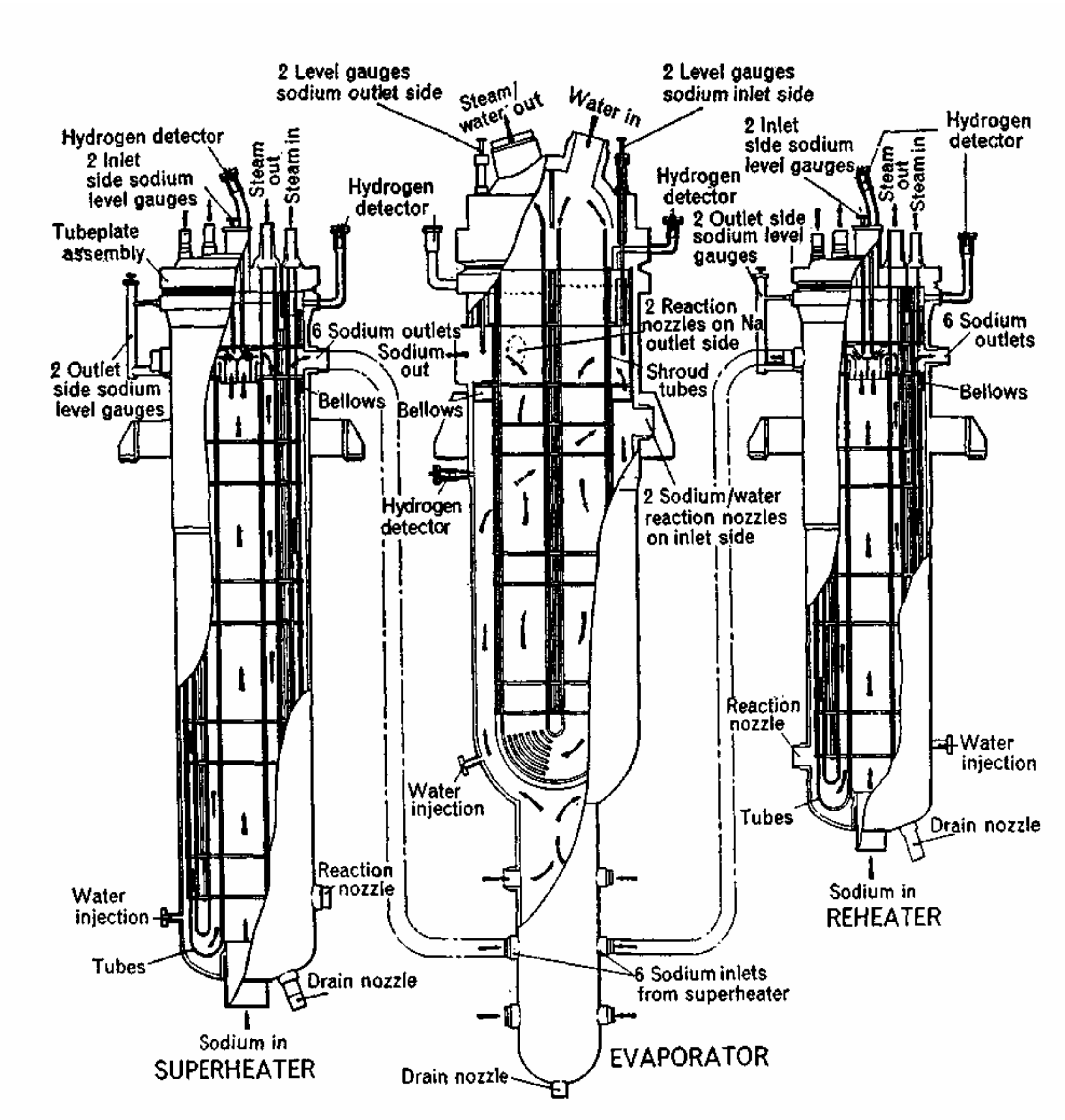


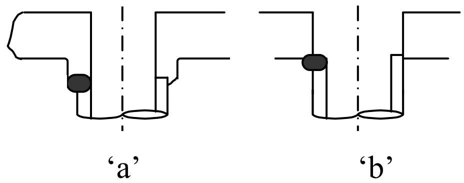
PFR annual load factors 1974-1994 (1994 for three months' operation only-before decommissioning), %[5]



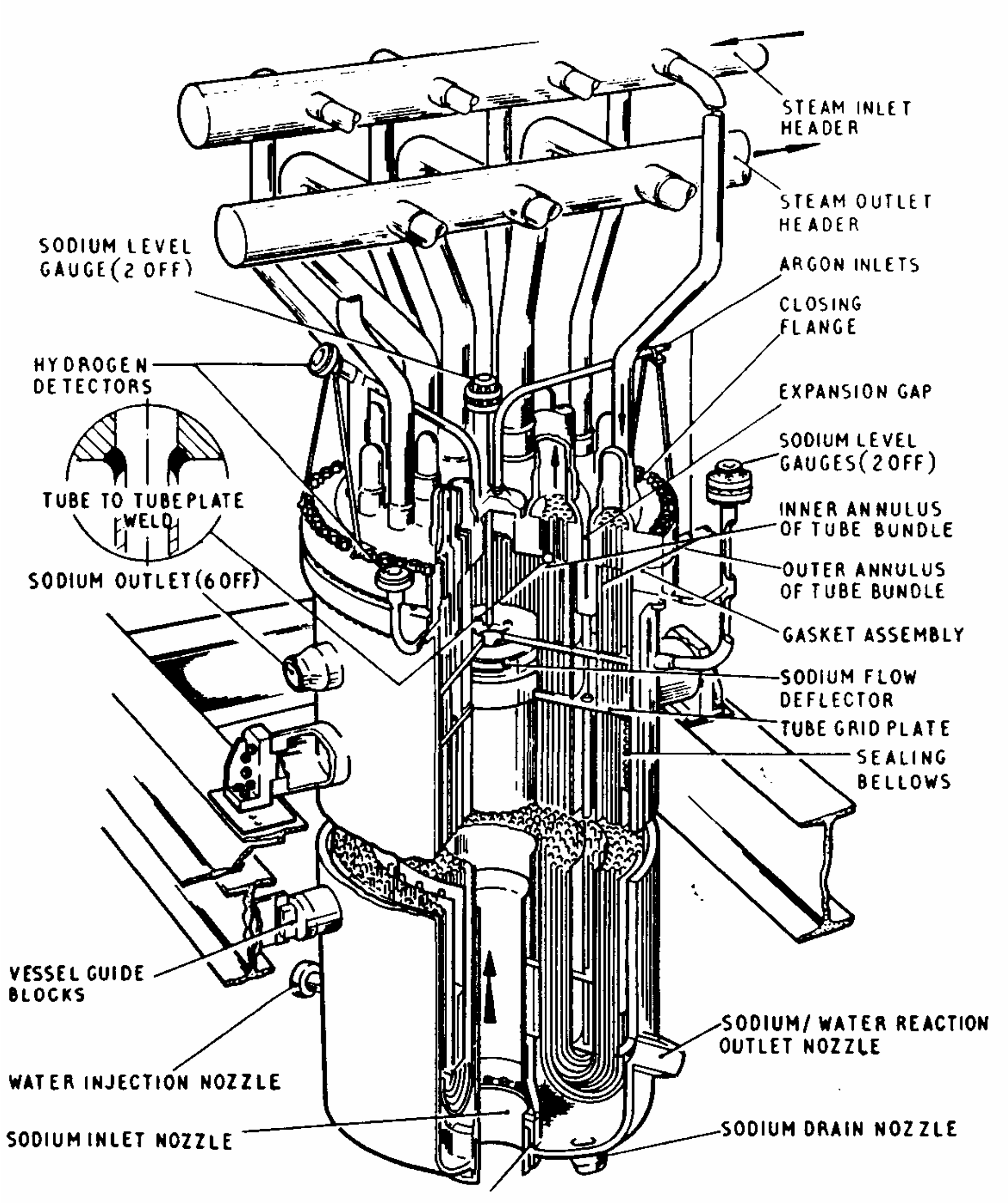
PFR core.

[5] In 1985, PFR was able to operate, for the first time since the commissioning period, with a full set of steam generator units. In the second decade of operation there was one major outage, in 1991/92. In this period, unto 1991 the reactor and primary circuit equipment were responsible for only a very small fraction of unplanned outage time; on 25 June 1991, a leakage of oil from a bearing of one of the primary pumps into the primary sodium led interruption of reactor operation for 18 months. PFR was started up for the last time on 14 January 1994.



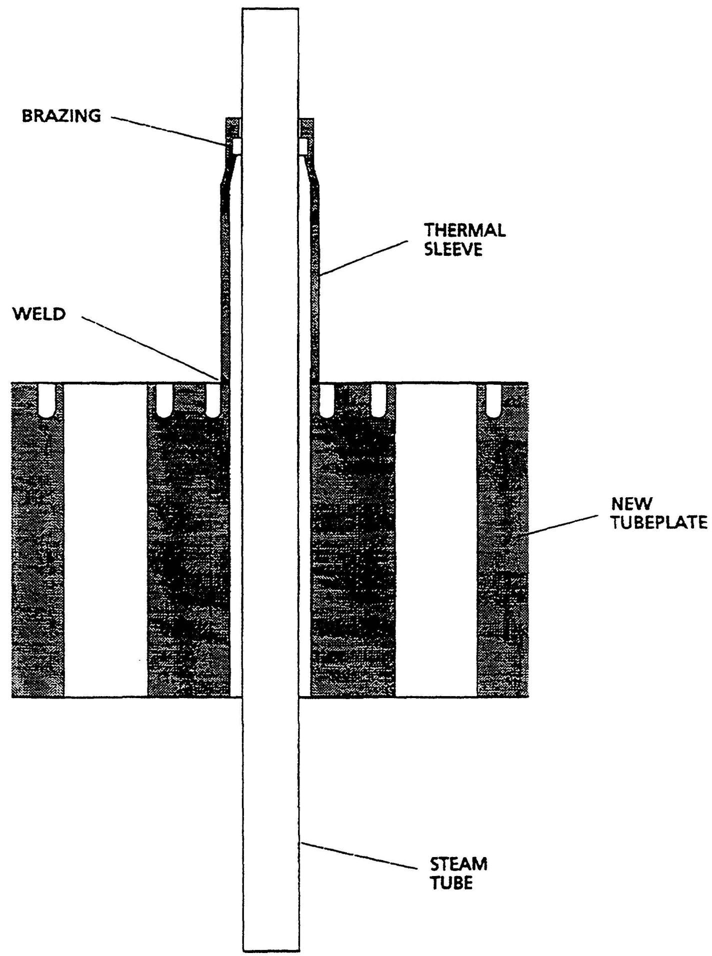


PFR steam generator (two types SG tube-to-tube plate weld joint designs have been studied for PFR SG: traditional, e.g., for fossil boiler ‘a’ and a new ‘b’(was used in PFR SG).

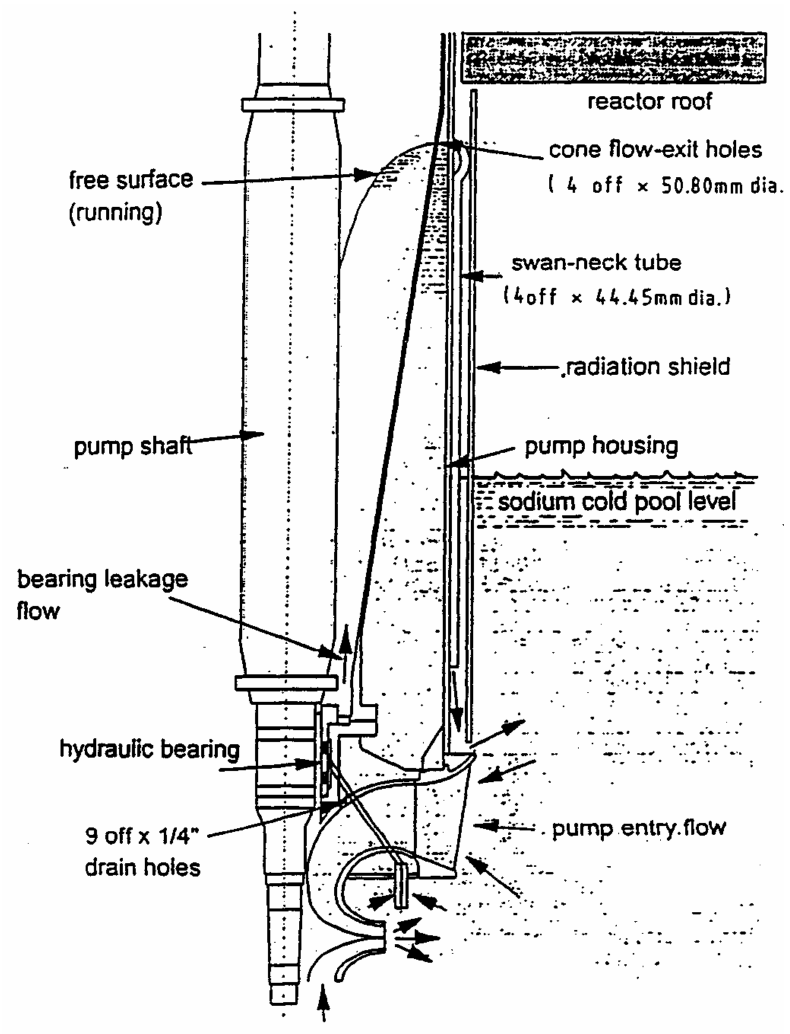


PFR superheater[6].

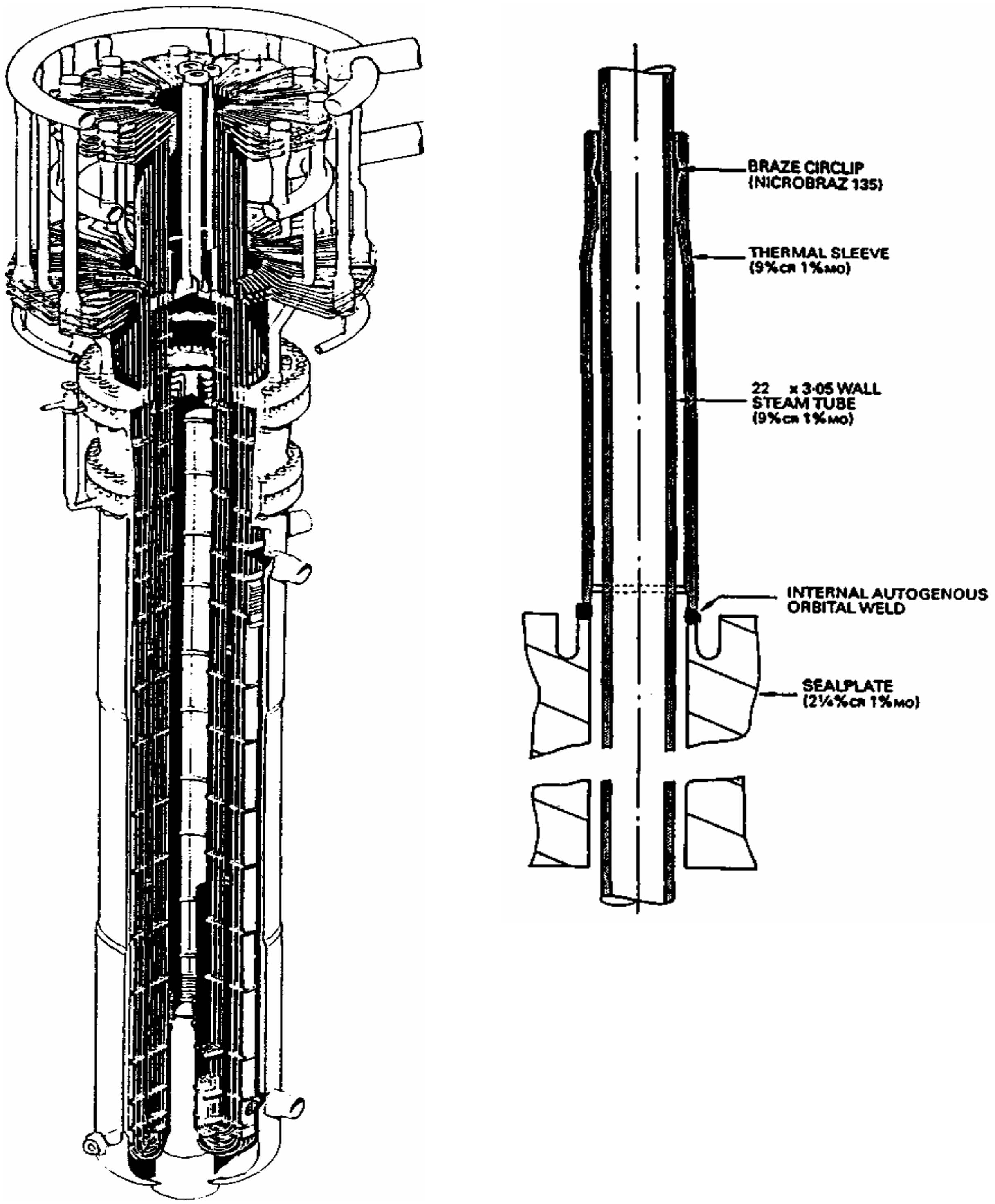
[6] A total of 37 leaks was experienced in PFR SG units in the period 1974 to 1984 with 33 of these occurring in evaporators, 3 in superheaters and 1 in a reheater. All the leaks originated at the welds between the tubes and the tube plates associated with cracking of the tube-to-tube plate welds. These were hard and had high residual stresses because there was no post-weld heat treatment. The type of direct tube-to-tube plate weld (the ‘butt/fillet' weld adopted initially at PFR, which could not be heat treated after manufacture, are being avoided in future fast reactor SGs.



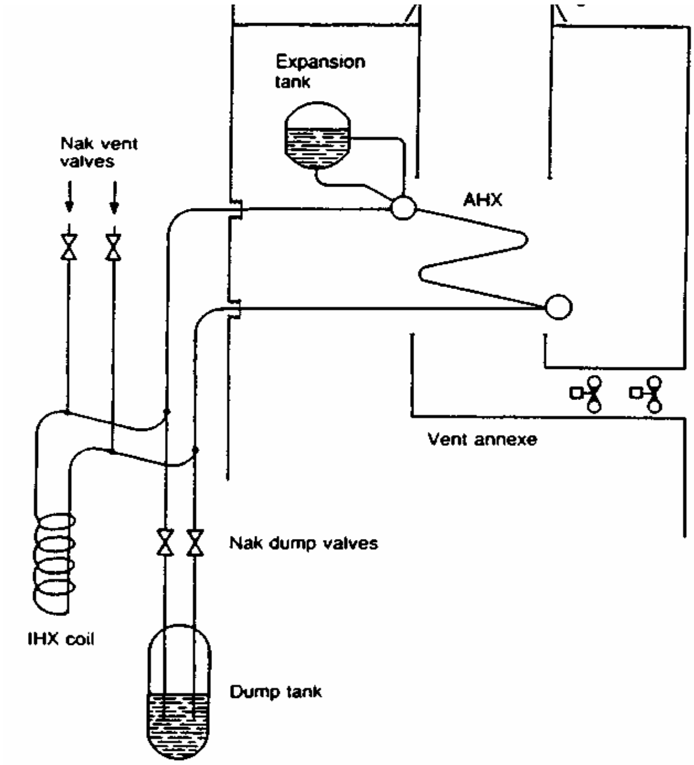
PFR tube/tubeplate junction of the replacement superheater and reheater tube bundles.



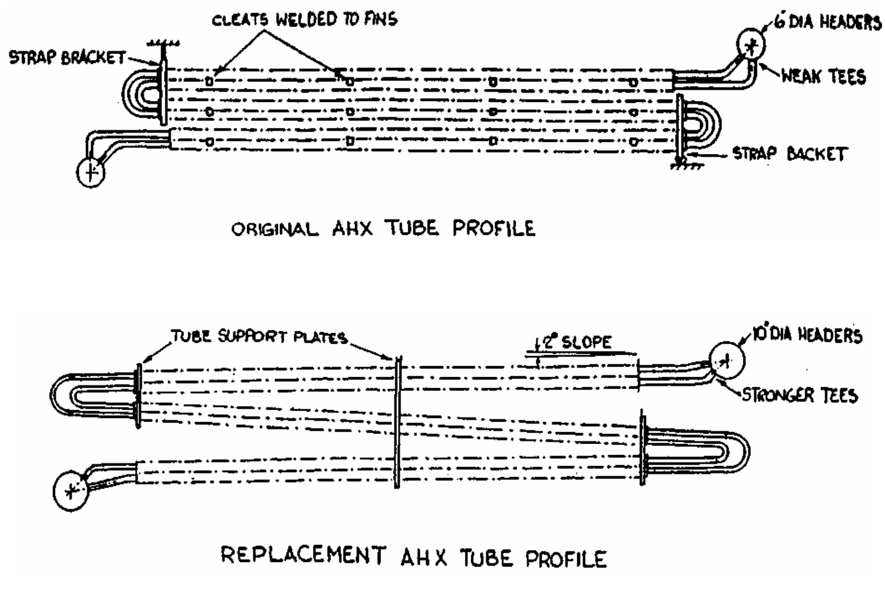
Detail of a PFR primary sodium pump housing.



PFR replacement reheater tube bundle, reheater thermal sleeve.



PFR thermal siphon decay heat rejection loop.



The original and replacement PFR thermal syphon air heat exchangers.[7]

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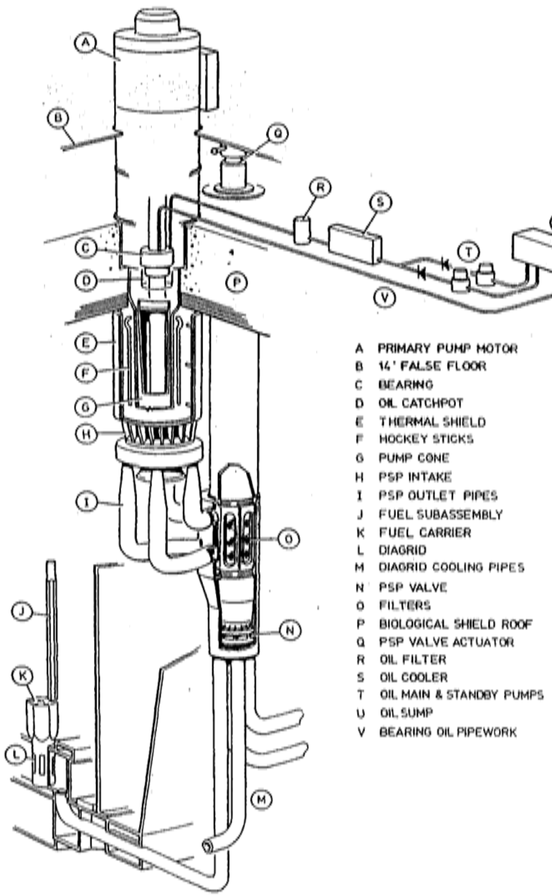
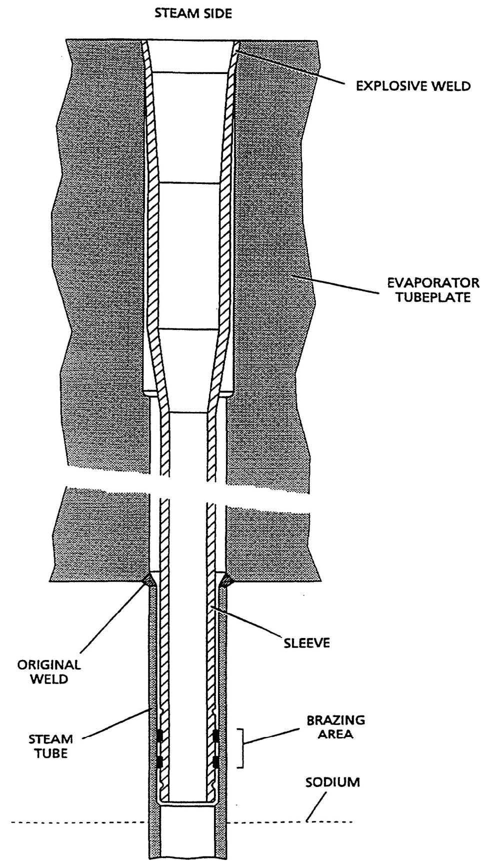
[7] In the decay heat removal system of PFR, leaks were detected in the air heat exchange (heat exchange between the NaK circuit and the atmosphere). These were associated with anomalous temperature differences between tubes in the heat exchanger, due to aspects of the design together with difficulties in achieving filling with NaK. The following changes were made: 1) the 2° slope was given to the tubes to give better venting and drainage; 2) Each tube was given individual support; 3) The tube-header connections were reinforced; 4) Larger diameter headers were fitted to give better NaK distribution.



PFR primary sodium pump (PSP) and its associated valve and filter assembly[8].



PFR sleeving to repair the evaporators.

[8] The PSP bearing oil spilled into the reactor sodium experienced during PFR operation resulted an 18-month had been spent in cleaning the primary sodium and in making preparations for examination of the three primary pump filters and the inlet filters on some of the fuel assemblies which had shown temperature increases at the time of the spillage The EFR design was changed following the PFR oil ingress incident by the introduction of the innovative magnetic bearing and ‘ferro-fluid’ seals to eliminate oil completely and remove the potential hazard of its ingress into the sodium.

13.2.4. BN-600

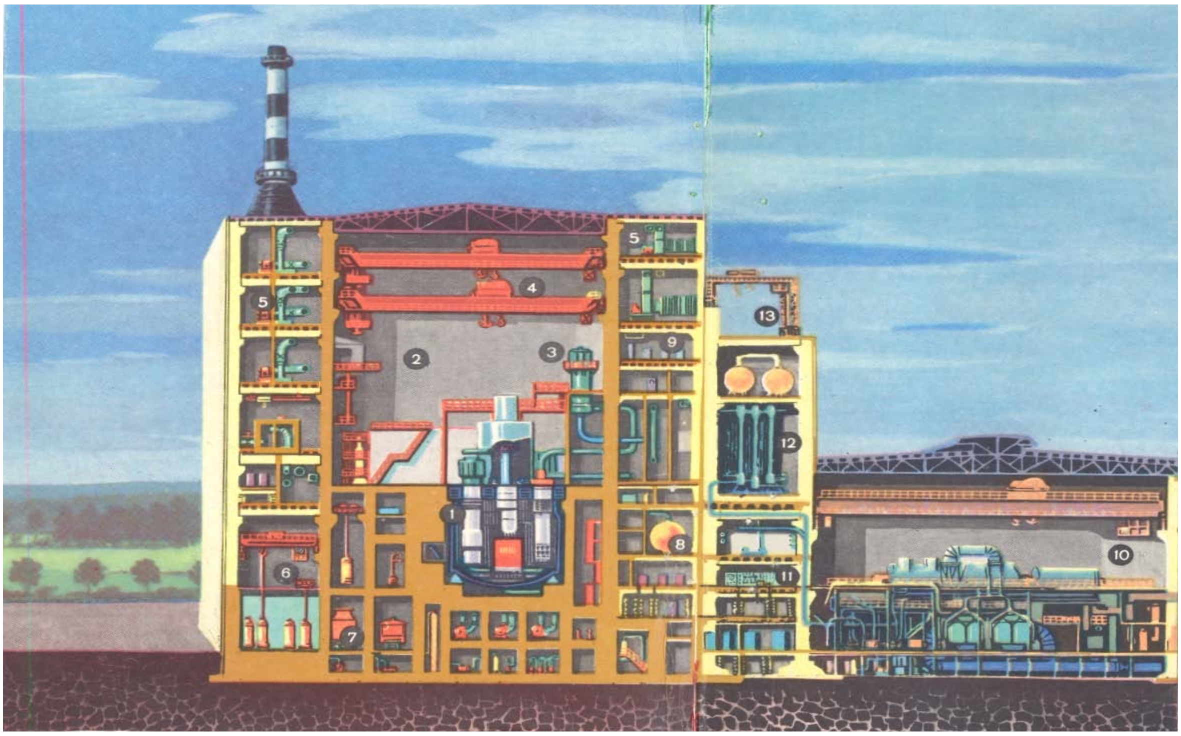
BN-600 has been operating since 1980 as the Beloyarsk-3 nuclear power plant.

First criticality was reached on 26 February 1980. The basic result of the physical startup in March 1980 (213 low (21%) enrichment fuel subassemblies (FSAs), 143 high (33%) enrichment FSAs, and 13 permanent reactivity compensators) showed that the measured physical characteristics of the reactor were in agreement with the design values. Measurement of sodium flow through each FSA was carried out two times: before and after the power startup of the reactor.

Primary circuit thermal hydraulics was investigated at zero reactor power, both under steady-state conditions and simulated emergency conditions. All the loops of secondary circuit were filled with sodium in February 1980. The investigation showed that the hydraulic resistance of the loops was two times below the design value. Power startup began on 5 April 1980. Forty and eighthy percent as well as fuel nominal power of 1470 MW(th) [600 MW(e)] was reached in mid June, mid August and on 18 December 1980, respectively.

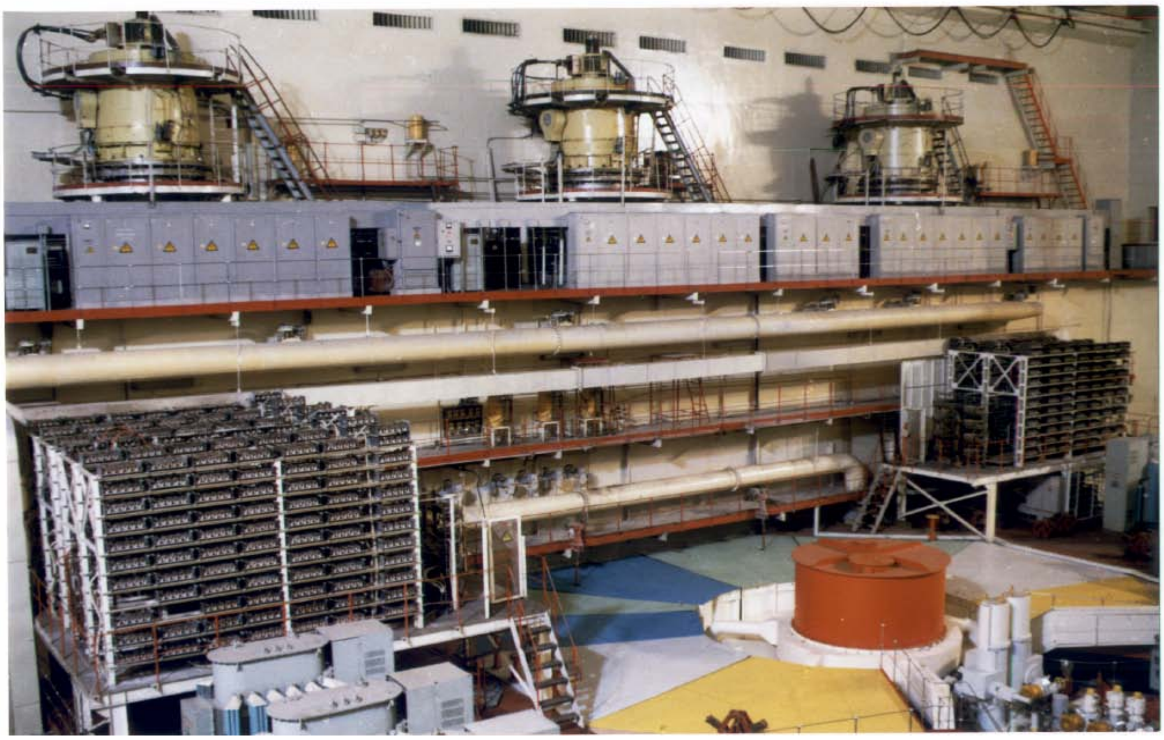
Reactor operation is stable with load factors 75-77% range, and turbine efficiency at ~ 43%. Till the end of 2004, the total BN-600 power operation time amounted to ~ 170 000 h, and ~ 91 billion kWh of electricity was generated.

BN-600 overall survey.



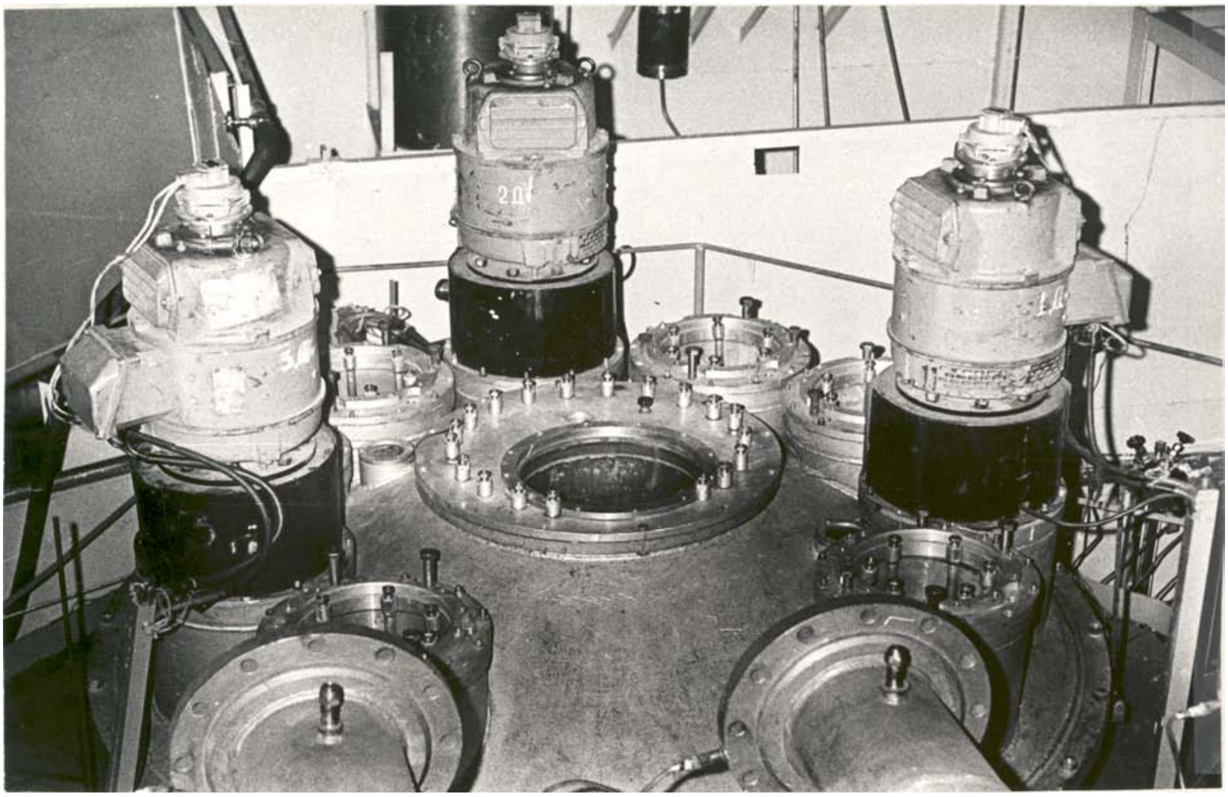
1-reactor, 2-reactor hall, 3-secondary pump, 4-crane, 5-ventilation system, 6-water pool, 7-irradiated fuel transfer cask, 8-sodium storage tank, 9-electric heating control system, 10-turbine hall, 11-control and protective system, 12-steam generator (SG), 13-crane (for SG)

Nuclear island and turbine building layout-elevation.

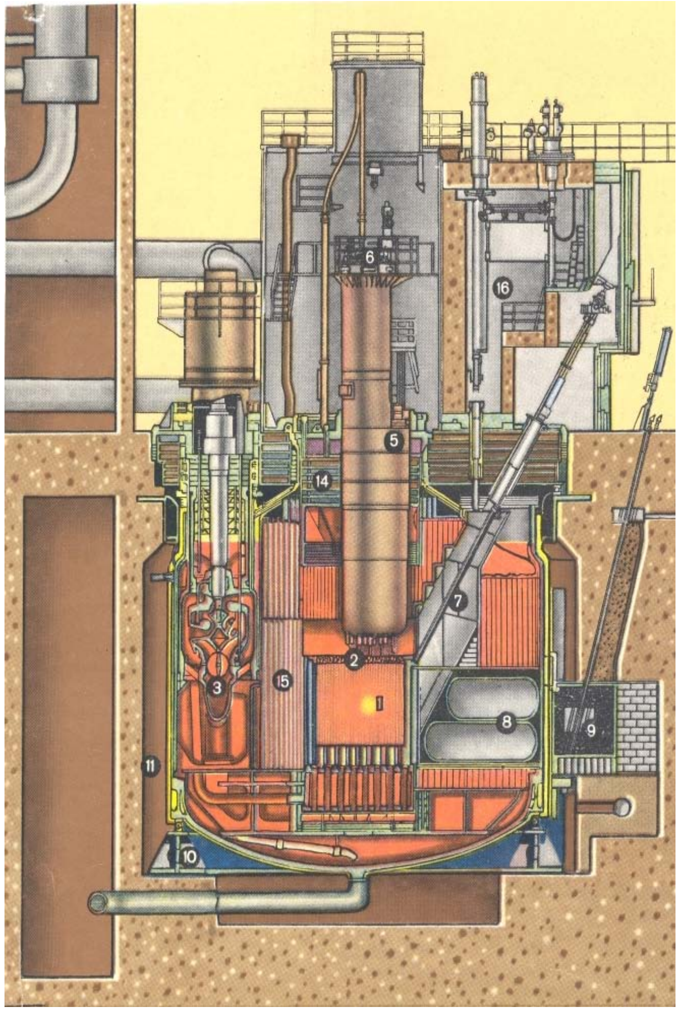


BN-600 reactor central hall (on the top-secondary pump electrical systems, bottom-reactor).

BN-600 turbine hall.

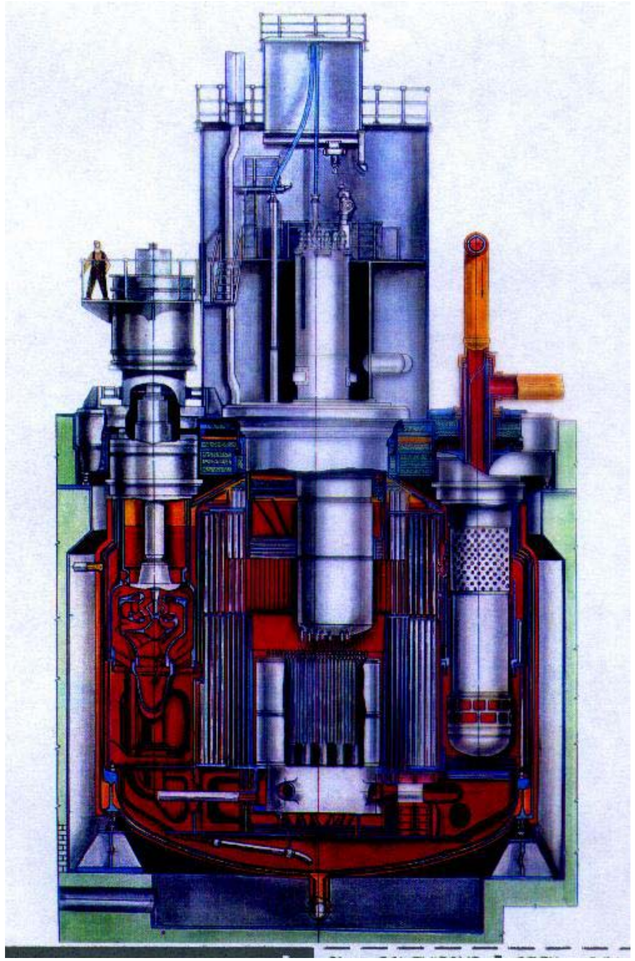


Hydraulic model of the BN-600 reactor.

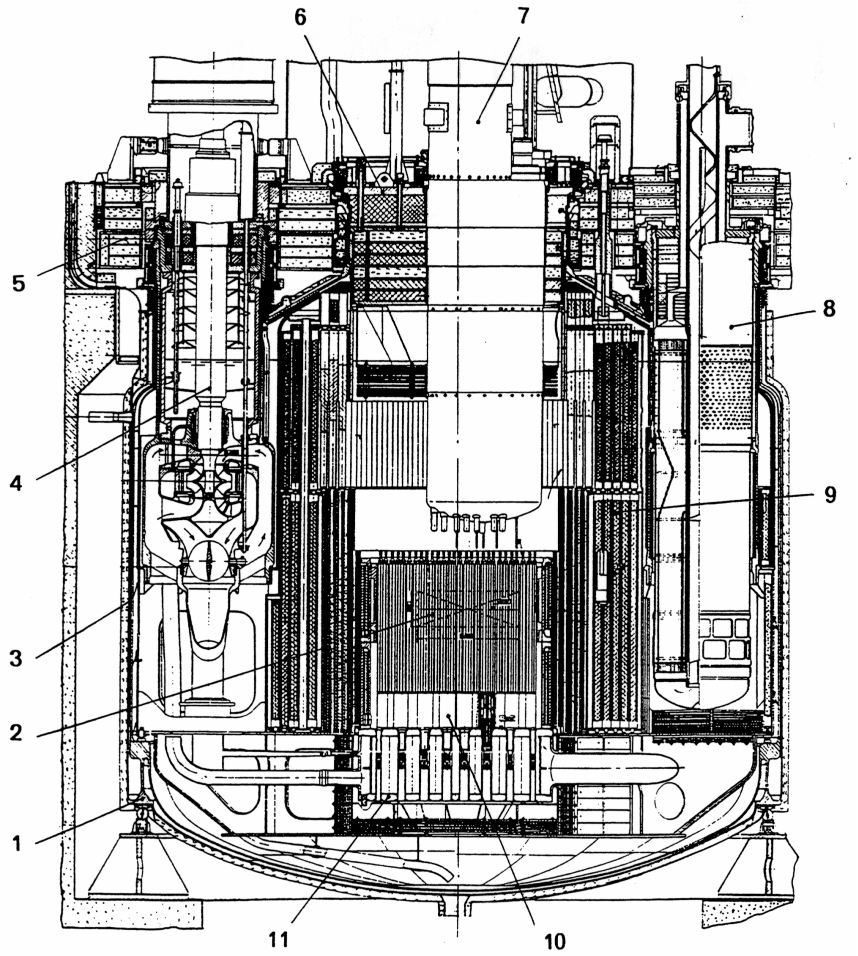


1, 2-core, fuel assembly, 3-primary pump, 4-intermediate heat exchanger (IHX), 5-central column, 6-control rod drive mechanism, 7-loading-unloading elevators, 8-neutron channel, 9-neutronic measurement chambers, 10-reactor supports, 11-reactor vault, 14-rotating plug, 15-neutronic protection, 16-refuelling cell

BN-600 reactor block.

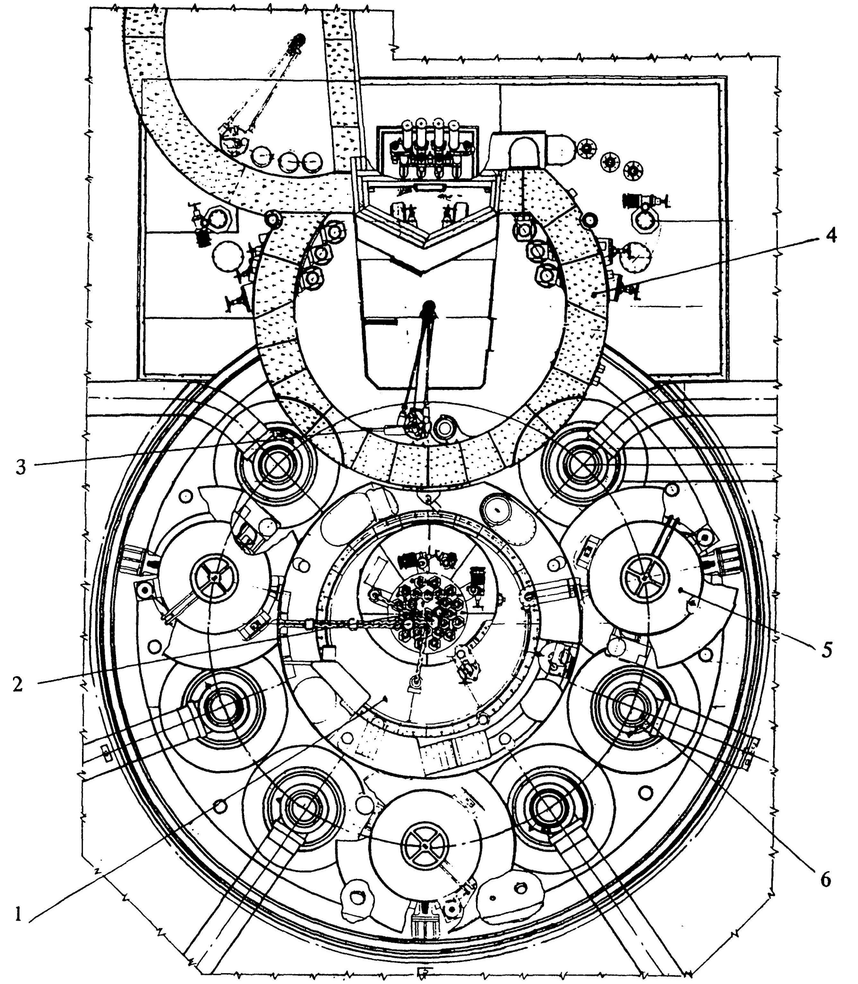


BN-600 perspective view.



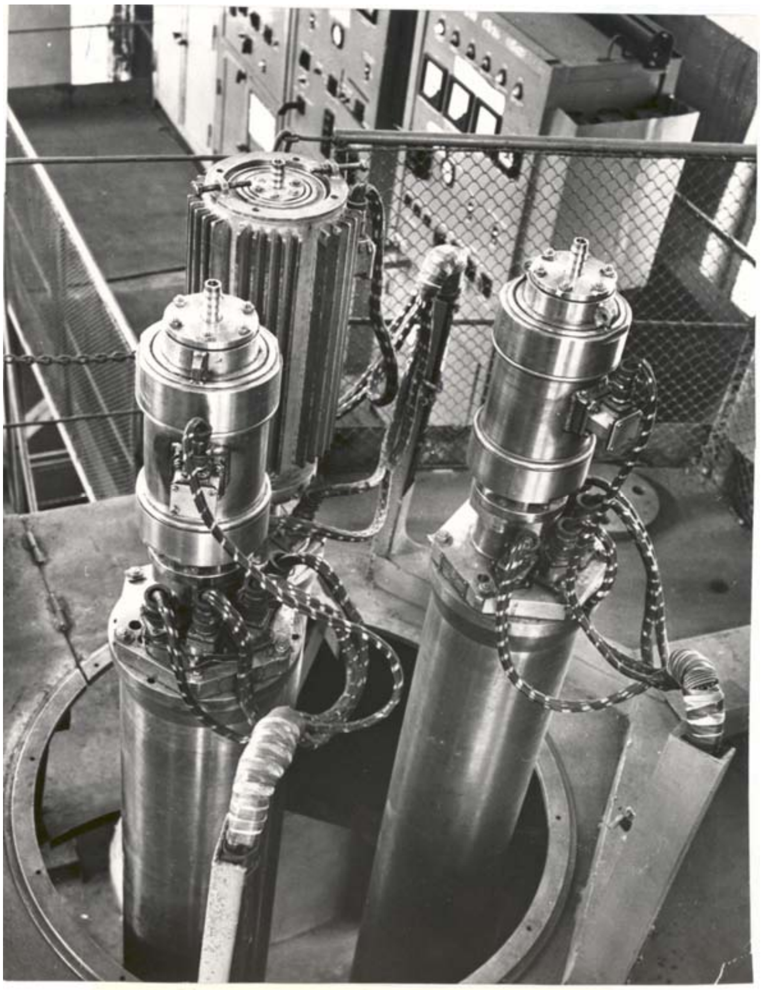
1-reactor support, 2-reactor core, 3-reactor vessel, 4-reactor coolant pump, 5-ex- vessel shield, 6-rotating plug, 7-above core structure, 8-intermediate heat exchanger, 9-in-vessel radial shield (steel and graphite), 10-core diagrid, 11-sodium pressure chamber

Elevation through BN-600 primary circuit.

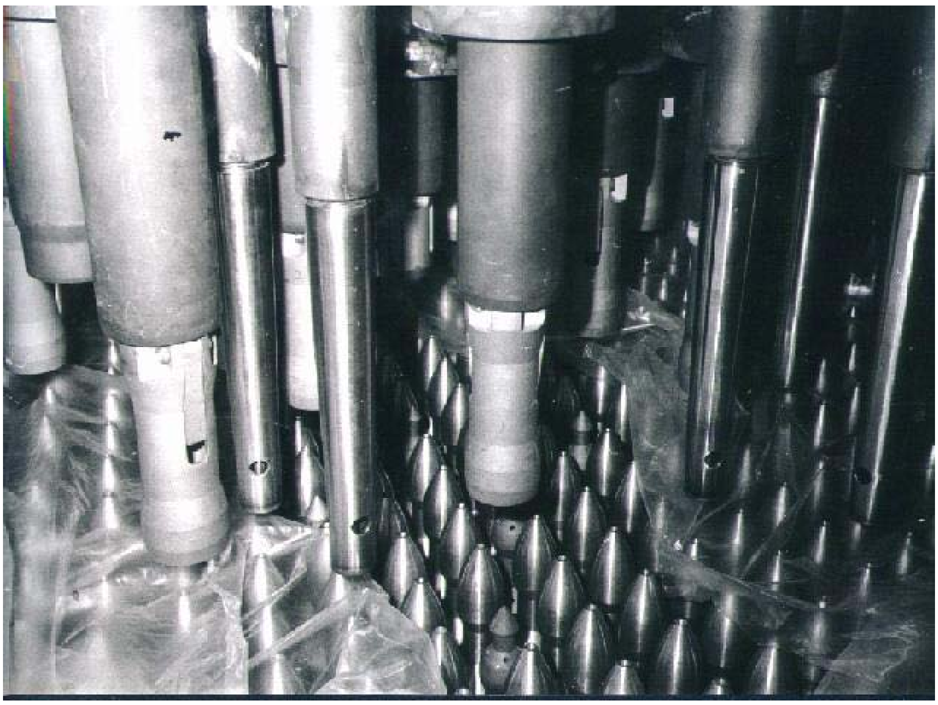


1-large rotation plug, 2-above core structure head, 3-fuel transfer mechanisms,4-refuelling cell, 5-reactor coolant pump, 6-intermediate heat exchanger

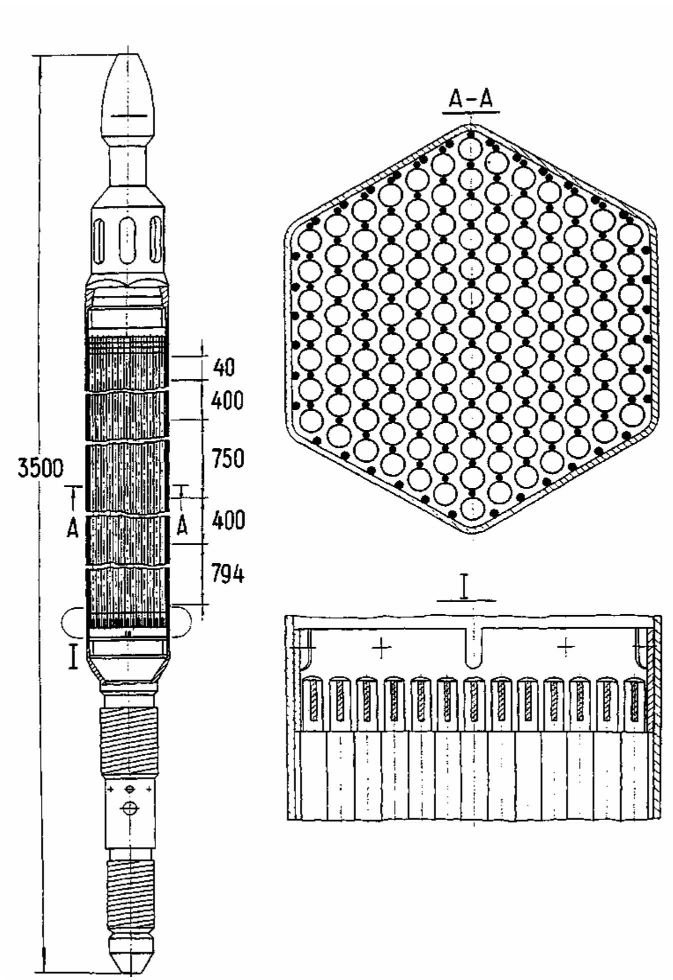
BN-600 reactor plan view.



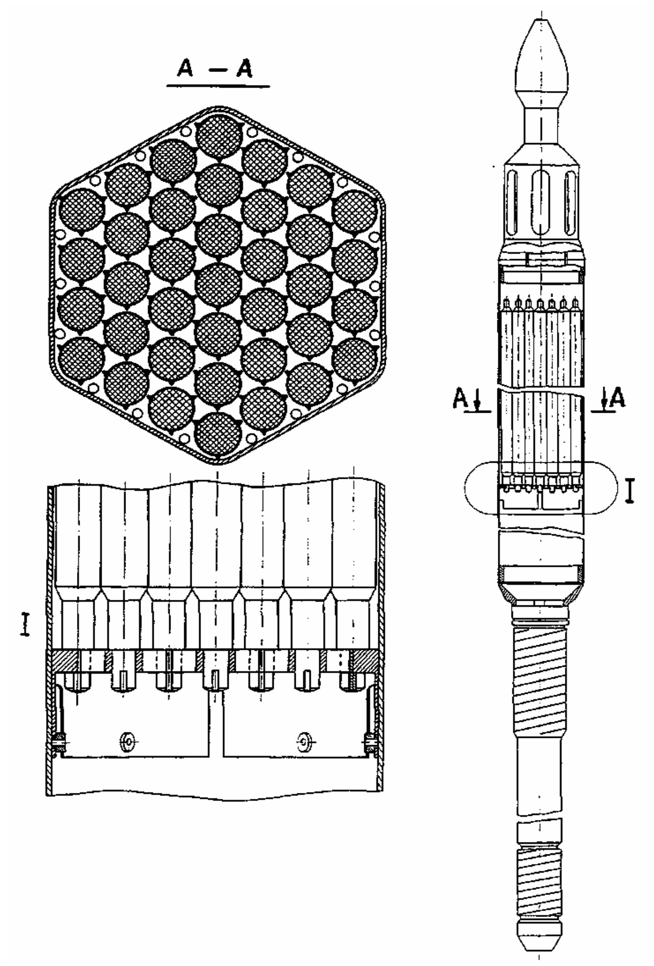
Sodium rig for testing of drives, control and safety system rods for the BN-600.



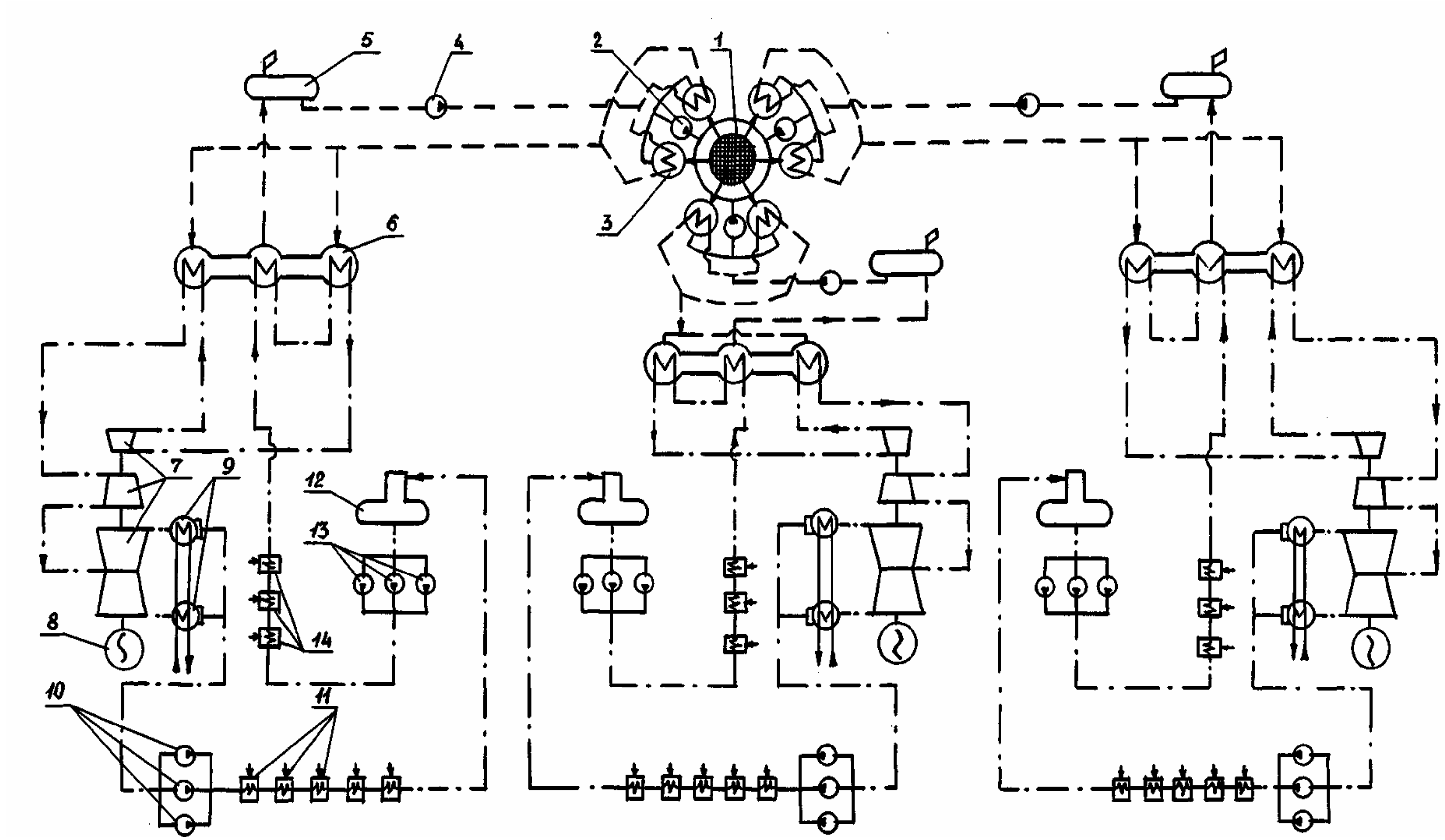
BN-600 control assemblies and refuelling system rig elements.



BN-600 reactor core fuel subassembly (first type - the core active height 75 cm).

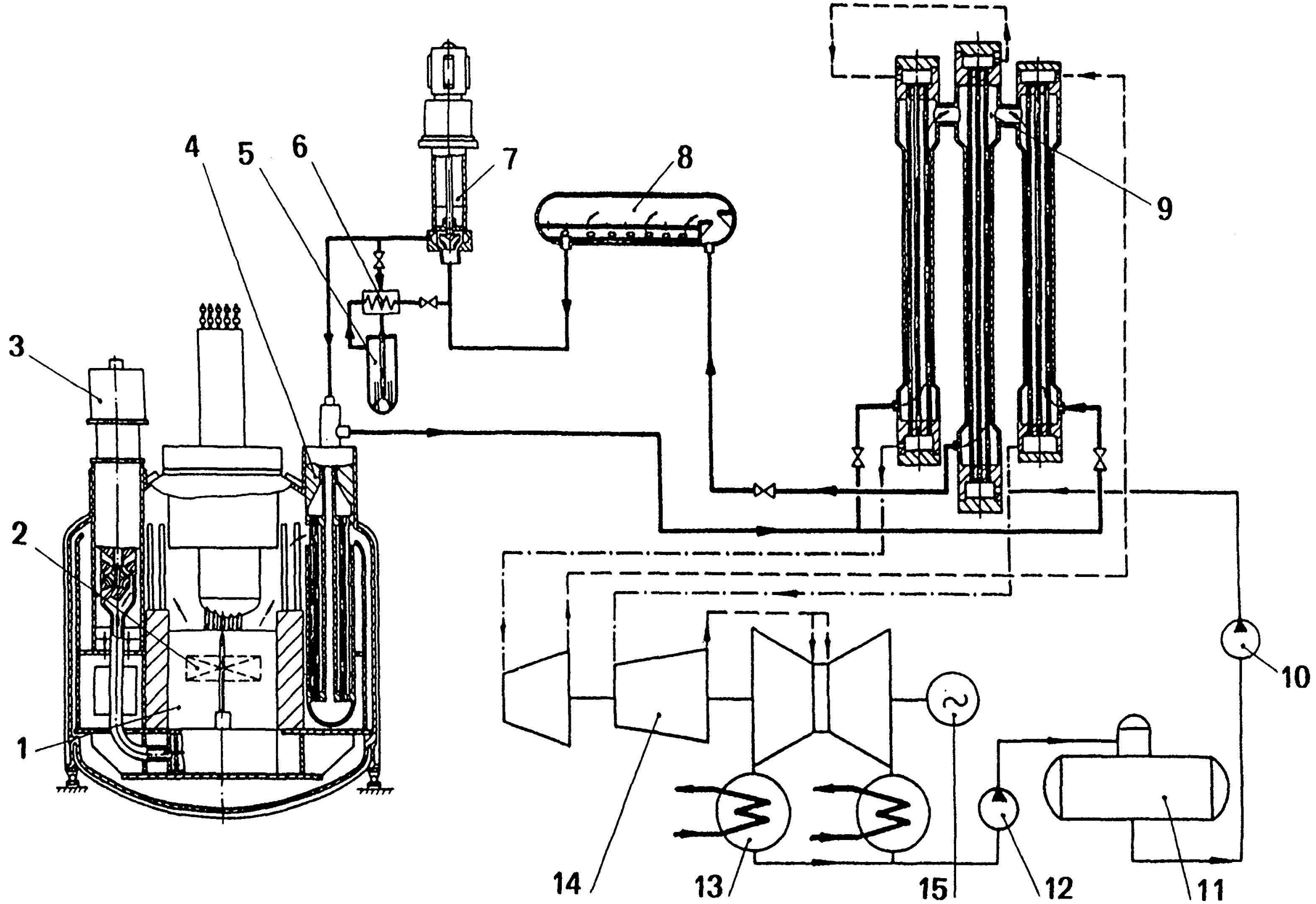


BN-600 radial breeder subassembly.



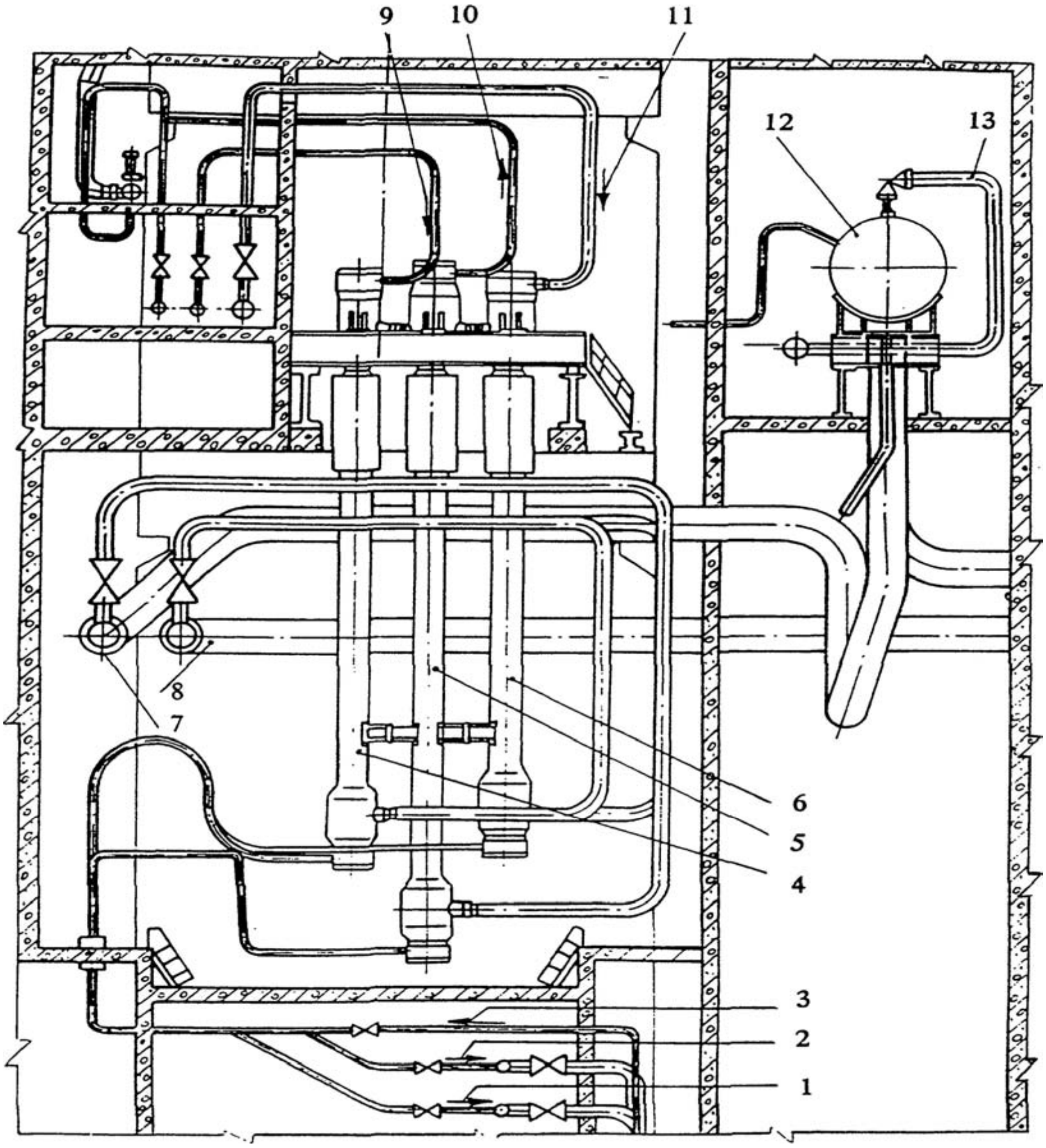
1-core, 2-primary pump, 3-intermediate heat exchanger, 4-secondary pump, 5-buffer tank, 6-steam generator, 7-turbine, 8-generator, 9-condensers, 10-condensate pumps, 11-low pressure heaters, 12-deaerator, 13-feed electric pumps, 14-high pressure heaters

Principle heat diagram of the power plant BN-600.



1-reactor, 2-reactor core, 3-reactor coolant pump, 4-intermediate heat exchanger, 5-filter-trap, 6-recuperator, 7-secondary coolant pump, 8-sodium expansion tank, 9-steam generator, 10-feedwater pump, 11-deaerator, 12-condensate pump, 13-condenser, 14-turbine plant, 15-turbogenerator

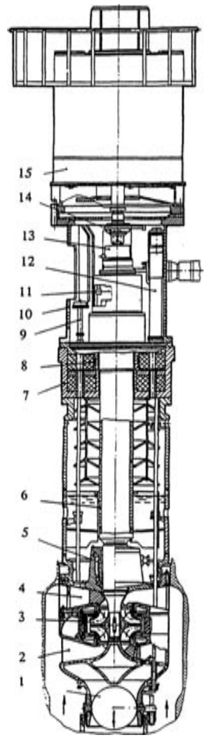
BN-600 reactor flow sheet.



1-main steam out, 2-reheated steam out, 3-feedwater in, 4-superheater, 5-evaporator, 6-reheater, 7-sodium out, 8-sodium in, 9-steam out, 10-steam out, 11-steam in, 12-sodium expansion tank, 13-steam- sodium reaction products dump line

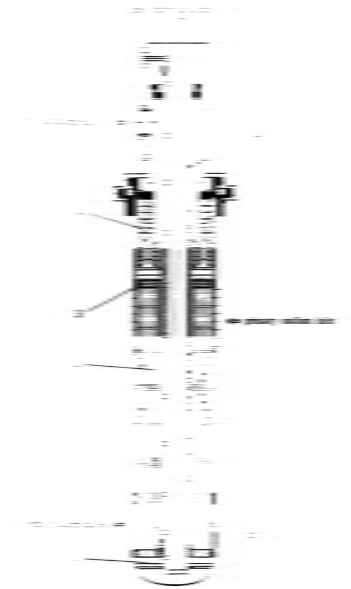
BN-600 steam generator layout in compartment[9].

[9] A total of 12 leaks was experienced in BN-600 SG units, half of which occurred in the first year of operation. The most likely cause of the leak was manufacturing faults. This situation occurred in the evaporator module (1 leak), superheater modules (7 leaks) and reheater modules (4 leaks). The point of the original leak was in the area of the upper tube plates welds. The suggested cause was the development during operation of initial defects at the point of junction between tube and tube plate. The presence of valves enabled one section (evaporator-superheater- reheater) to be cut off with the heat removal loop in operation, virtually without reducing the reactor power. At least partly because of this the availability of BN-600 has been consistently high. In 10 events the failed modules have been replaced with new ones and in 2 events the failed modules have been restored and put into operation again.



1-check valve, 2-lower scroll, 3-impeller, 4-upper scroll, 5-hydrostatic bearing, 6-shaft, 7-cover, 8-cooler, 9-level gage, 10-motor base, 11-face seal, 12-check valve drive, 13-radial-thrust bearing, 14-coupling, 15-motor

BN-600 reactor coolant pump[10].



1-sodium pressure chamber, 2-tubing system, 3-upper tube sheet, 4-shielding unit, 5-central downcomer tube, 6-lower tube sheet

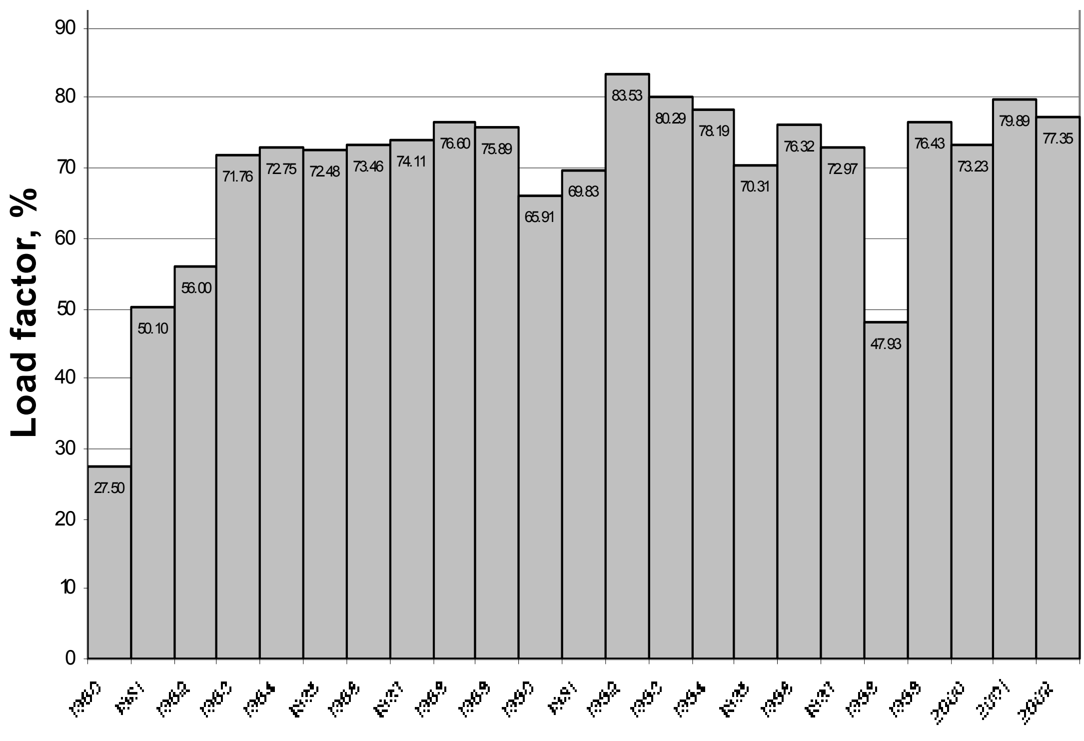
BN-600 intermediate heat exchanger.

---

[10] During operation of the primary pumps a high amplitude of torsional vibrations of the pump shaft were observed. Breakages were occurred in the-coupling teeth and its springs. The removable parts of the primary pumps have been replaced. The use of advanced shafts and couplings and changing to a steady mode of pump operation eliminated any failures of the pumps since 1985.

System	Number	Quantity, liters	Number of Na burnings
Reactor	0	—	-
Intermediate heat exchanger	0	—	-
Storage drum	0	—	-
Primary auxiliary systems	5		-
— Gas purification	1	0.1	-
— Sodium purification system	4	0.3; 3; 0.2; ~1000	1
Secondary auxiliary systems	18	—	-
— Main pipelines	0	—	-
— SG valve seals	4	1; 300; 30; 10	3
— SG leak detection system	1	2.0	1
— Drain and blow-off lines	10	0.2; 1; 10; 600; 300; 100; 0; 0; 1; 0 000000000000000.0; 0.0;1.0	6
Sodium reception and storage system	7	10.0; 50.0; 10.0; 0.0; 1.0; 0; 0	3
TOTAL	27	~ 2 500	14

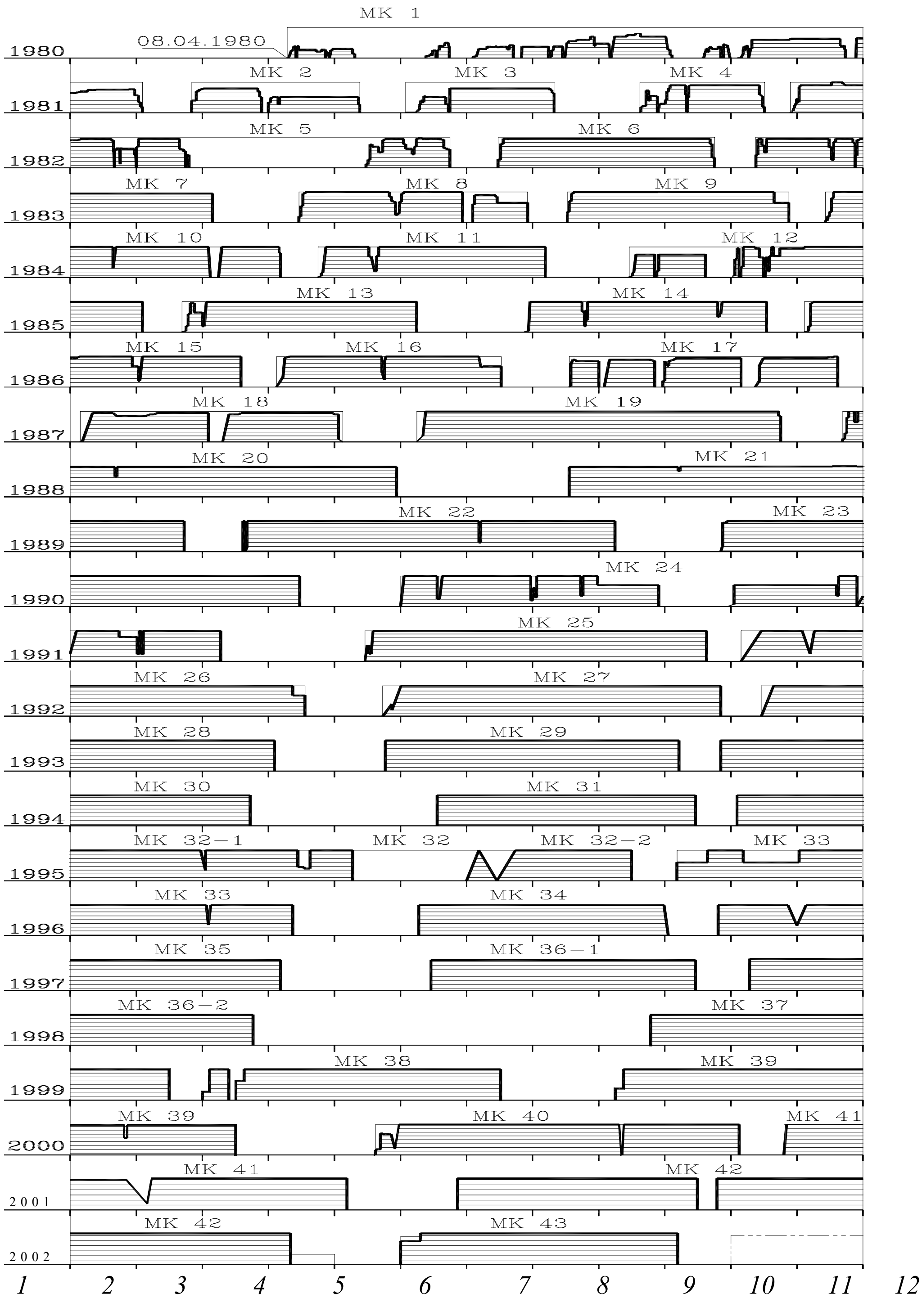
BN-600 sodium leaks.[11]



BN-600 load factors 1980-2002 (1998 the repair of the rotating plug).

[11] The main causes of sodium leakages were:

- poor quality repair - 8 events;
- latent defects of manufacturing and mounting - 6 events;
- depletion of equipment lifetime due to inadequacy of the design - 7 events;
- equipment design imperfections -4 events;
- human errors during operation - 2 events.



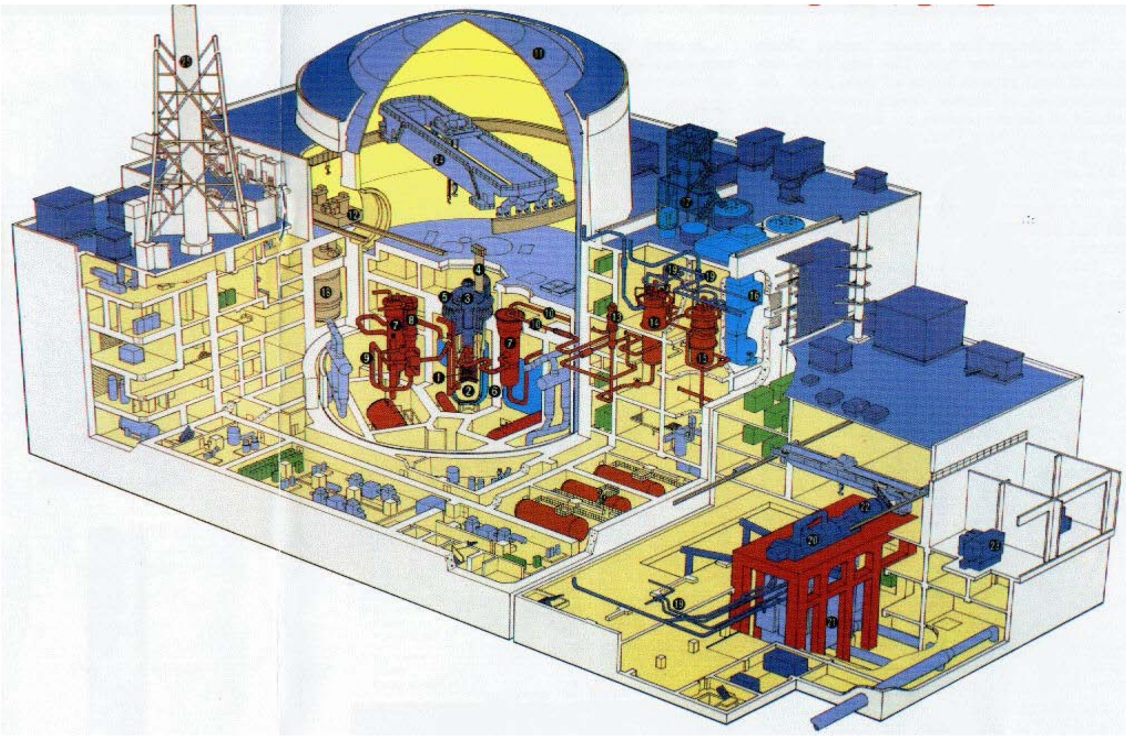
BN-600 operating histogram (reactor is being shutdown two times per year for refuelling, 1998-the rotating plug repair).

13.2.5. MONJU

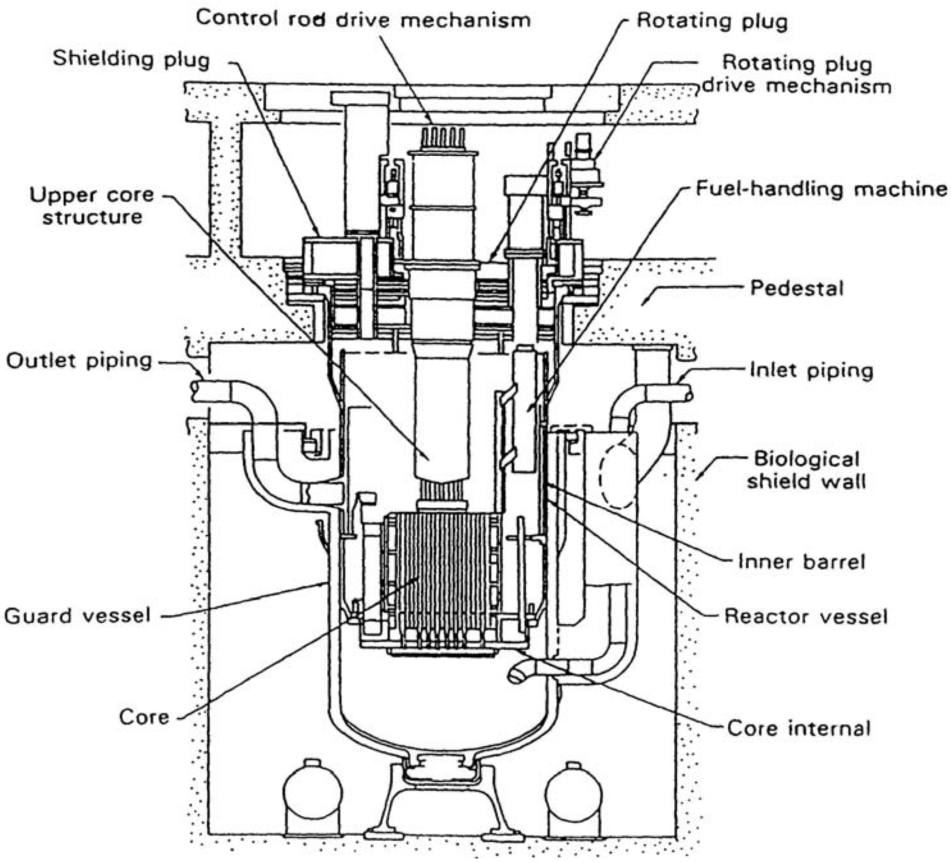
The 280 MW(e) prototype reactor MONJU was stopped temporarily due to a leak in the non-radioactive secondary heat transport system that occurred in December 1995 during the 40% power pre-operational testing phase. In the Japanese programme, it was clarified that MONJU is at the core of the fast reactor research activities, and steps were taken to resume its operation as soon as possible. Considerable effort has been put into activities aiming at regaining public understanding and acceptance. The local governor of Fukui gave pre-consent for plant modification work of MONJU on 7 February 2005. The Japan Nuclear Cycle Development Institute (JNC) started the preparatory work and the plant modification work on 3 March and 1 September 2005, respectively. MONJU restart is foreseen in 2009.

MONJU overall survey.

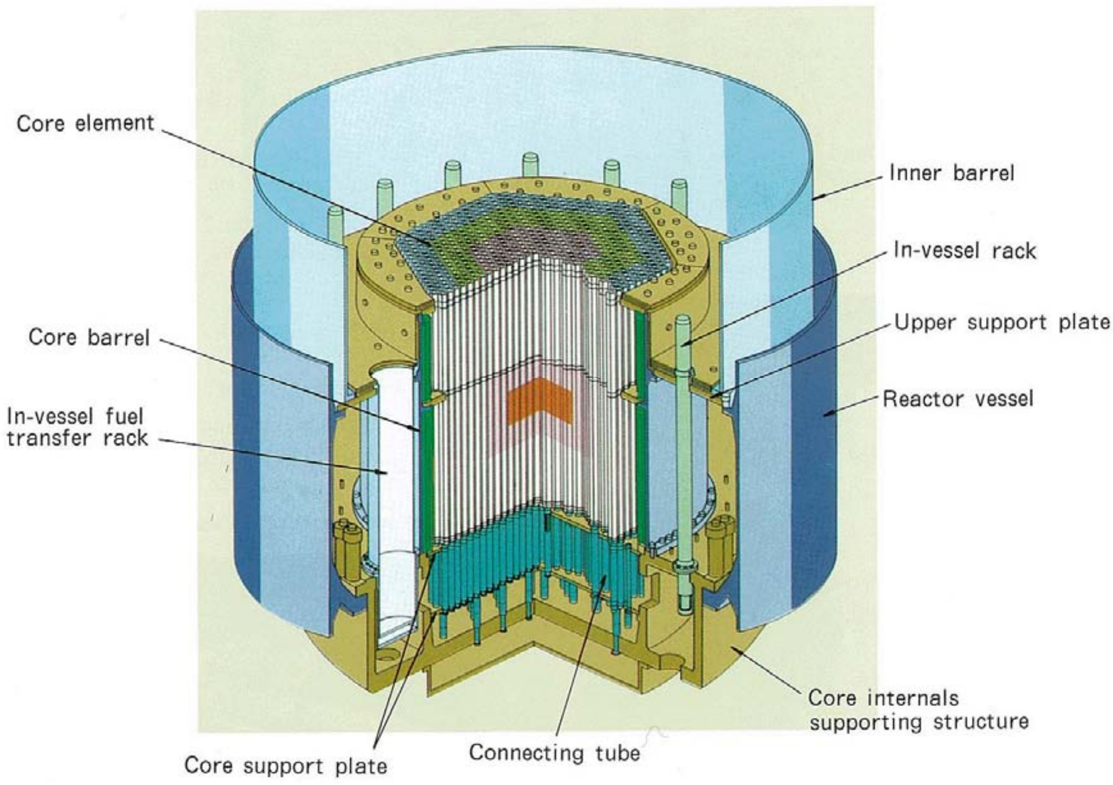
MONJU main view.



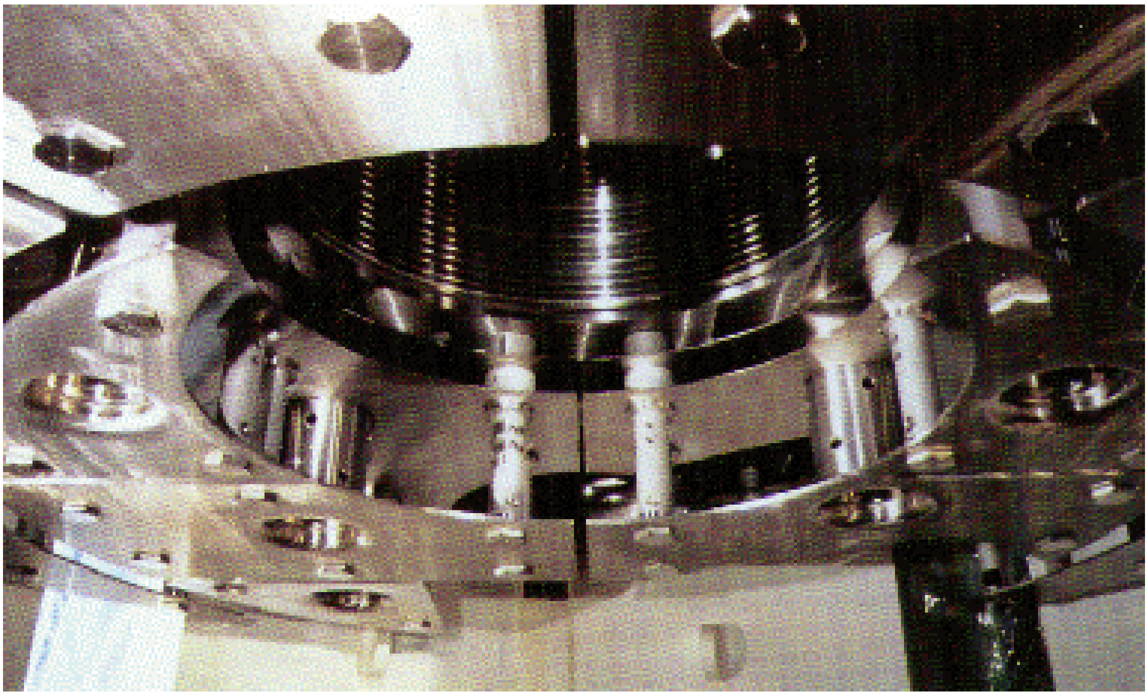
MONJU general arrangement.



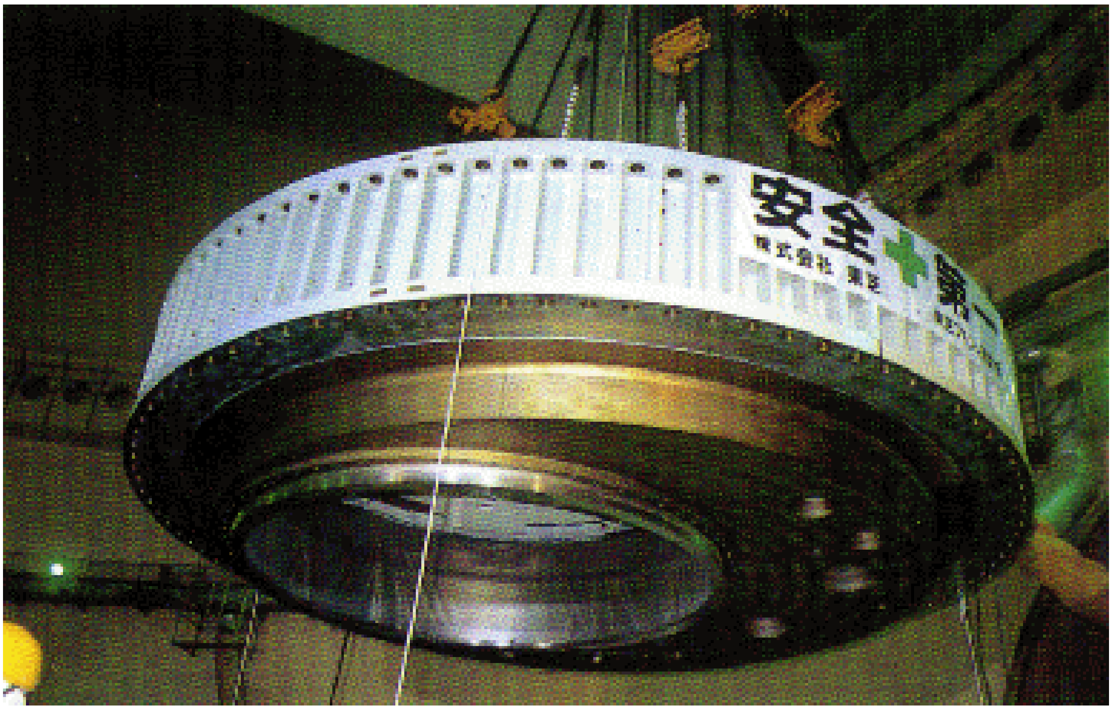
MONJU reactor system..



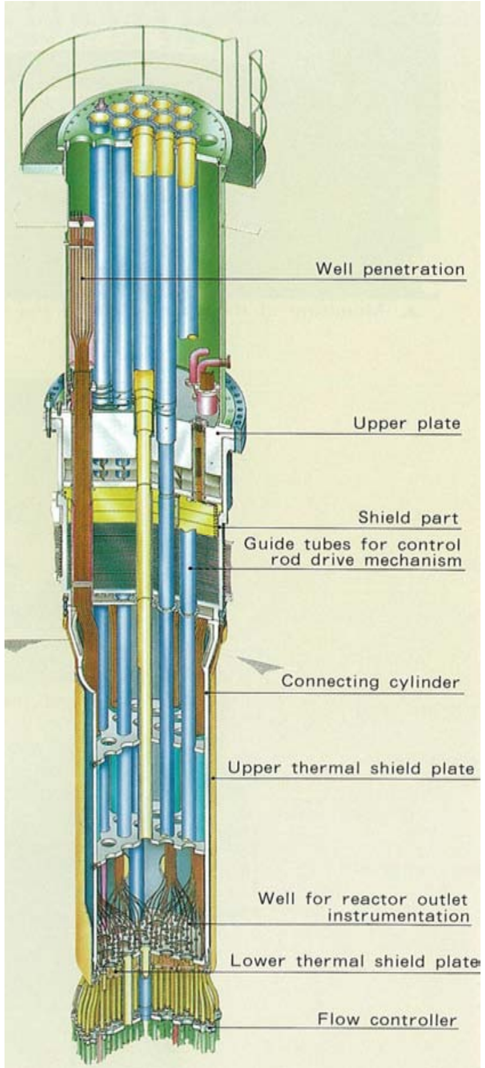
MONJU reactor core.



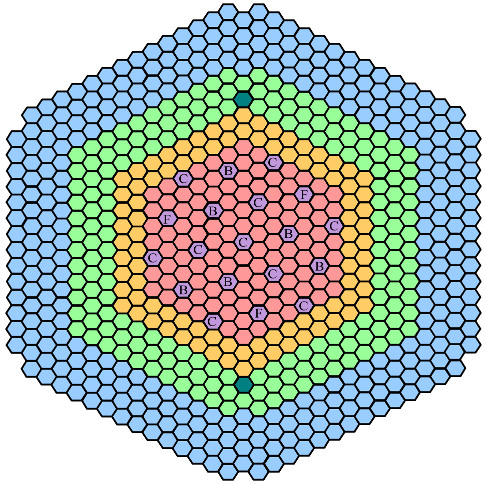
MONJU lower structure of the shield plug.



MONJU mounting of the upper plate of the fixed plug.

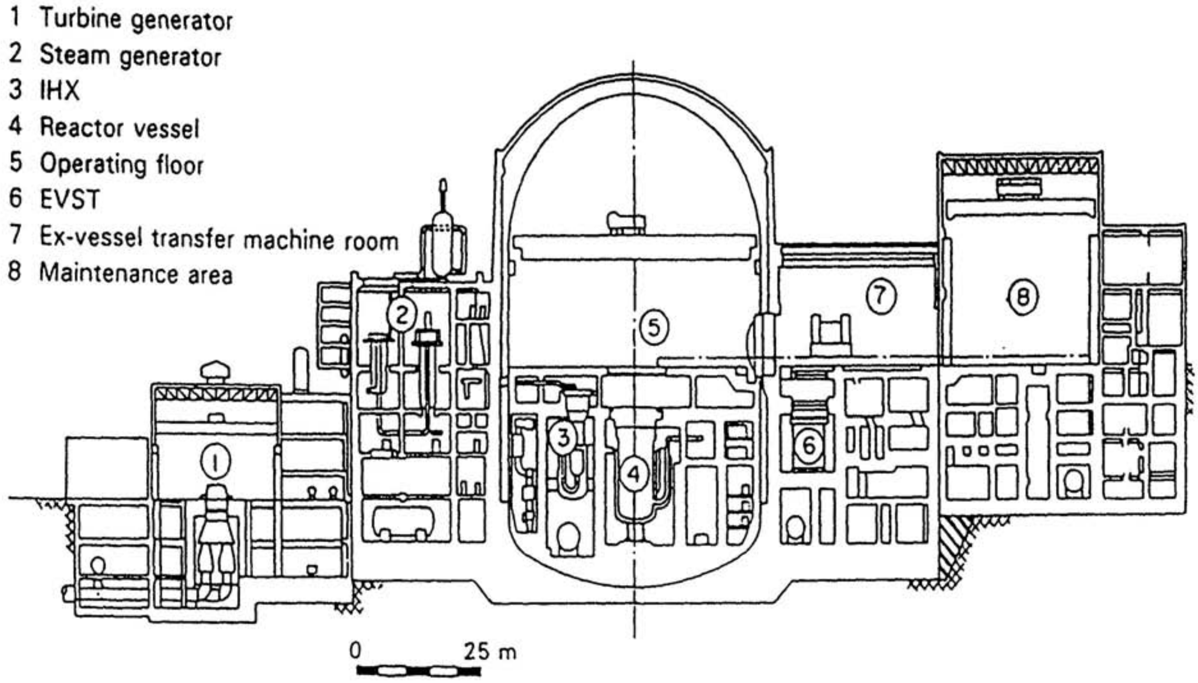


MONJU reactor upper part.

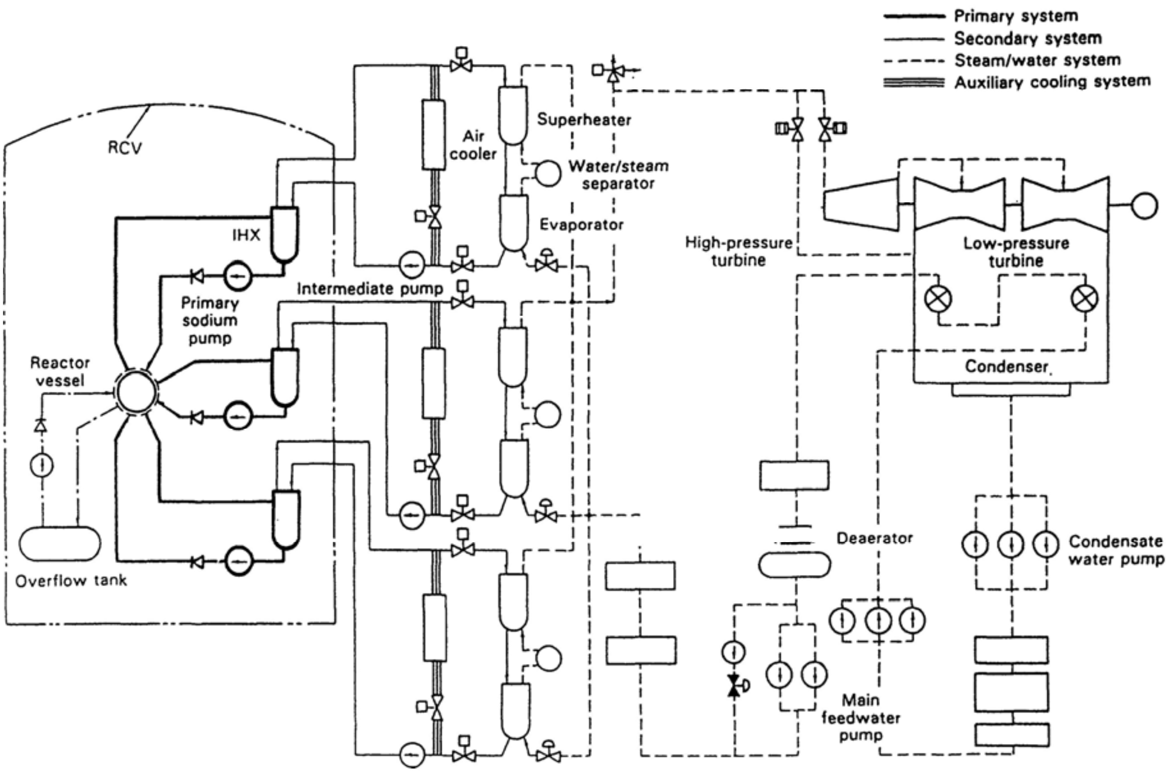


Core fuel assembly	Inner core		108
	Outer core		90
Blanket fuel assembly			172
Control rod	Fine	F	3
	Coarse	C	10
	Back-up	B	6
Neutron source			2

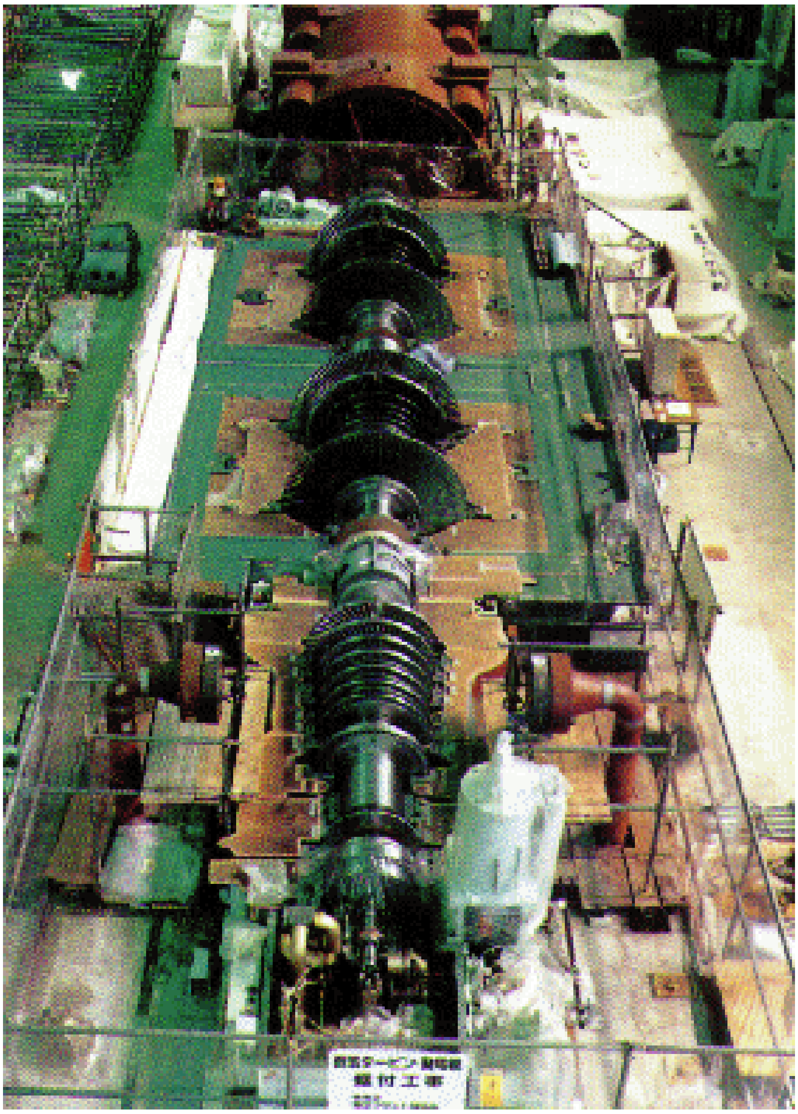
MONJU reactor core configuration.



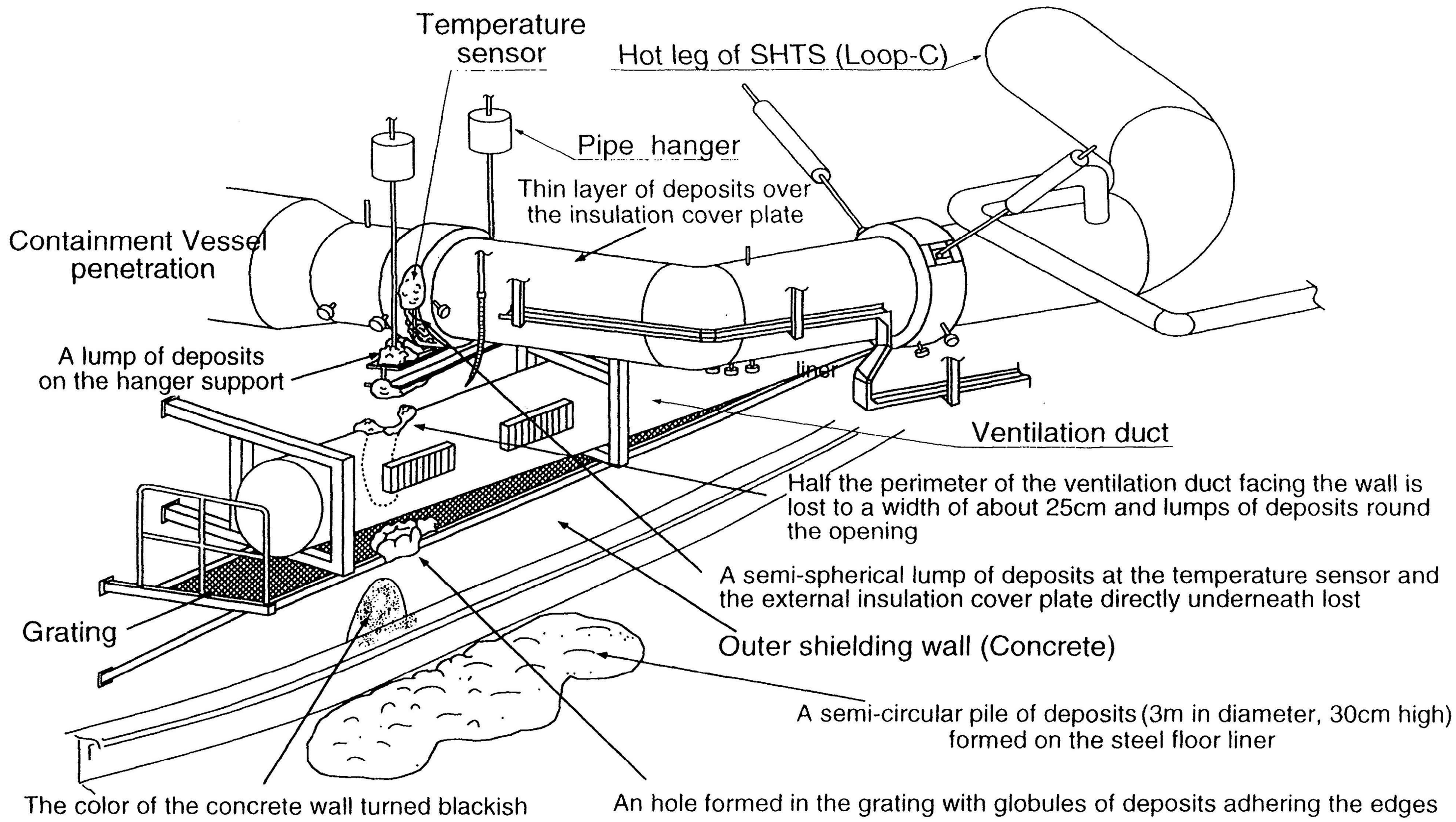
MONJU sectional view of main building.



Flow diagram reactor plant.



MONJU turbine.



MONJU the place of the sodium leak and sketch of the affected area. [12]

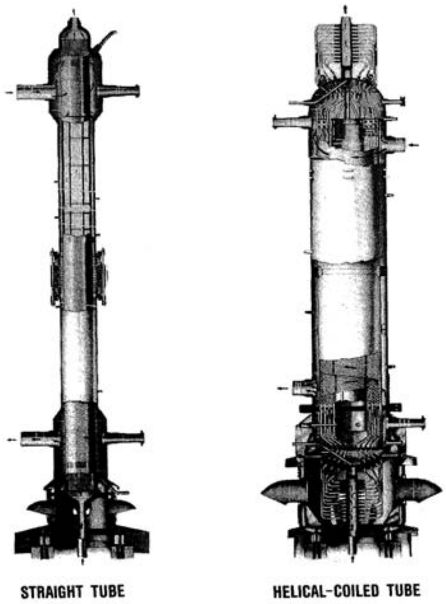
12 The prototype reactor MONJU of 280 MW(e) power was stopped temporarily due to a leak in the non-radioactive secondary heat transport system, that occurred in December 1995 during the 40% power pre-operational testing phase.

13.2.6. SNR-300

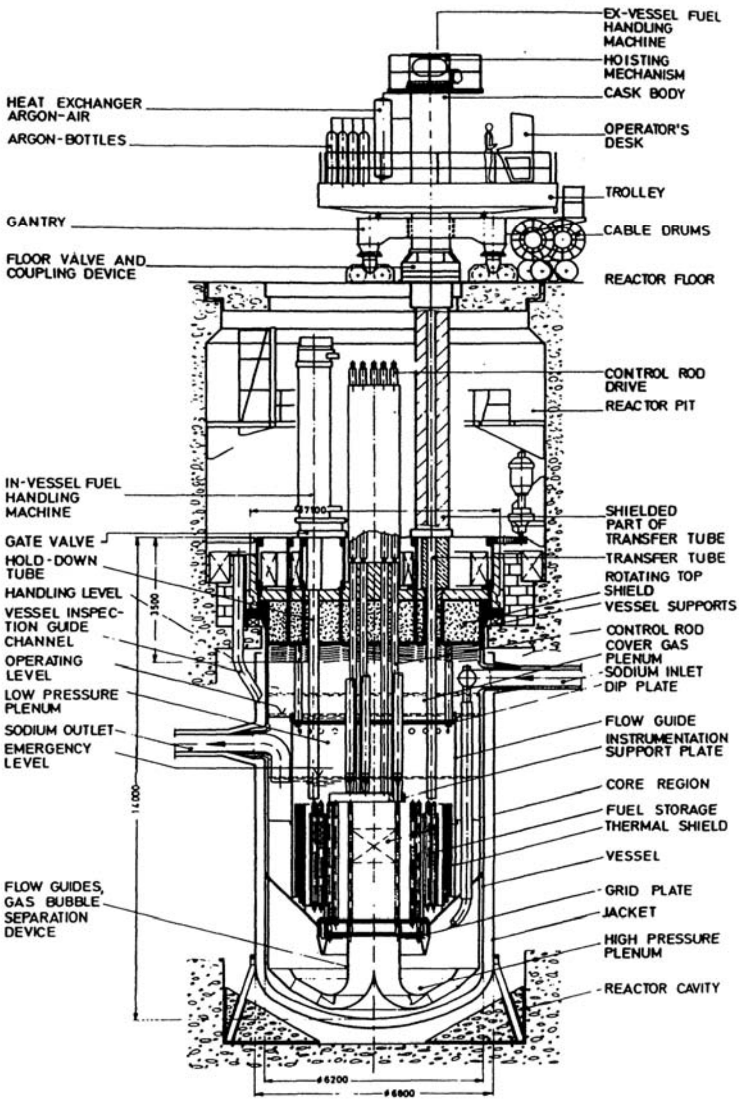
Construction began in April 1973 and was finished in mid 1985. Non-nuclear commissioning began also in 1985. In August of 1985 all fuel sub-assemblies were fabricated. In March 1991 the Federal Government announced that SNR-300 will not be put into operation. The cause of termination of the SNR-300 project is attributed to the Authorities of the State of North Rhine-Westphalia.

SNR-300 overall survey.[13]

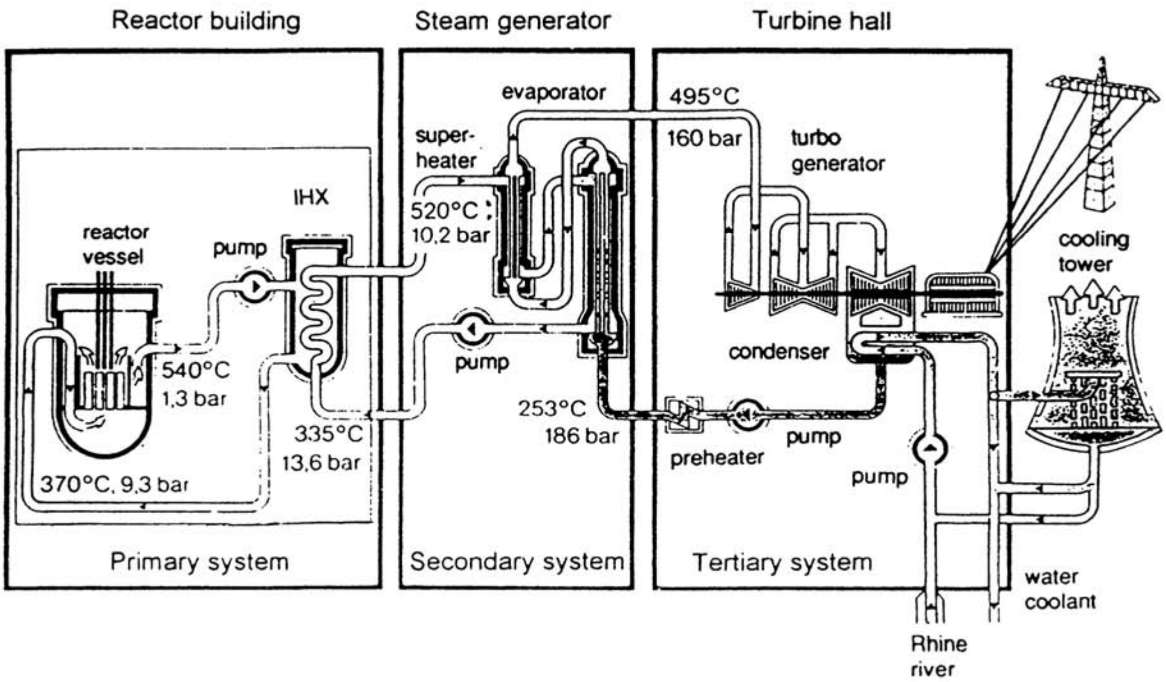
[13] C onstruction began in April 1973 and was finished in mid 1985. In March 1991 the Government announced that SNR-300 should not proceed to commence operation.



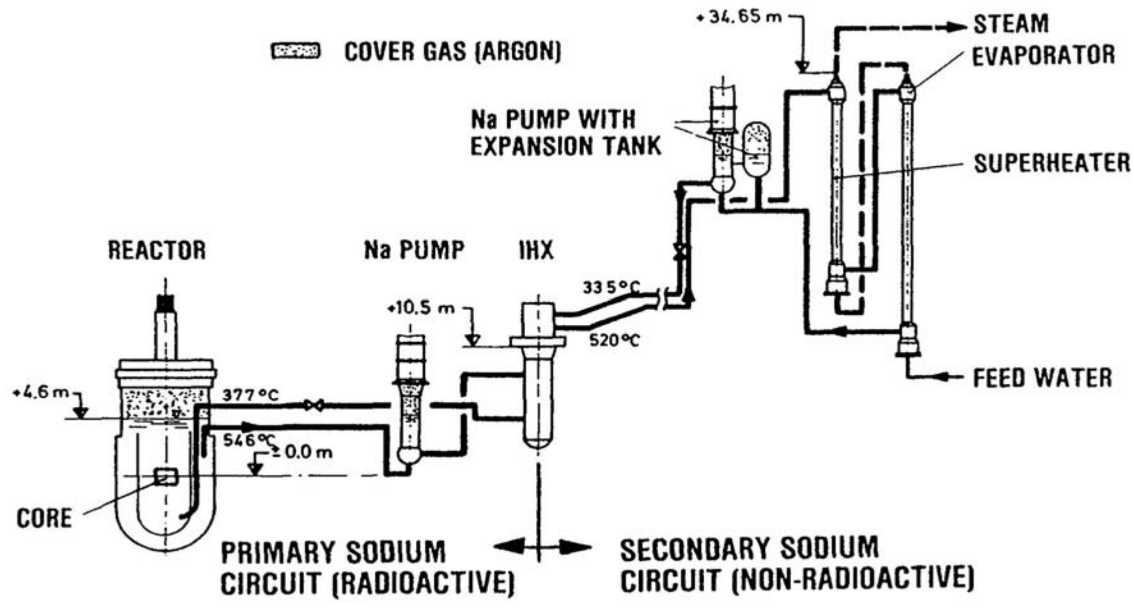
Straight tube and helical-coiled tube steam generators of SNR-300.



SNR-300 arangement of refuelling equipment.



SNR-300 schematic flow scheme of the SNR-300 fast breeder plant in Kalka.



SNR-300 hydraulic profile of heat transfer system.

13.2.7. PFBR

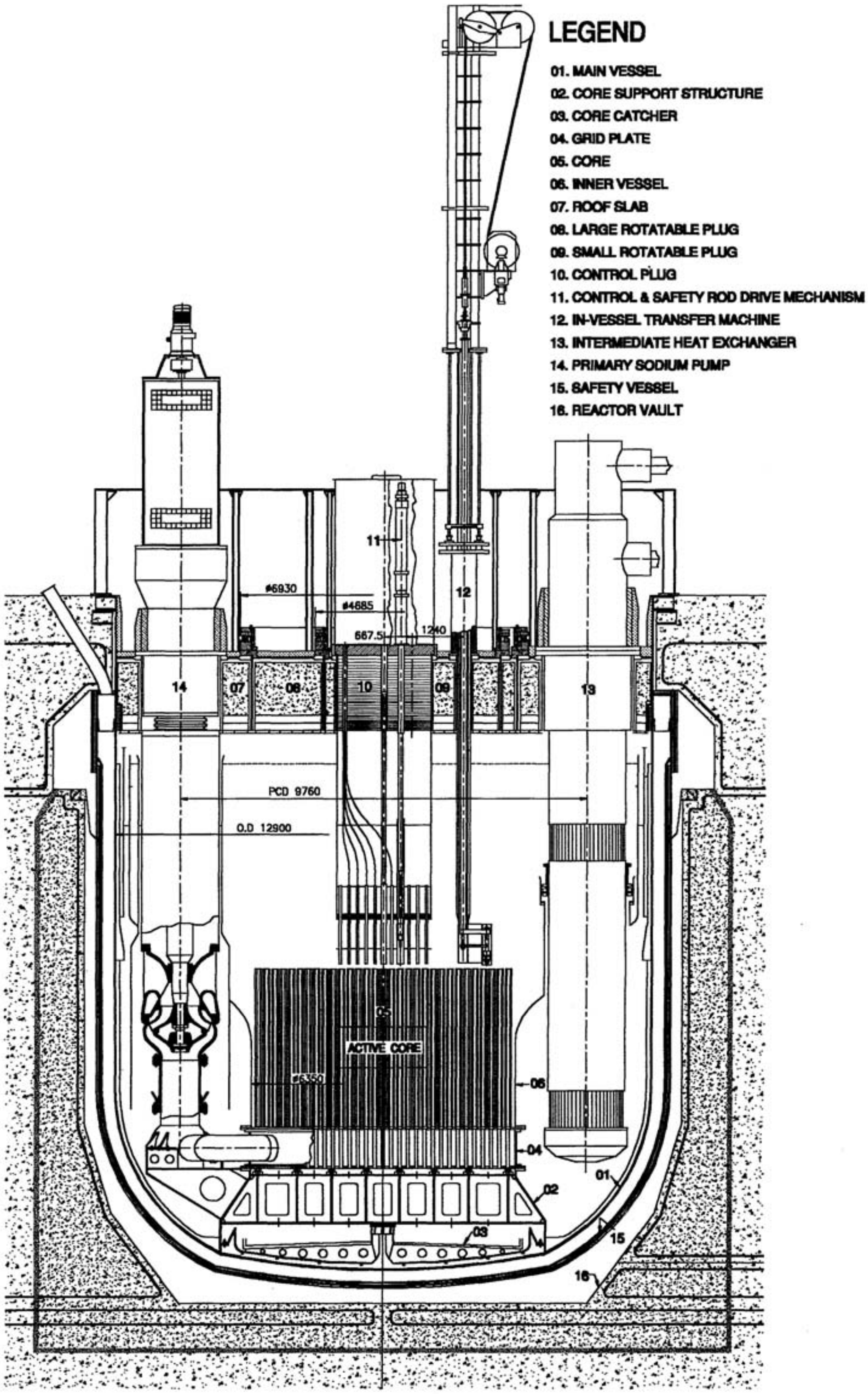
The 500 MW(e) prototype fast breeder reactor (PFBR) is under construction in India. PFBR is a 500 MWe capacity, pool type sodium cooled fast reactor with 2 primary pumps, 4 intermediate heat exchangers and 2 secondary loops. There are 8 integrated steam generator (SG) units; 4 per secondary loop where steam at 763 K and 17.2 MPa is produced. Four separate safety grade decay heat exchangers are provided to remove the decay heat directly from the hot pool. The hot and cold pool sodium temperatures are 820 and 670 K, respectively.

Detailed design has been completed for almost all the major components. All the eighteen Preliminary Safety Analysis Report (PSAR) chapters were revised after incorporating the comments of the Internal Safety Committee (ISC), Project Design Safety Committee (PDSC) and Civil Engineering Safety Committee (CESC). The PDSC formed Specialists Groups to check the compliance of the submitted revised PSARs.

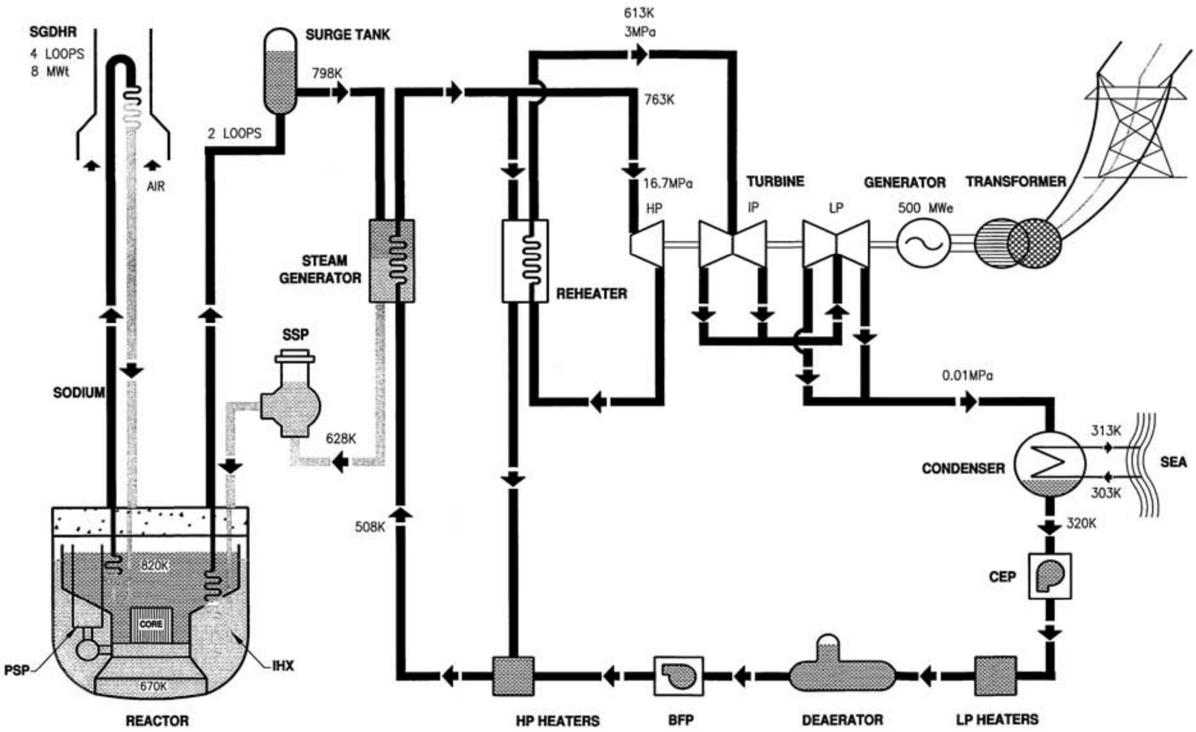
A document has been prepared consolidating the R&D activities for safety related components replaceable, safety related components non-replaceable, and other components.

So far manufacturing orders had been placed for main vessel, inner vessel, safety vessel, grid plate, core support structure, thermal baffles, core catcher, roof slab, Control and Safety Rod Drive Mechanisms (CSRDM), Diverse Safety Rod Drive Mechanisms (DSRDM), Intermediate Heat Exchangers (IHX), primary sodium pumps, steam generators, sodium and argon tanks, control plug, secondary sodium pumps, safety vessel thermal insulation, inclined fuel transfer machine and shielding subassemblies. Tenders were released / bids are under processing for the fuel & blanket subassemblies, remaining core subassemblies, variable speed drive for sodium pumps, cranes, sodium service valves, diesel generators, primary sodium piping, sodium to sodium and sodium to air heat exchangers, etc.

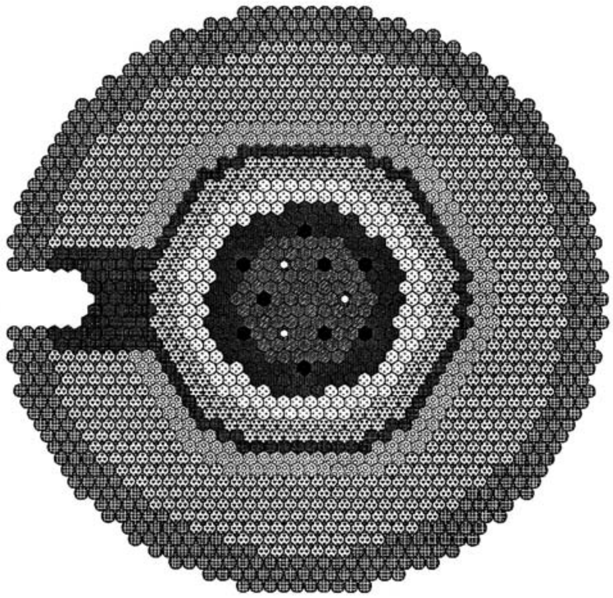
Financial sanction for the construction was obtained in September 2003. The capital cost of the project is Rs.3492 crores (approximately 656 million Euro), the specific cost is 1312 Euro/kWe. Physical progress achieved is 17% at end March 2006. Part clearance is available for the reactor vault construction up to the Safety Vessel (SV) support location. The manufacture of both safety and main vessels is progressing well. The form tolerances achieved so far ($< \pm 9$ mm) are very much encouraging. First criticality is planned for September 2010.



PFBR reactor assembly.

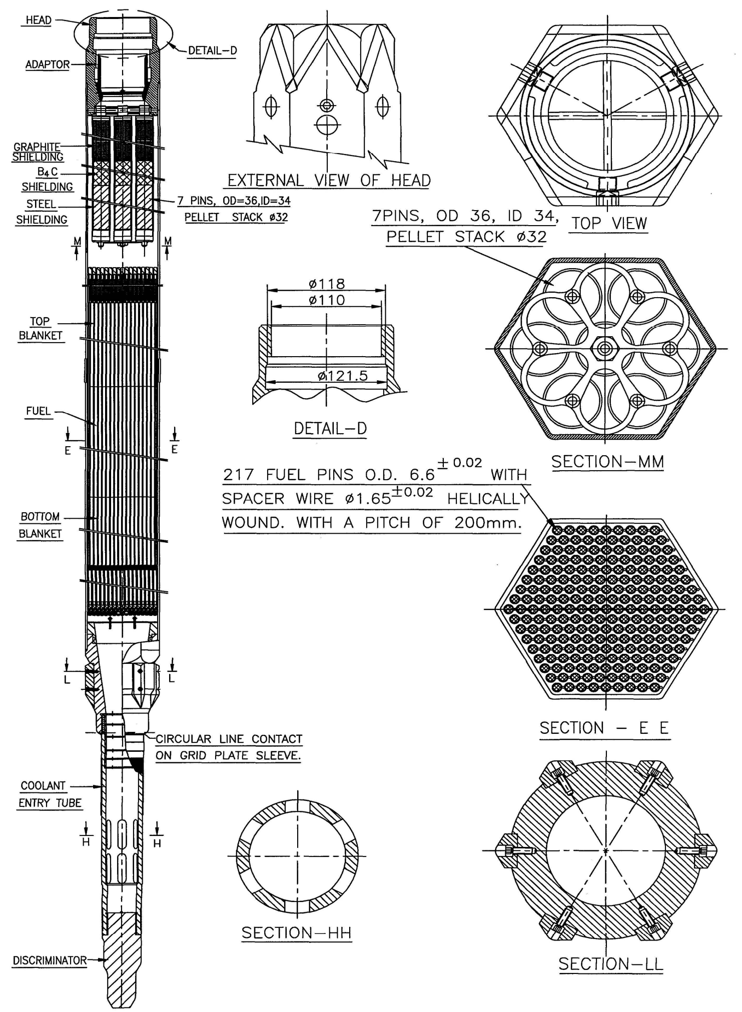


PFBR plant flow sheet.

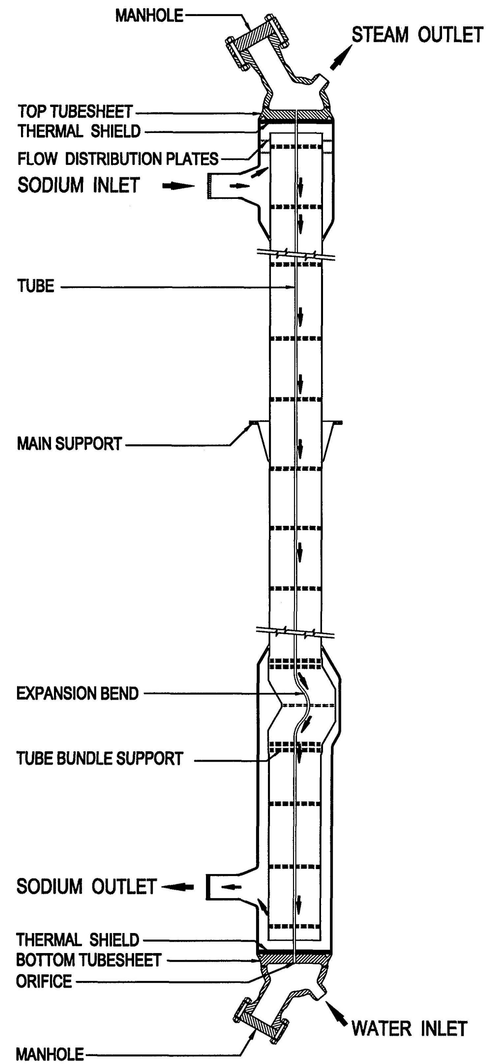


SYMBOL	TYPE OF SUBASSEMBLY	No.	MASS PER SUBASSY. IN Kg
	FUEL (INNER)	85	245
	FUEL (OUTER)	96	245
	CONTROL AND SAFETY ROD	9	200
	DIVERSE SAFETY ROD	3	180
	BLANKET	120	320
	STEEL REFLECTOR	138	355
	B_4C SHIELDING (INNER)	125	185
	STORAGE LOCATION	156	245/320/355.
	STEEL SHIELDING	609	330
	B_4C SHIELDING (OUTER)	417	265
	TOTAL SUBASSEMBLIES	1758	

PFBR core configuration.



PFBR fuel subassembly.

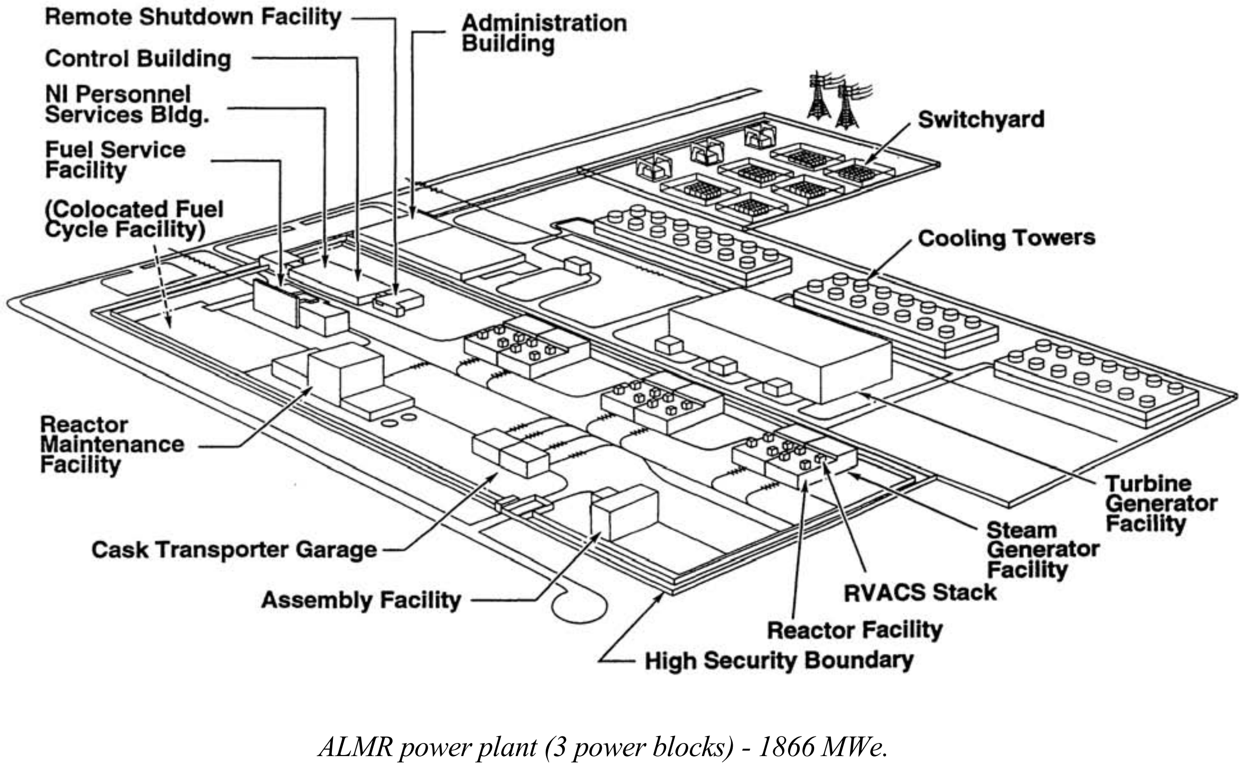


PFBR steam generator.

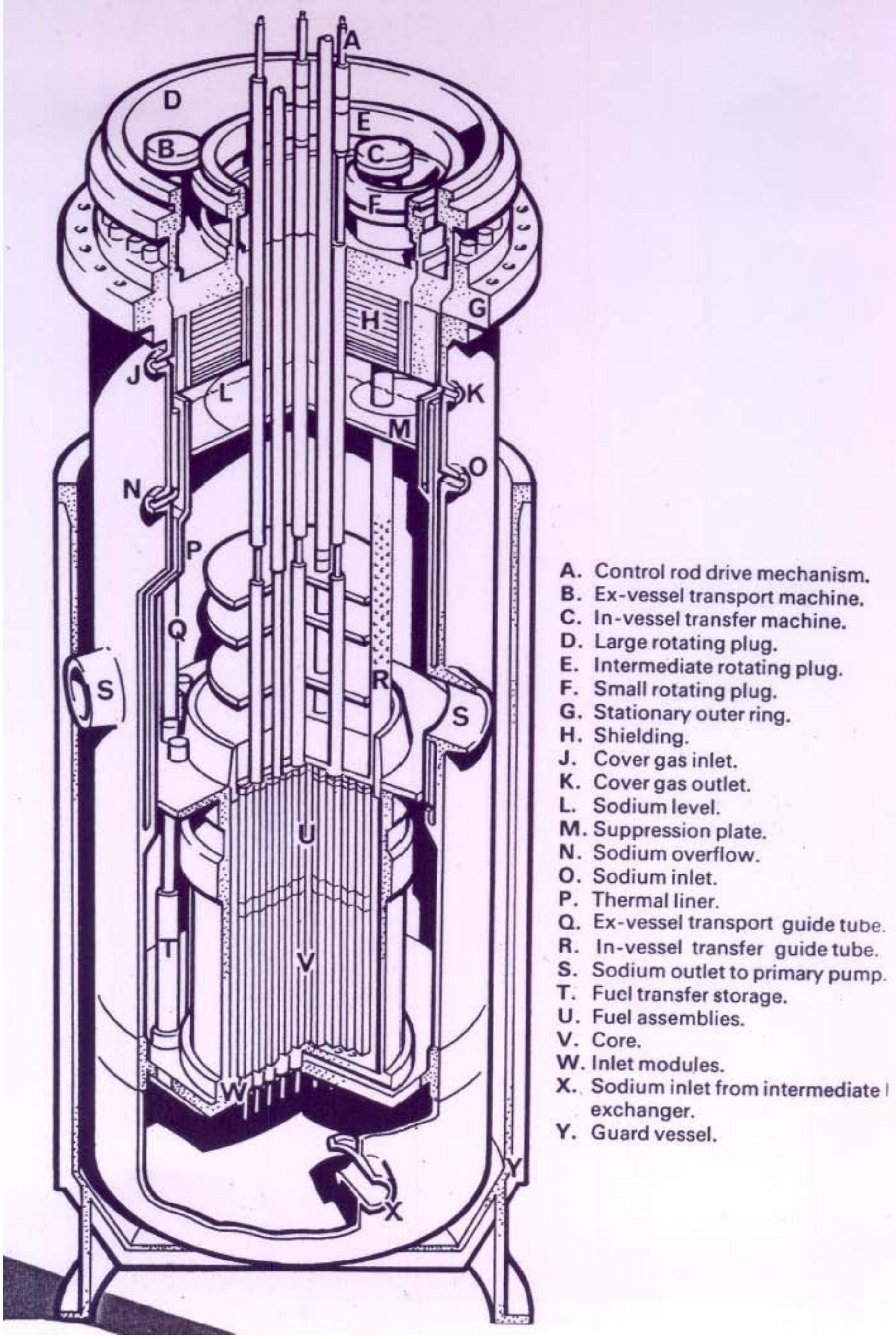
13.2.8. CRBR

Plant history :

1969/70	The US Congress authorized the US AEC to define technical and economic characteristics of the CRBR (Clinch River Breeder Reactor) plant and to undertake plant design
1972	Definitive arrangements were made to combine resources of the US AEC and some 750 private, public, co-operative, municipal electric utility systems thtoughout the country
1975	Completion of the design concept including a first version of an environmental impact statement. Many of procurement were placed
1977	Decision of the Carter Administration on an indefinite postponement of CRBR construction and of nuclear fuel reprocessing in the USA
1981	Endorsement of the CRBR project by the Reagan Administration
1982	The NRC permitted site preparation work to began. In March 1983, a limited work autorization was issued
1983	After extended debates on the funding of high additional costs, the US Congress refused to make any further appropriations for the project in the fiscal year 1984 (Status of liqued metal cooled fast breeder reactors, Technical Report Series, No. 246, IAEA, Vienna, 1985, p. 135)



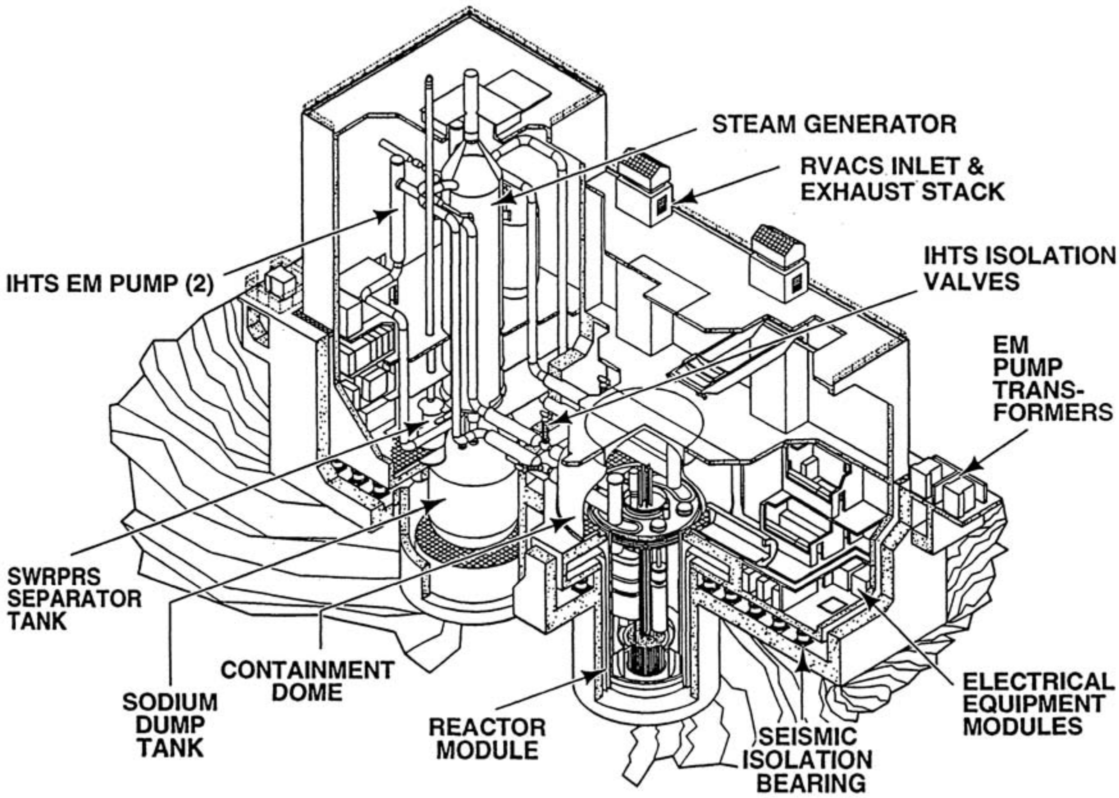
ALMR power plant (3 power blocks) - 1866 MWe.



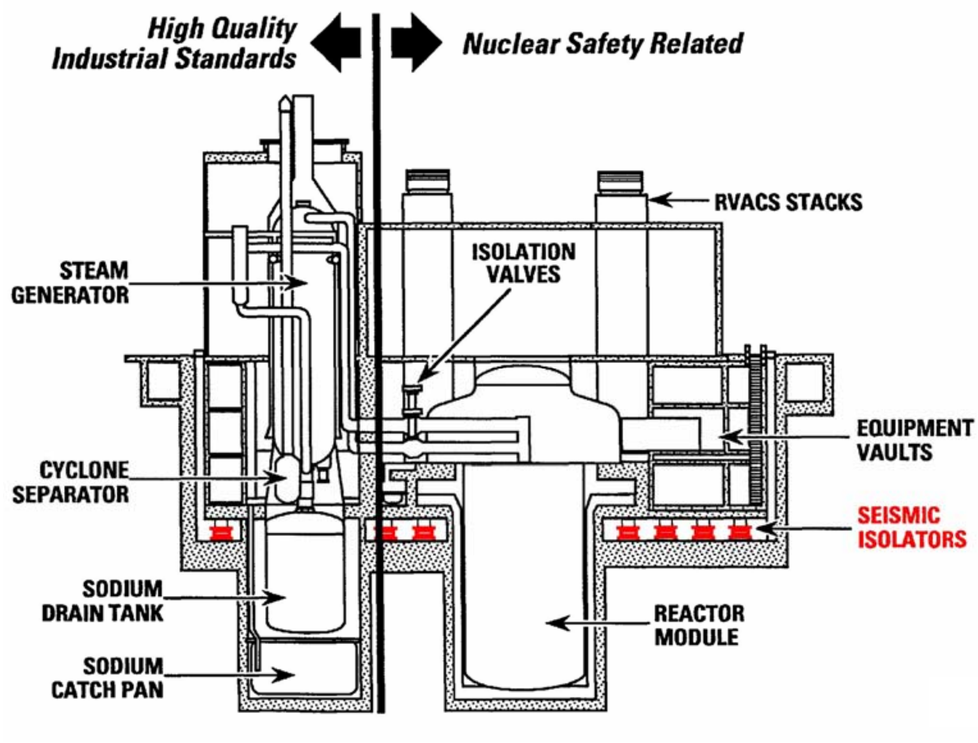
CRBR reactor assembly.

13.2.9. ALMR

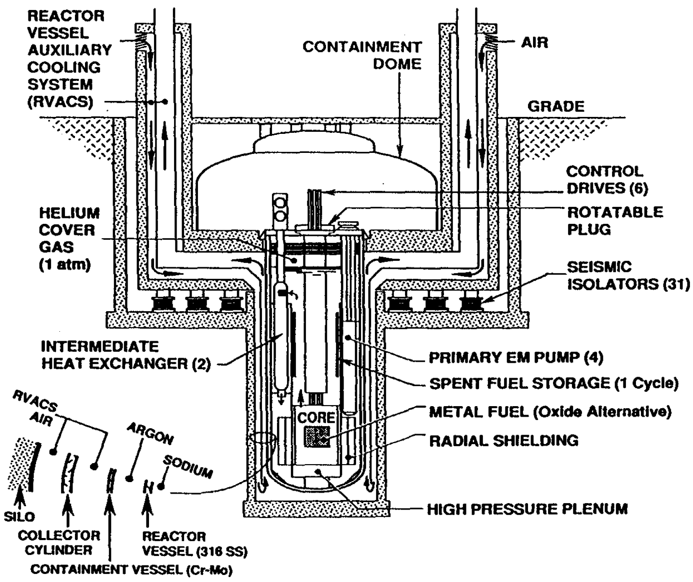
The PRISM (power reactor innovative small module) design was initiated by General Electric (GE) in 1980. Accordingly, in late 1988 GE was awarded a five year contract for advanced conceptual design and preliminary design for the DOE advanced liquid metal reactor (ALMR) programme. The fundamentals of this design remained unchanged, and the enhancements made since its selection as the ALMR in 1988 improve its economic viability and licensebility. The objective of the ALMR programme was to verify the performance, reliability, and safety of the innovative fast reactor design. The concept utilized the wealth of safety and sodium components technology developed for US reactors, including the EBR-II, FERMI reactor, Southeast Fast Oxide Reactor (SEFOR), Fast Flux Test Facility (FFTF), and Clinch River Fast Breeder Reactor.



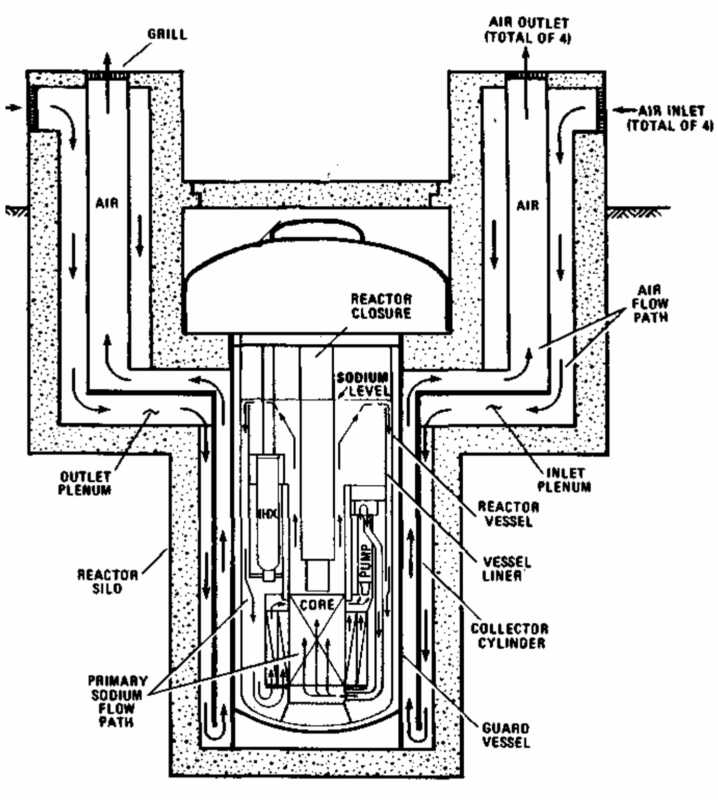
ALMR reactor & steam generator facility general arrangement.



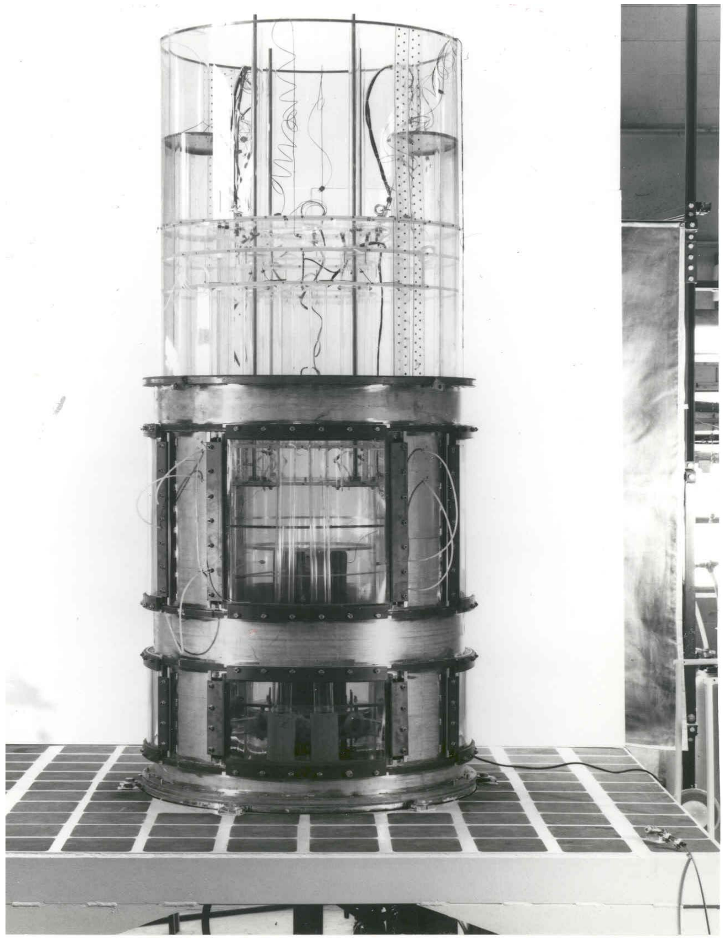
PRISM (ALMR) nuclear steam supply system.



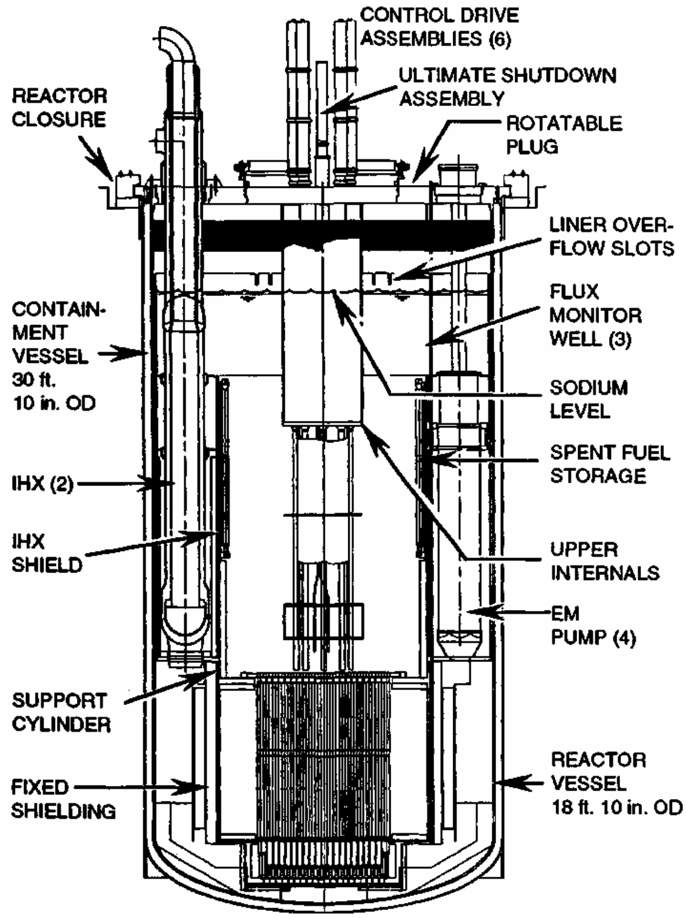
ALMR reactor vessel auxiliary cooling system.



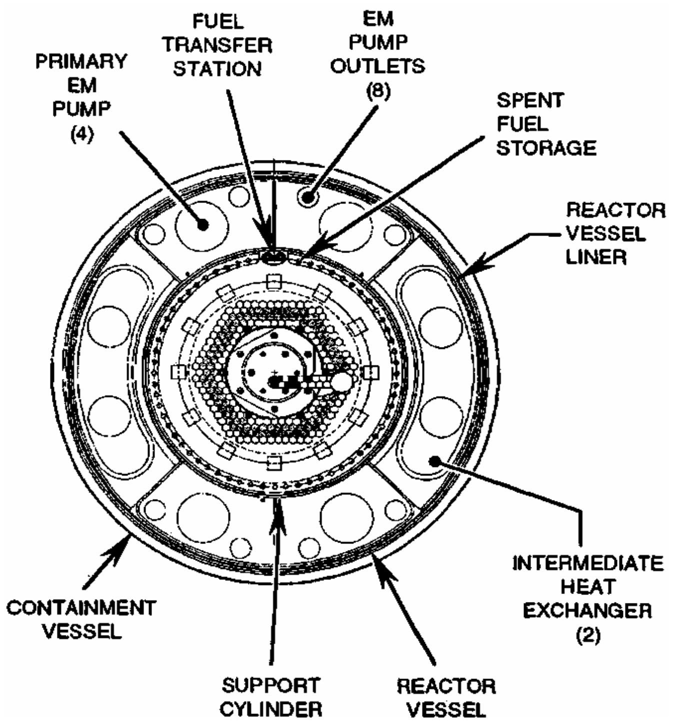
ALMR primary sodium and reactor vessel auxiliary cooling system (RVACS) air flow circuit using for heat removal.



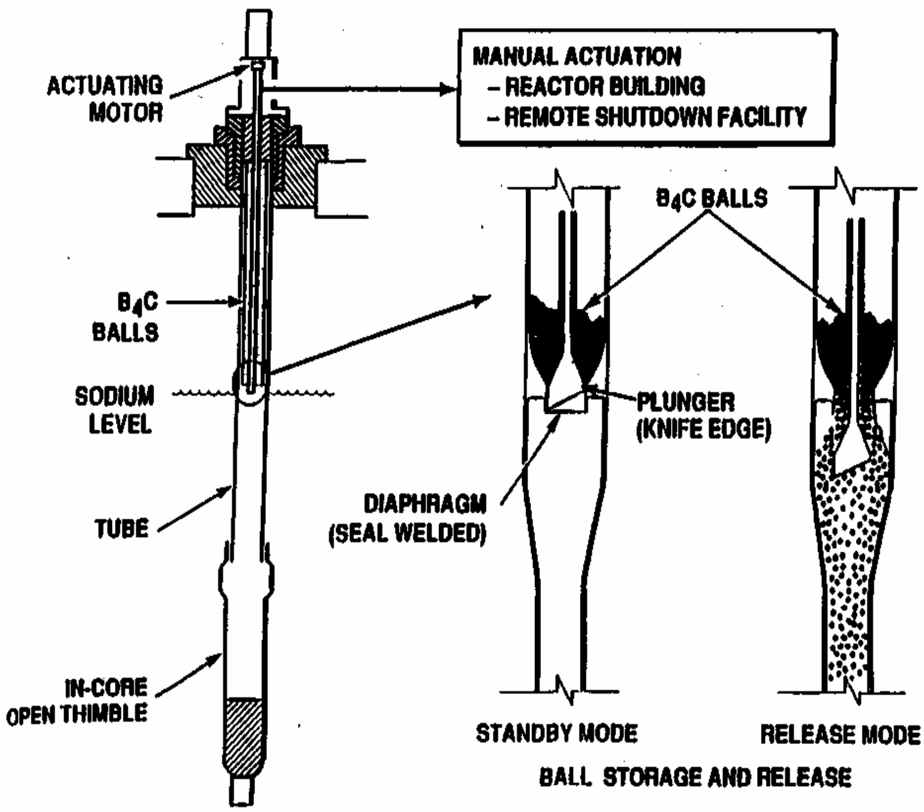
Reactor vessel auxiliary cooling system (RVACS) water model arrangement.



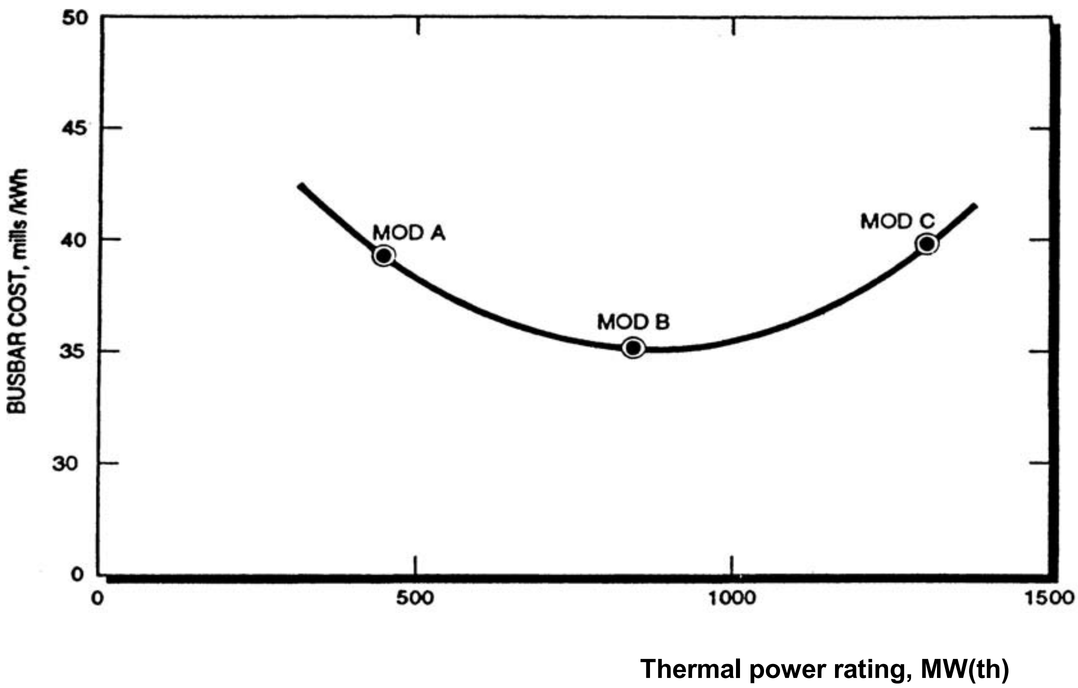
ALMR reactor modul (1 of 2).



ALMR reactor module (2 of 2).



ALMR ultimate shutdown system (USS) assembly.



Economic trend for the ALMR.

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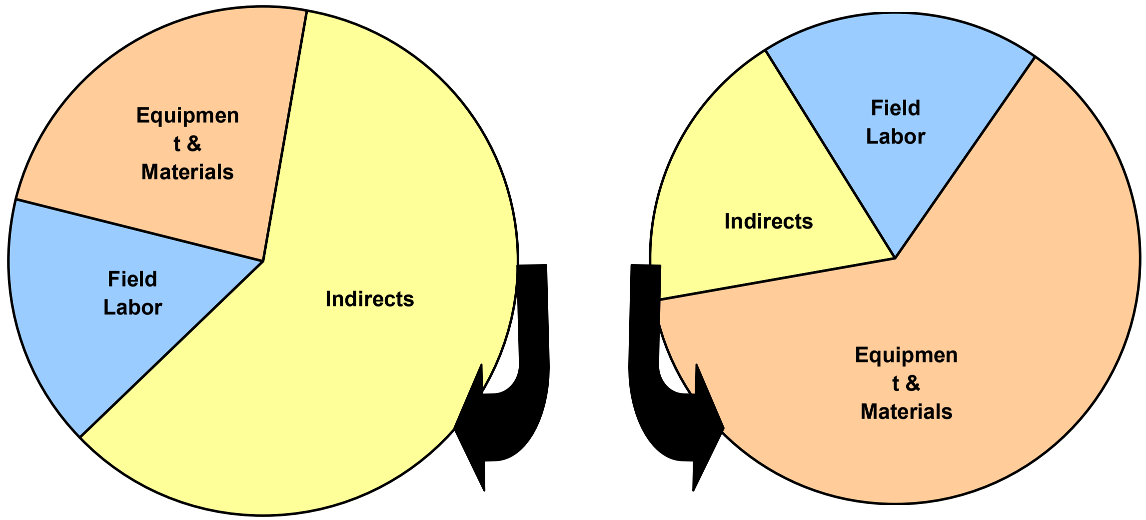


TRADITIONAL TECHNOLOGY (NPP WITH A HIGH SELF POWER REACTORS)

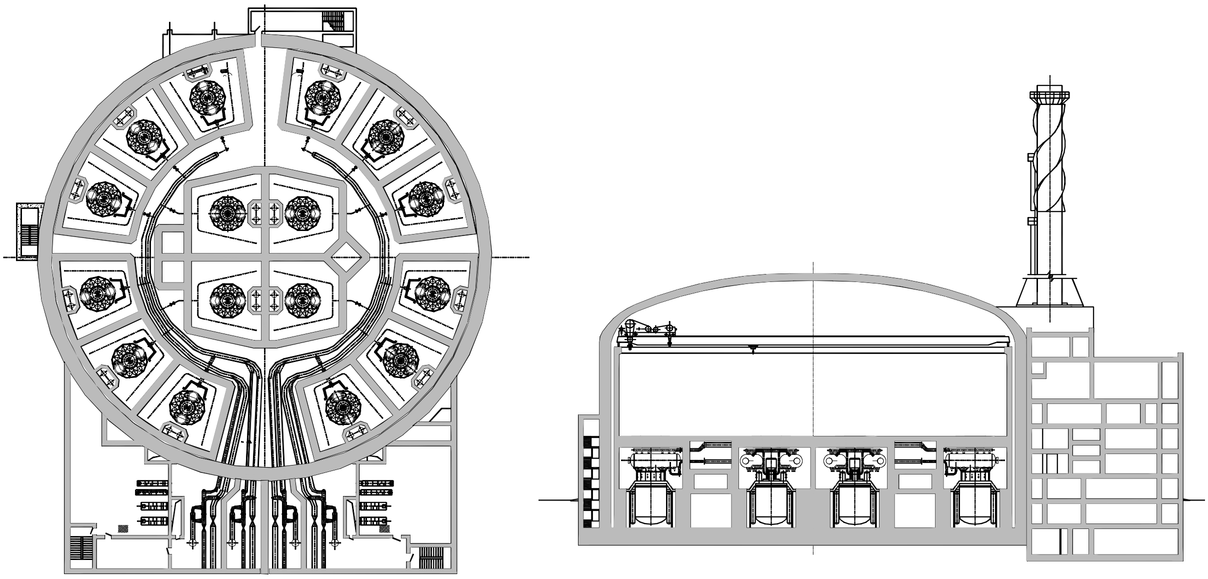
MODULAR REACTORS (PRISM/ALMR) ECNOLOGY (NPP WITH MODULAR REACTORS)

Nuclear power plant's cost structure.

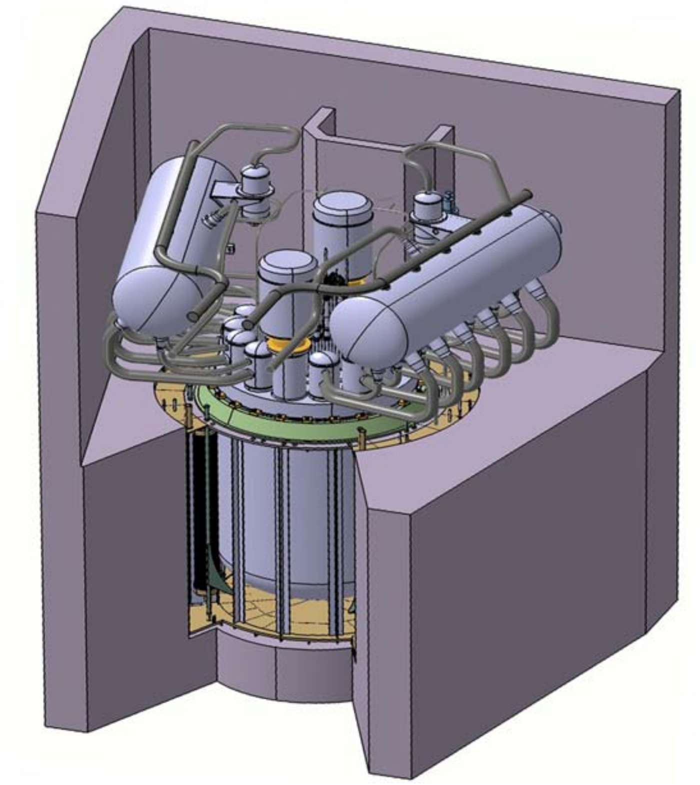
13.2.10. SVBR-75/100

The advantages of lead-bismuth and lead reactor cooling are high boiling temperatures and the relative inertness to water as compared with sodium. The melting and boiling points of sodium are 98 and 883°C respectively. For lead-bismuth eutectic, these values are respectively 123.5 and 1670°C, and for lead 327 and 1740°C at atmospheric pressure. In a lead-bismuth or lead cooled reactor, the coolant boiling point may increase up to about 2300°C because of high coolant pressure inside the core. However, the boiling points are well above cladding failure temperatures. The specific heat per unit volume of lead-bismuth and lead are similar to that of sodium, but the conductivities are lower by about a factor of four.

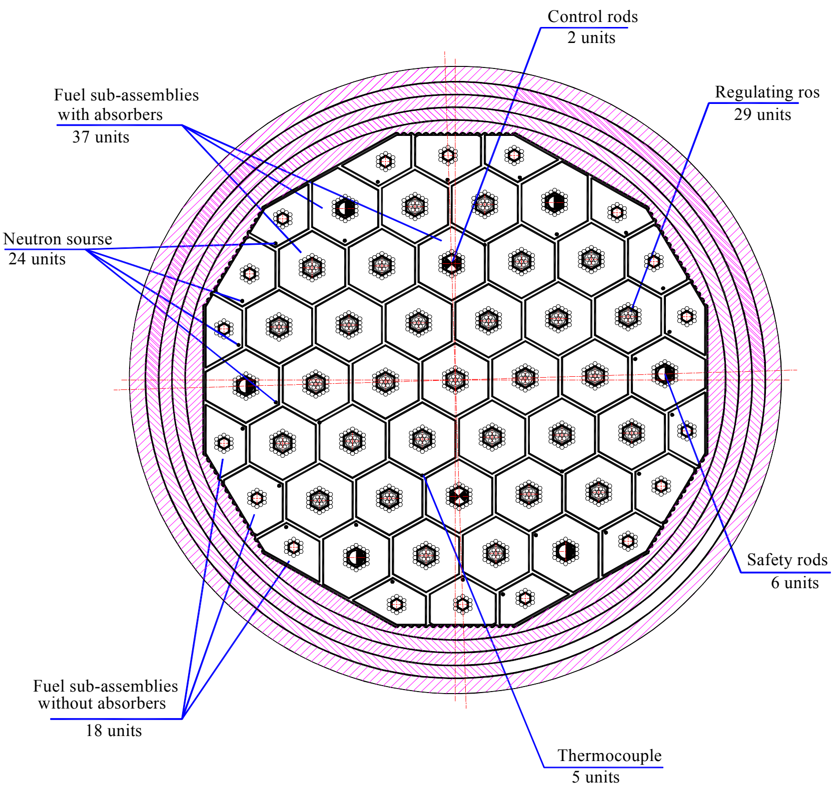
Studies of lead-bismuth cooled fast reactors have been carried out in the Russian Federation organizations SSC RF IPPE (Institute of Physics and Power Engineering and EDO GIDROPRESS, in which a great deal of experience has been accumulated in the course of the development and operation of submarine reactors cooled with lead-bismuth eutectic. The key results of operating experience of the propulsion nuclear steam supply system using lead-bismuth coolant, as well as R&D on lead-bismuth cooled reactor technology have been incorporated into the SVBR-75/100 reactor designs.



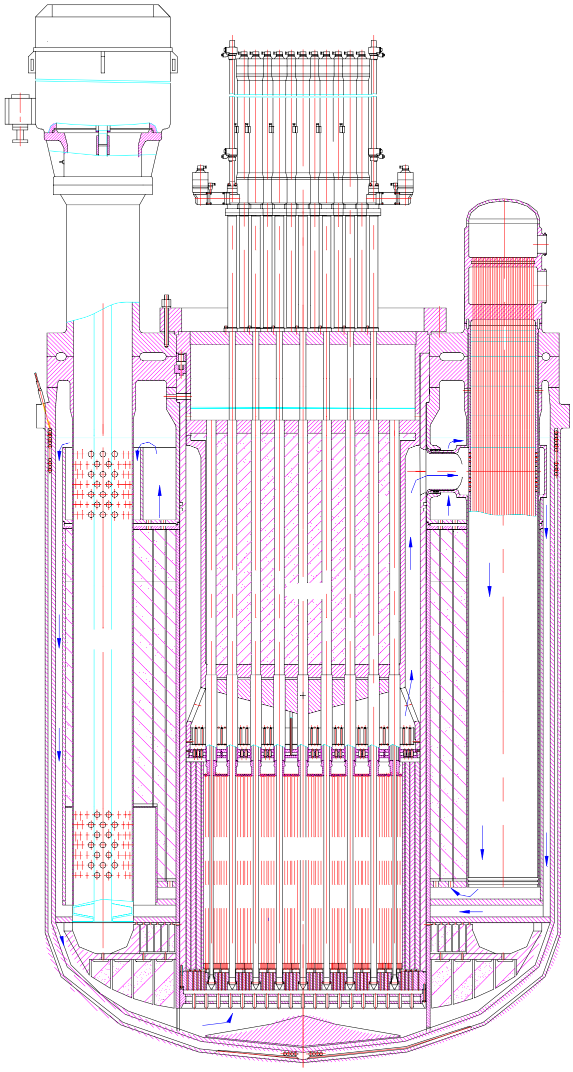
FR power block with 16 SVBR-100 (plan-on the left and plants cutway view-on the right).



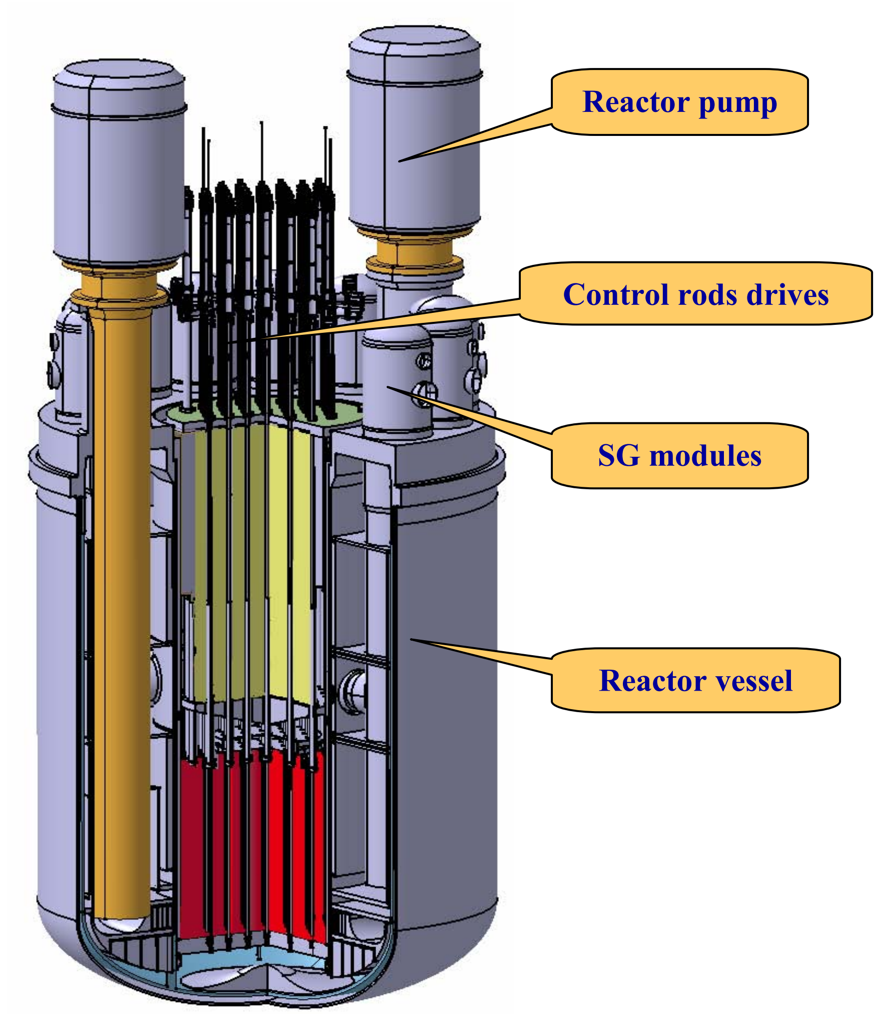
SVBR-75/100 reactor block.



SVBR-75/100 core layout.



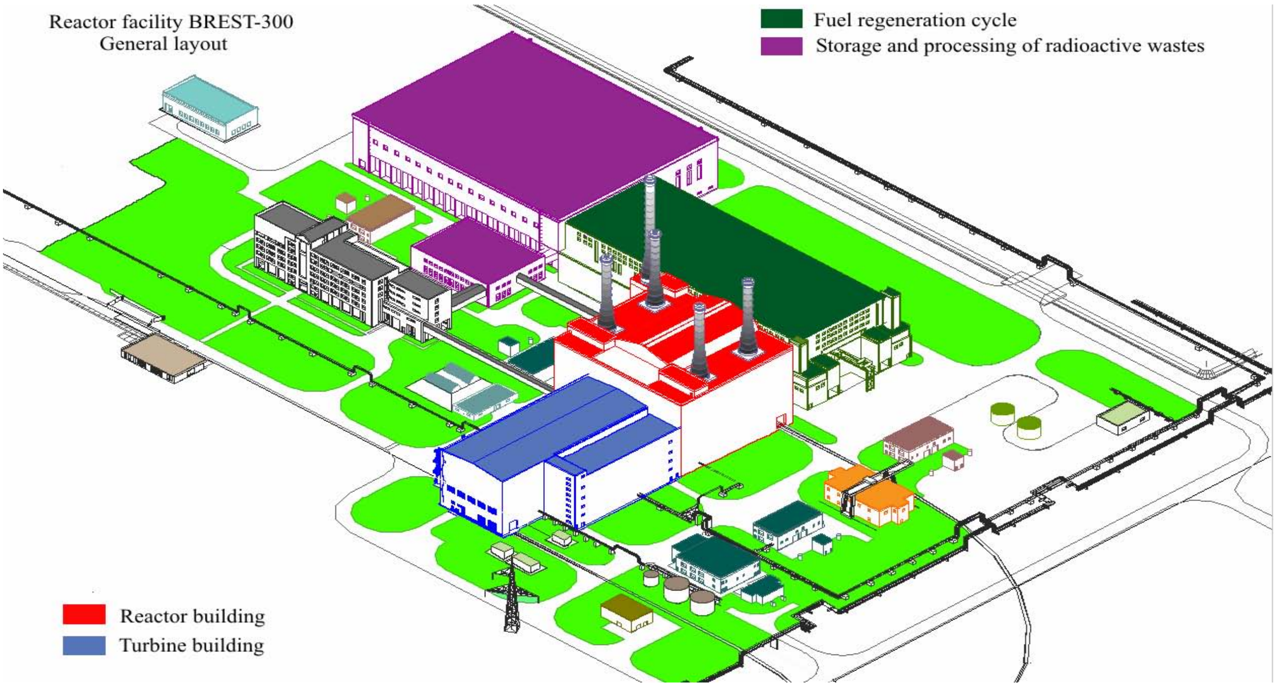
SVBR-75/100 reactor cut-away view (1 of 2).



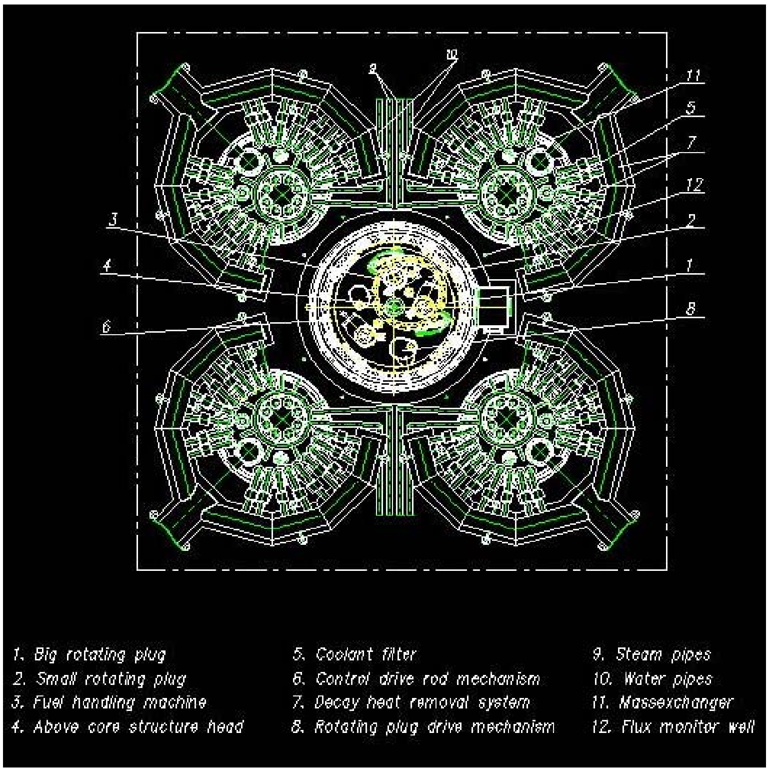
SVBR-75/100 reactor cut-away view (2 of 2).

13.2.11. BREST-OD-300

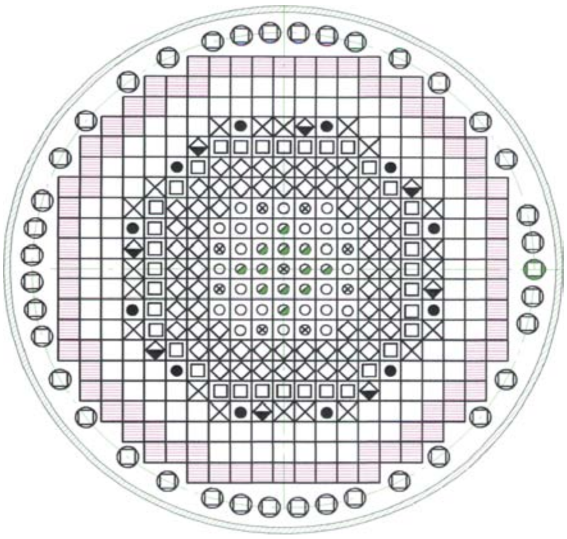
Activities in the fast reactor area in Russian Federation include design studies of fast reactors with alternative coolants, including lead (BREST-OD-300 and BREST-1200).



BREST-OD-300 overall survey.



BREST-OD-300 plan view.

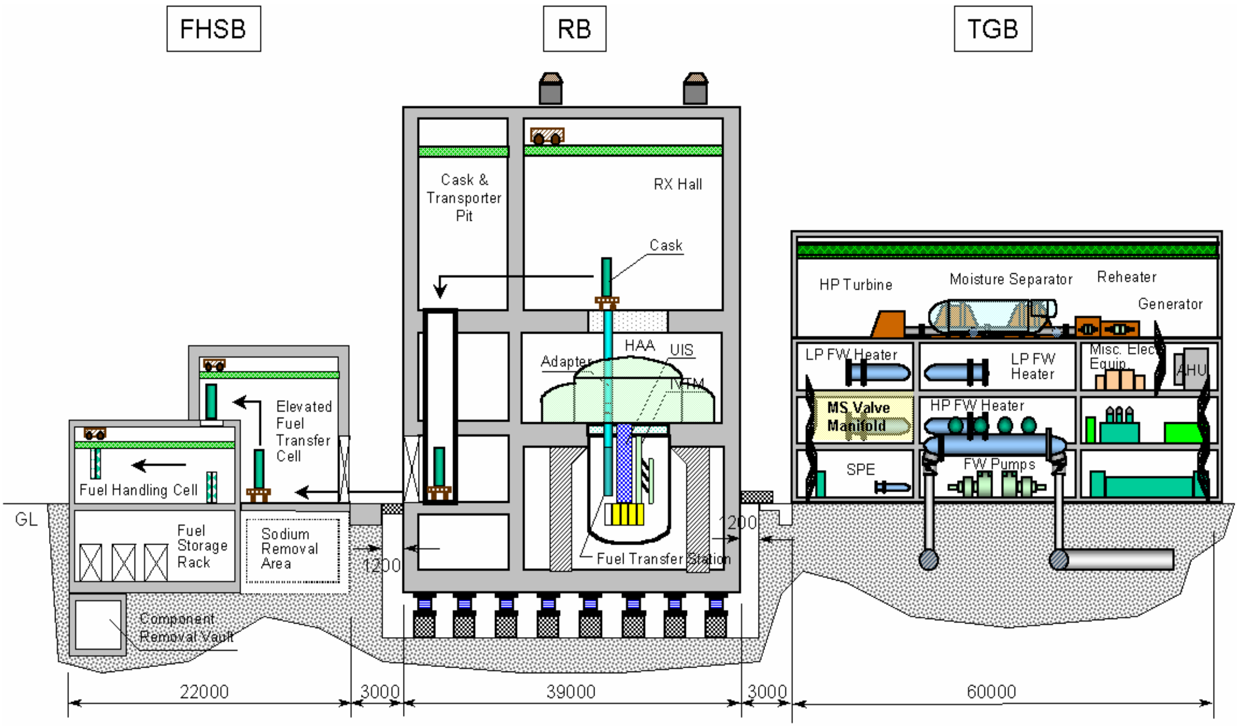


BREST-OD-300 reactor core configuration.

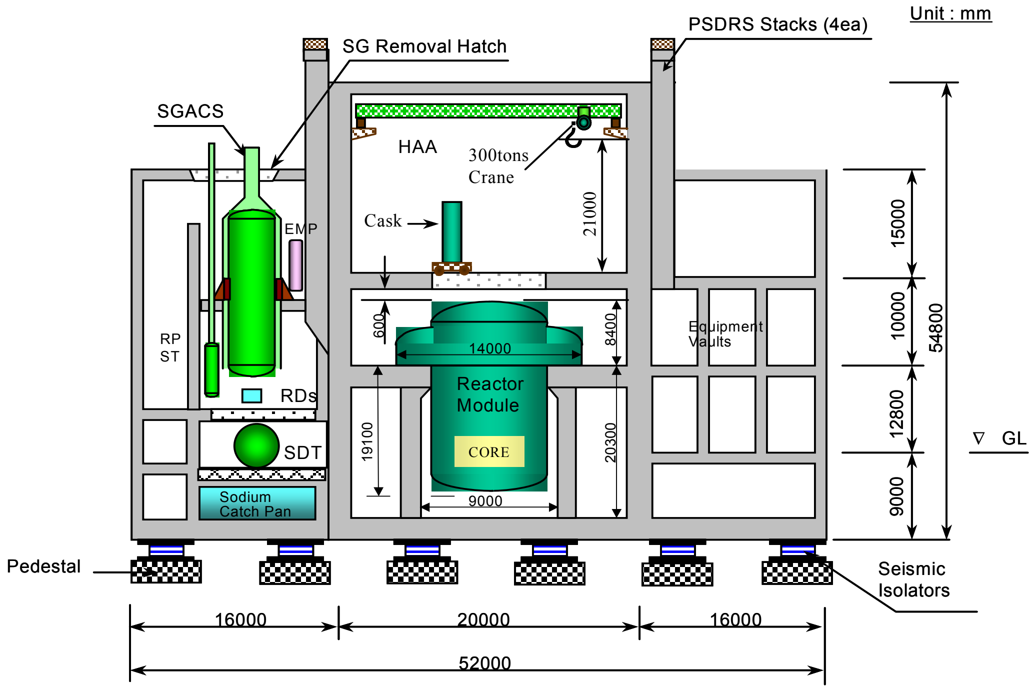
Type of subassembly	No
Fuel (inner) with emergency protection rods	45
Fuel (intermediate)	64
Fuel (outer)	36
Removal reflector blocks (total)	148
Removal reflector blocks with emergency protection rods	8
Removal blocks of reflector with control and reactivitycompensating rods	20
Removal reflector blocks with passive feedback features	12
Stationary reflector blocks	80
Block of fuel handling	1
Storage location	38

13.2.12. KALIMER-150

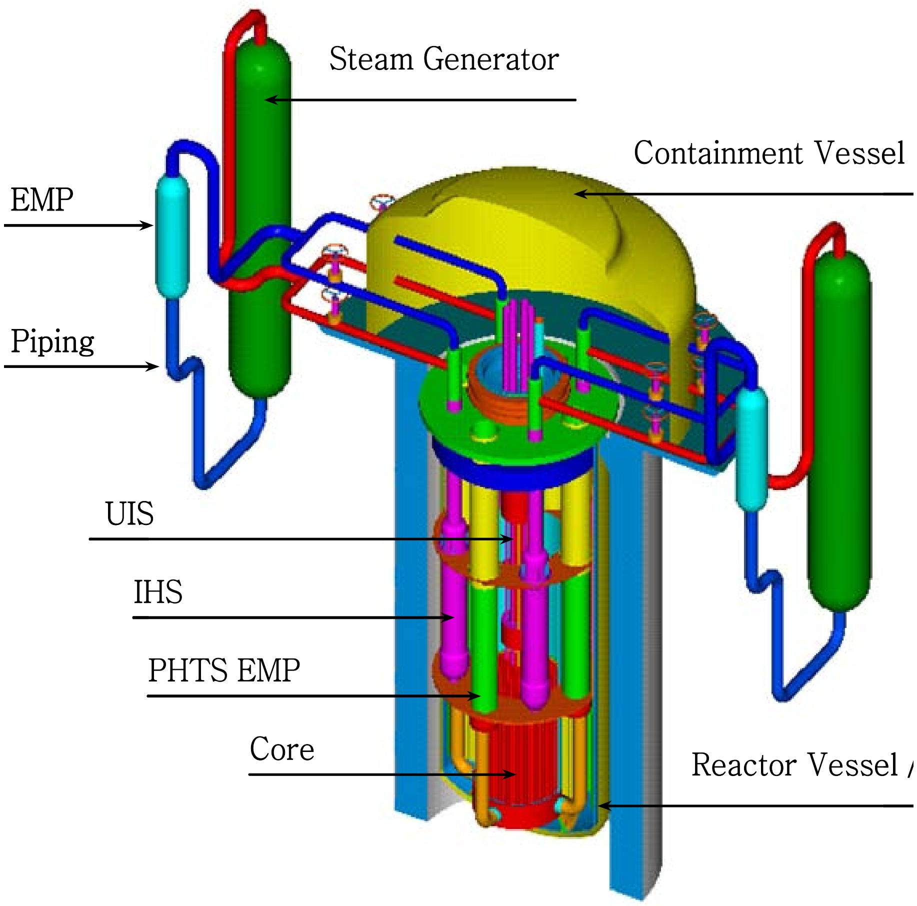
Republic of Korea's LMFR programme consists in the development of basic design technologies. During Phases 1&2 (1997–2001) of the programme, basic technologies and the conceptual design of KALIMER-150 of 150 MW(e) capacity has been developed. Basic key technologies and the advanced concept KALIMER-600 with a capacity of 600 MW(e) is being developed during Phase 3.



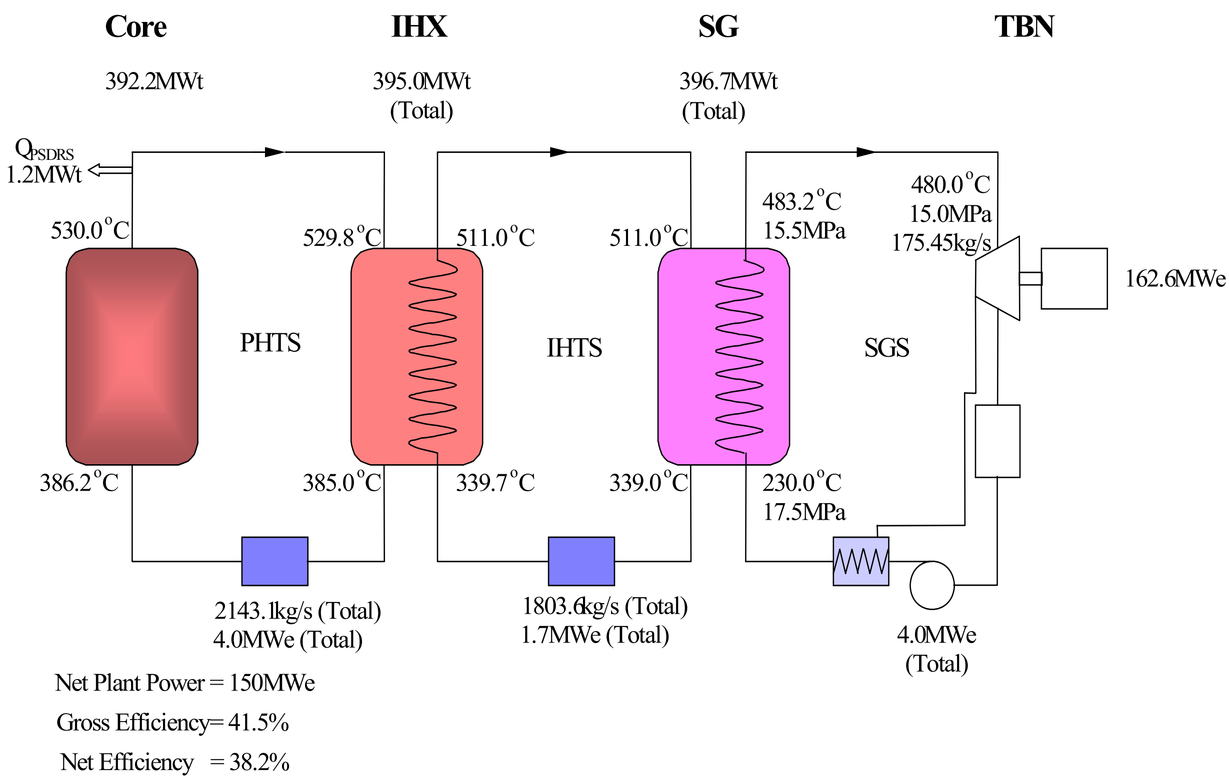
KALIMER-150 storage building-reactor building-turbine generator building; view of fuel handling.



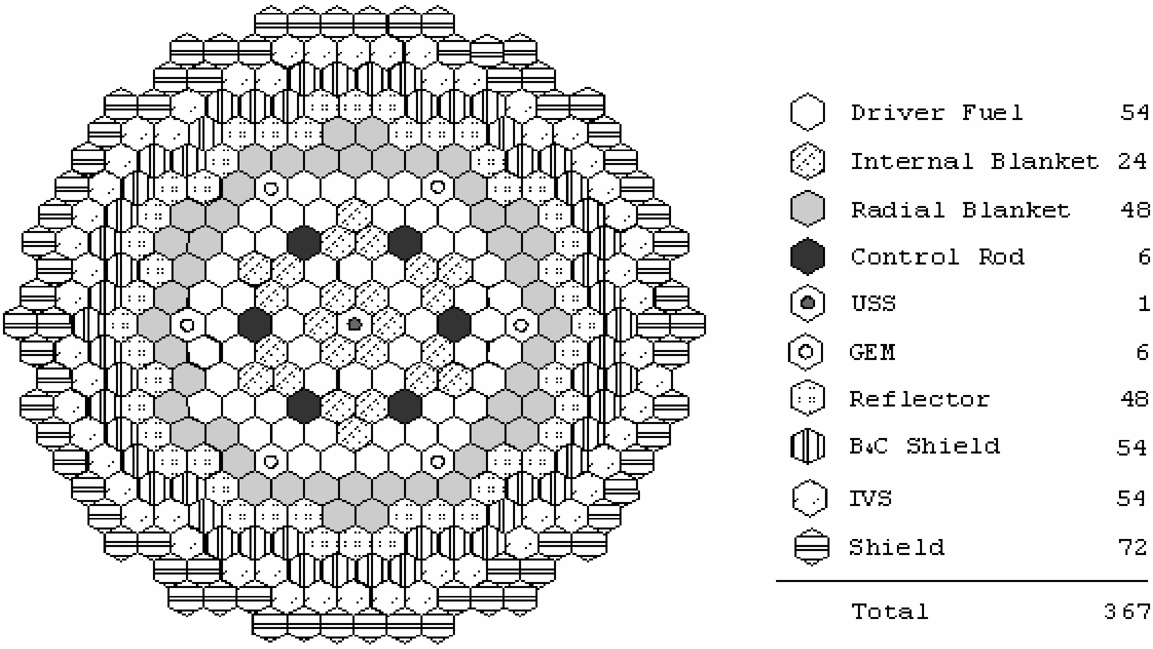
KALIMER-150 conceptual drawing of reactor building.



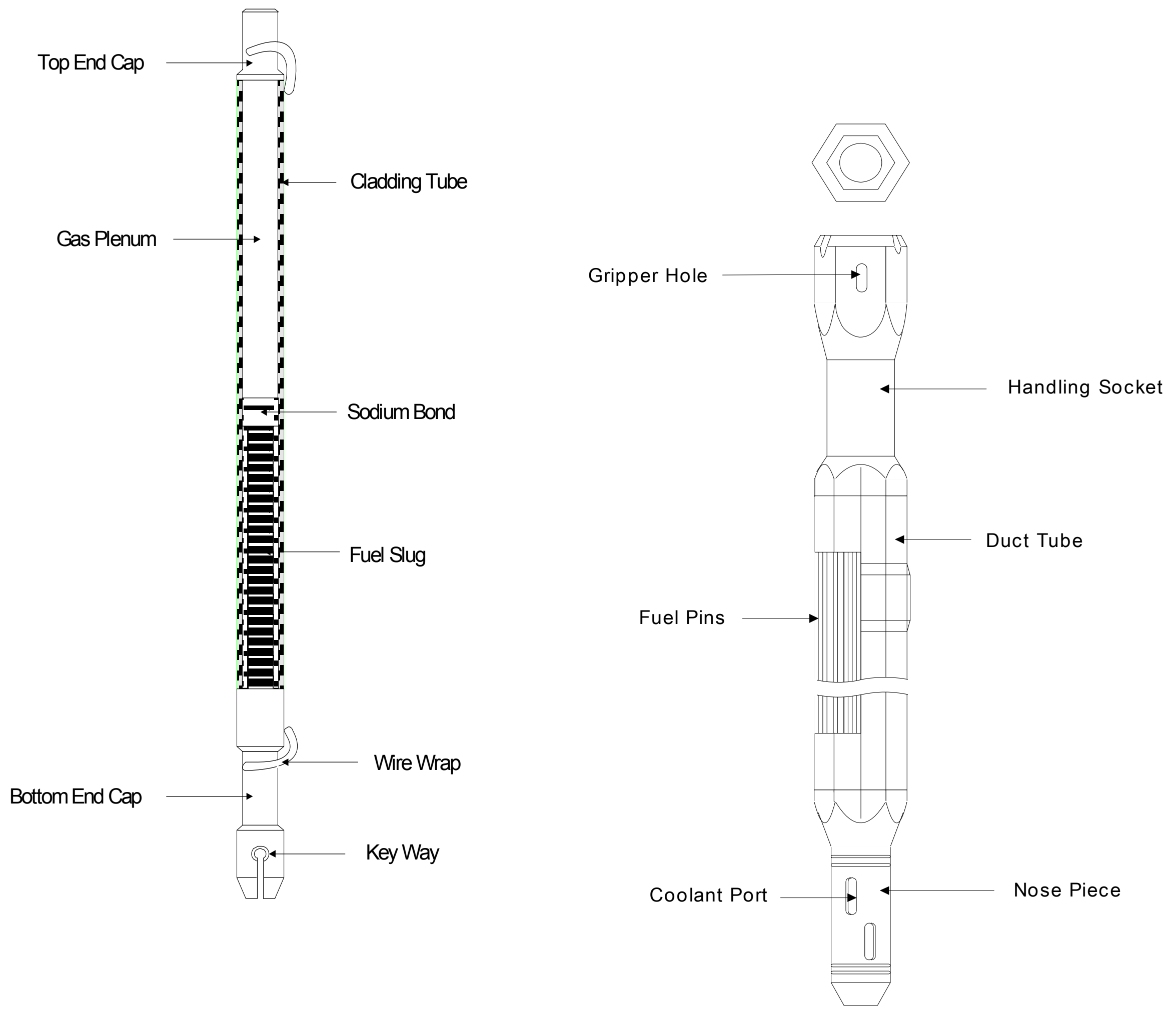
KALIMER-150 conceptually designed reactor structures.



Summary of the heat transport condition in KALIMER-150 at the 100% power operation.



KALIMER-150 core layout.



Schematic of the KALIMER-150 fuel pin along with key section view assembly duct.

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13.3. Commercial size fast reactors (unforeseen events)

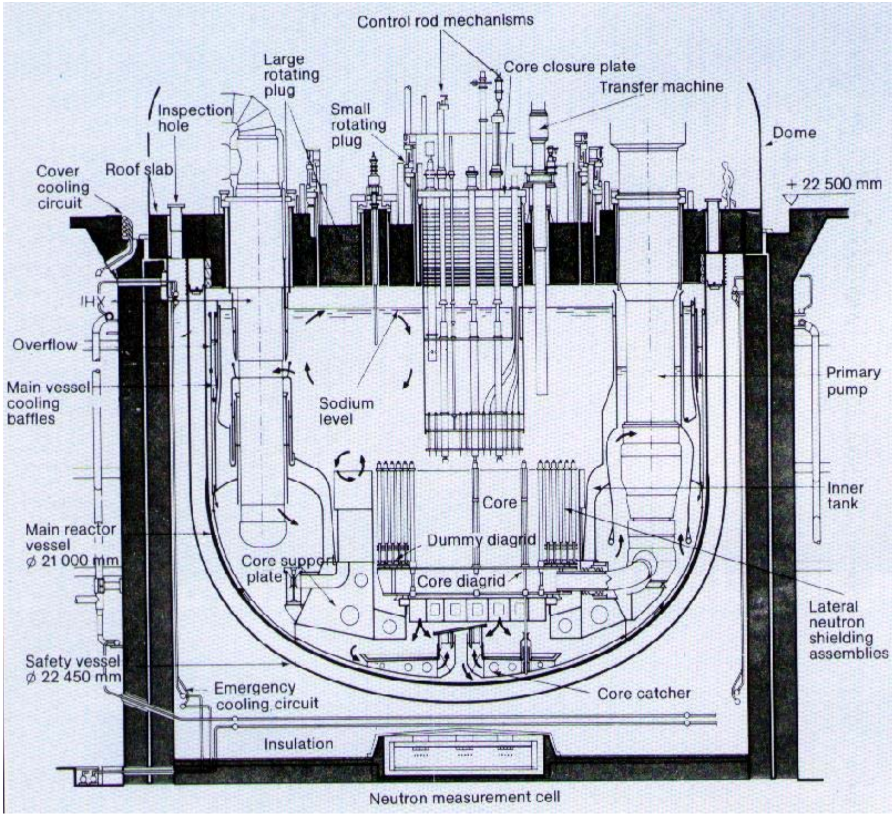
13.3.1. Super-Phénix 1

Super-Phénix 1 (SPX), worldwide the first large LMFR, was connected to the grid on 14 January 1986. Full power was reached on 9 December 1986.

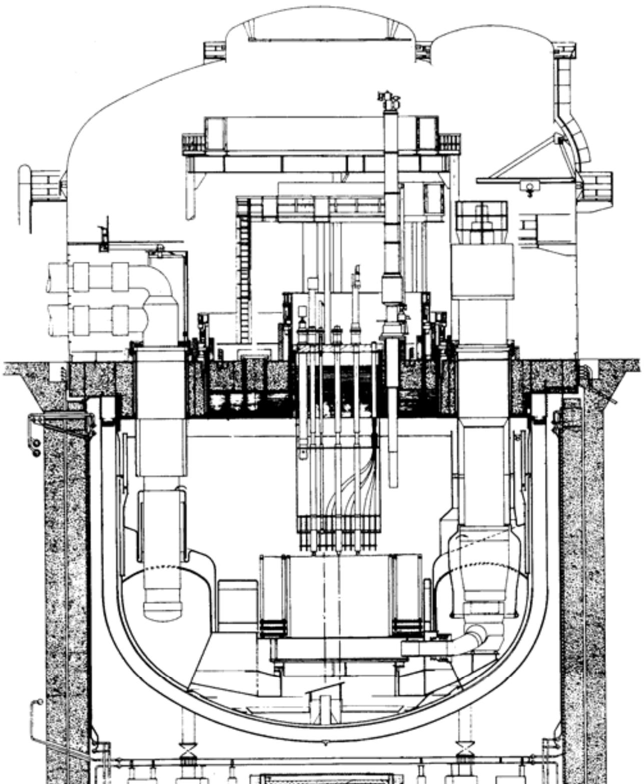
As a whole, operating experience of SPX was incomplete: over eleven years of existence it has been operating during four and half years producing 7.9 billion kWh (half of it in 1996). However, experience feedback on large components remains significant in spite of the short operating period. Primary and secondary pumps total more than 60 000 hours on main motor, and the continuous improvement of maintenance operations has allowed an increase in reliability and availability. As far as the steam generators are concerned, the sodium/water reaction detection systems have been improved on the basis of validated analytical methods through experience. The only experience in the world with 800 helical alloy 750 MW(th) SG units were obtained in SPX, where such SG units were installed and very successfully operated.

Numerous draining and filling operations (more than 30 for the secondary loops and more than 20 for the decay heat removal emergency circuits) have allowed validation of the corresponding procedures. Knowledge of primary circuit behaviour has in fact been improved thanks to natural convection tests which showed that natural convection was established in the core in about 5 minutes.

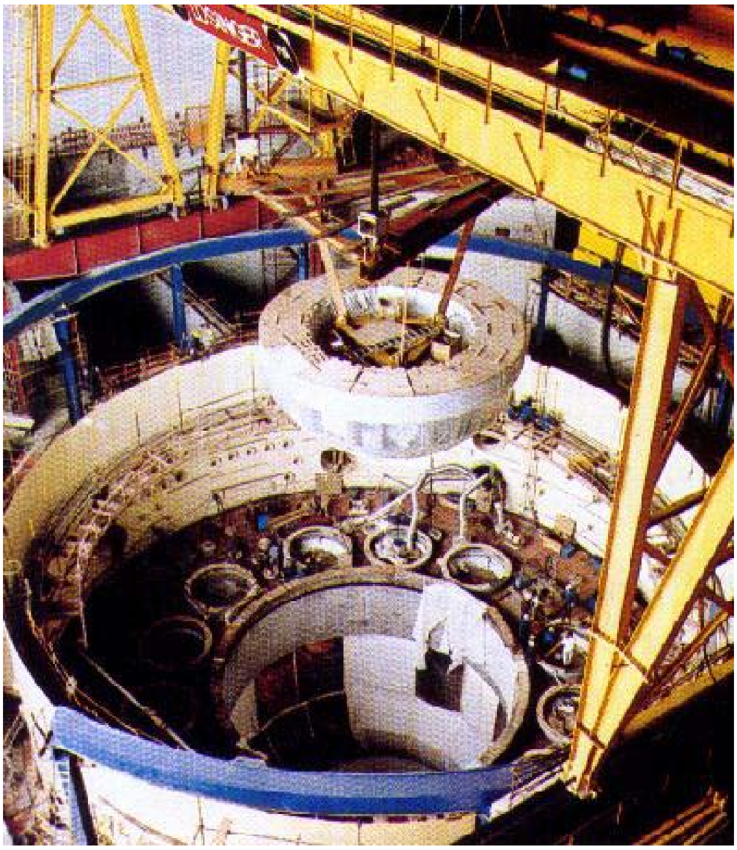
Super-Phénix 1 overall survey.



Super-Phénix-1 reactor vertical cross-section (1 of 2).

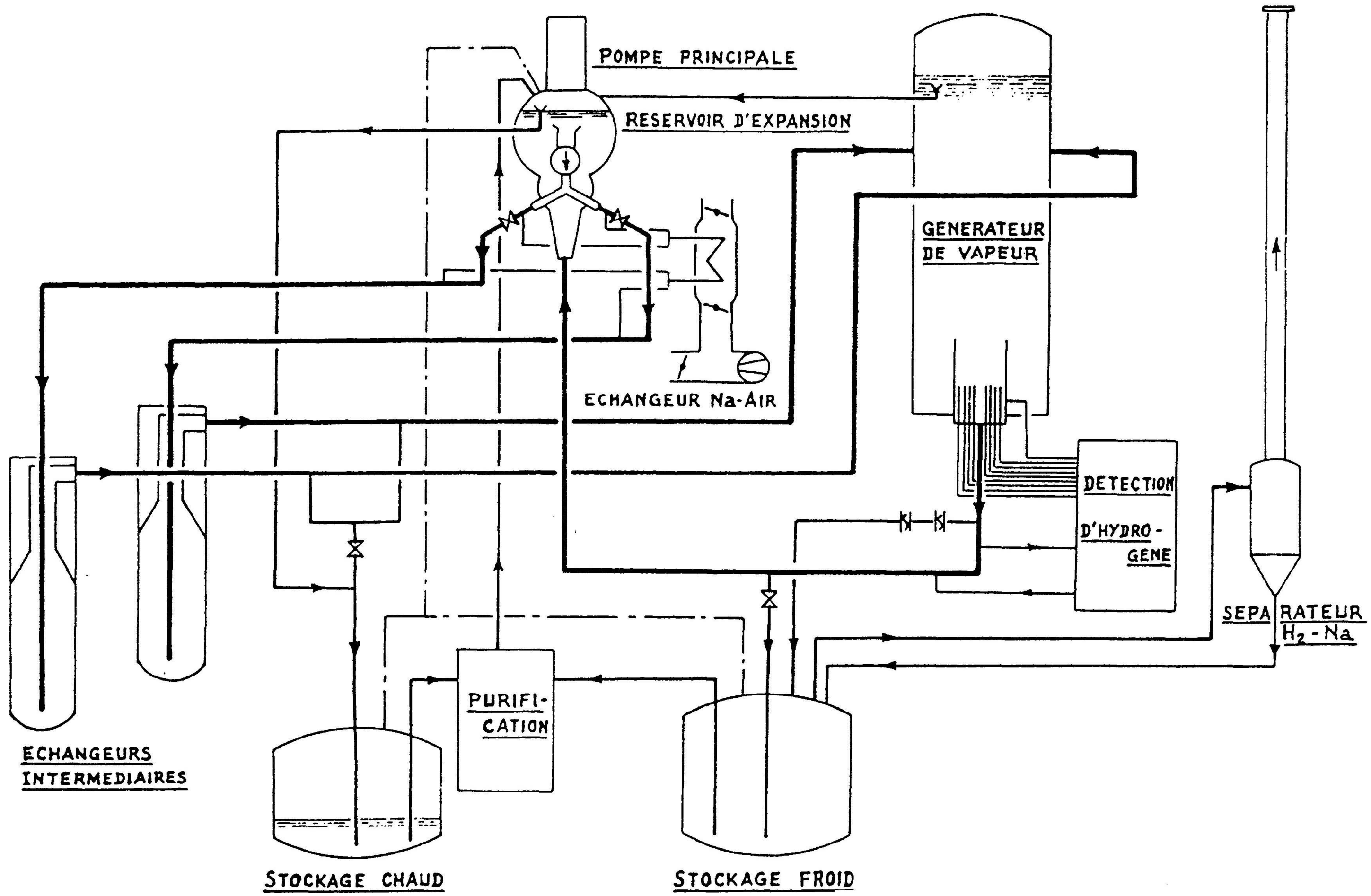


Super-Phénix 1 reactor vertical cross-section (2 of 2).

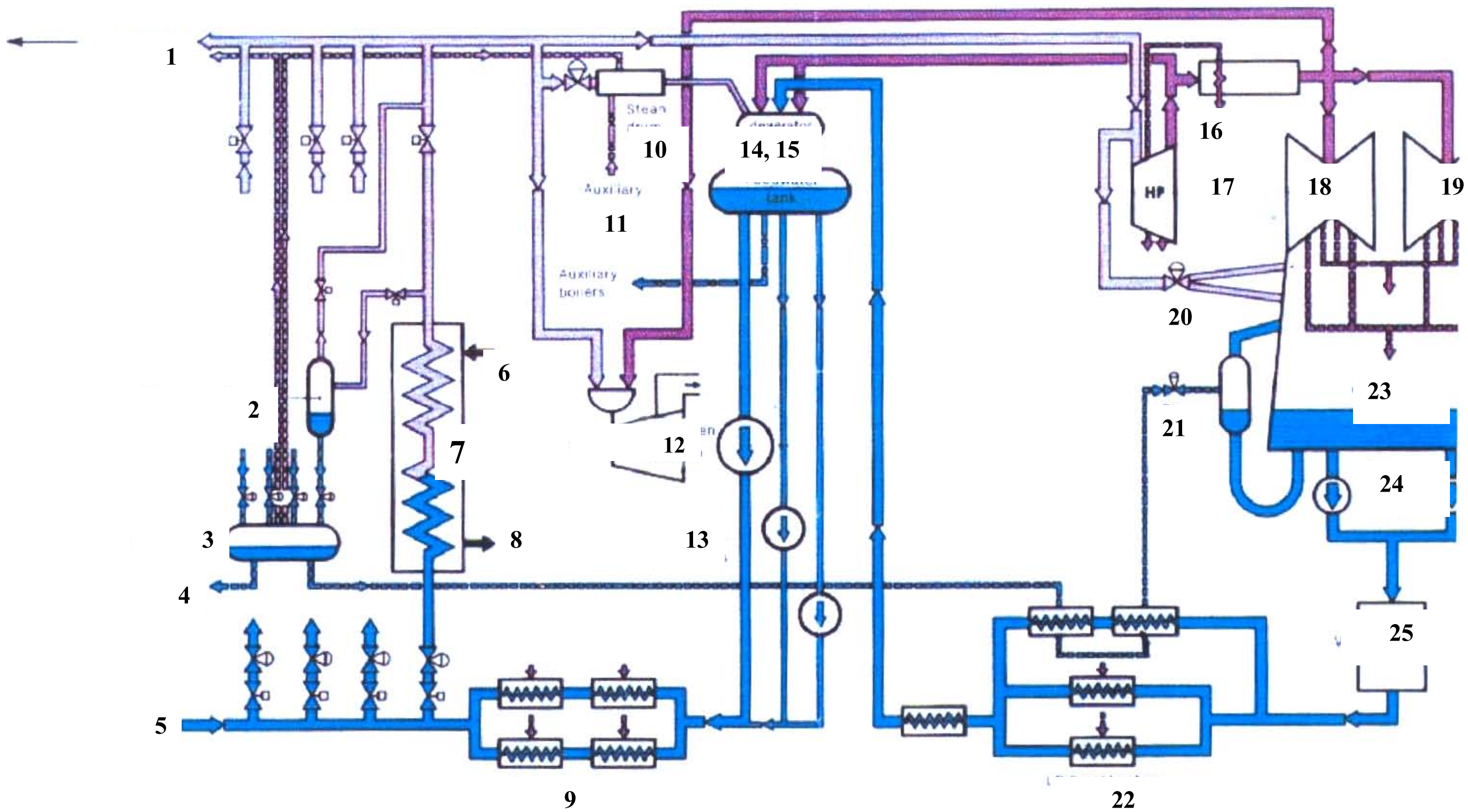


Super-Phénix 1 montage diagrid in the reactor vessel.

Super-Phénix 1 complete roof slab.

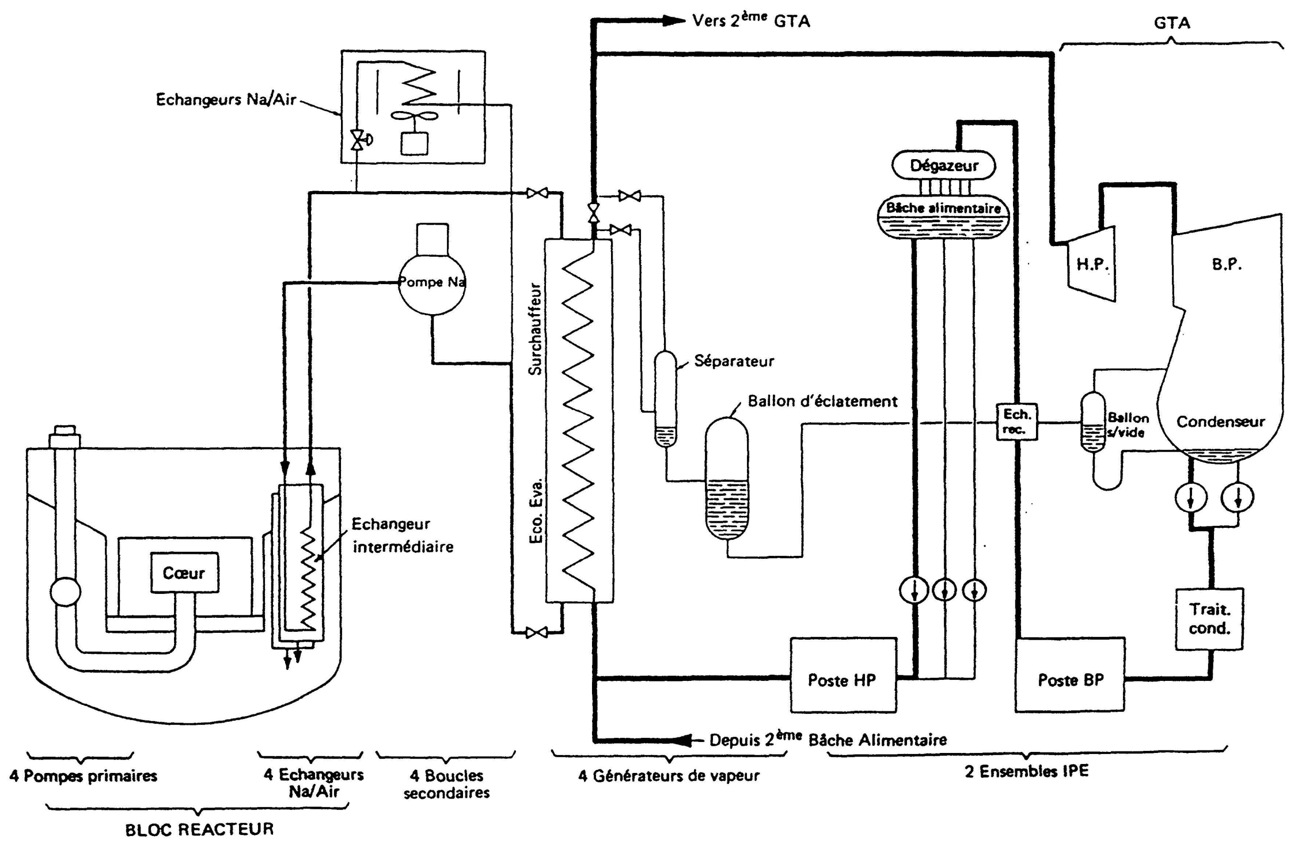


Super-Phénix 1 secondary circuit scheme.



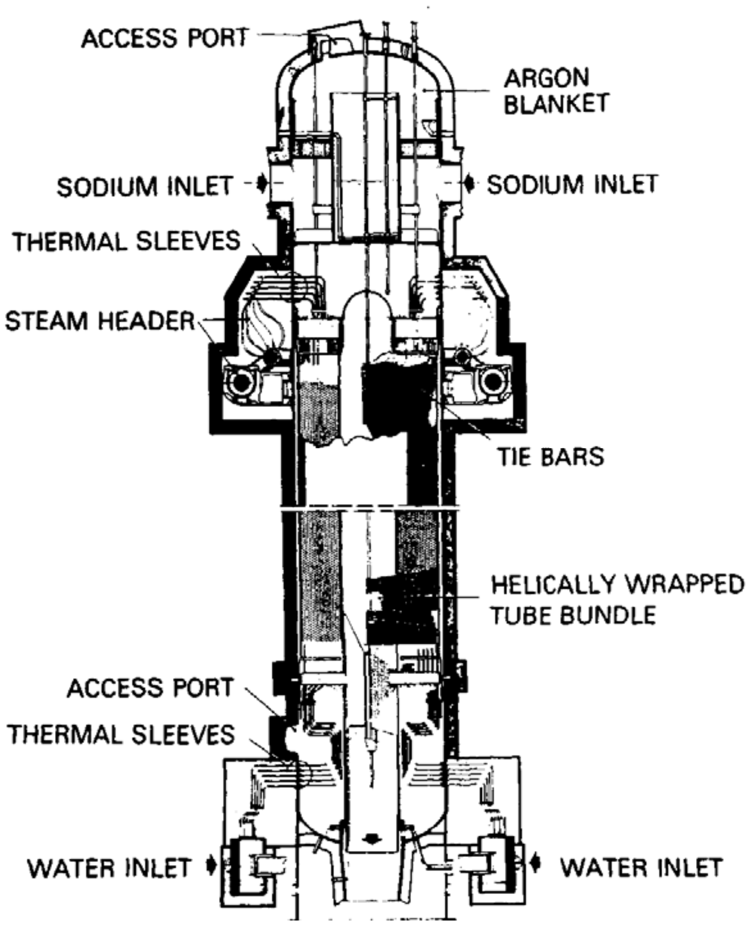
1-turbine, 2-start up tank, 3-flash tank, 4, 5-water treatment plant, 6, 8-sodium inlet/outlet,7-steam generator, 9, 22-HP, LP feed heaters; 10, 11-steam drum, auxiliary boiler, 12, 13-feed water pumps (12-turb. driven), 14, 15-deaerator-feed water, 6-reheator/moisture separator, 17, 18, 19-HP, LP1, LP2 turbine, 20-bypass, 21-blowdown tank, 23-condenser, 24, 25-extraction pumps, water treatment

Super-Phénix 1 steam-water flow scheme.

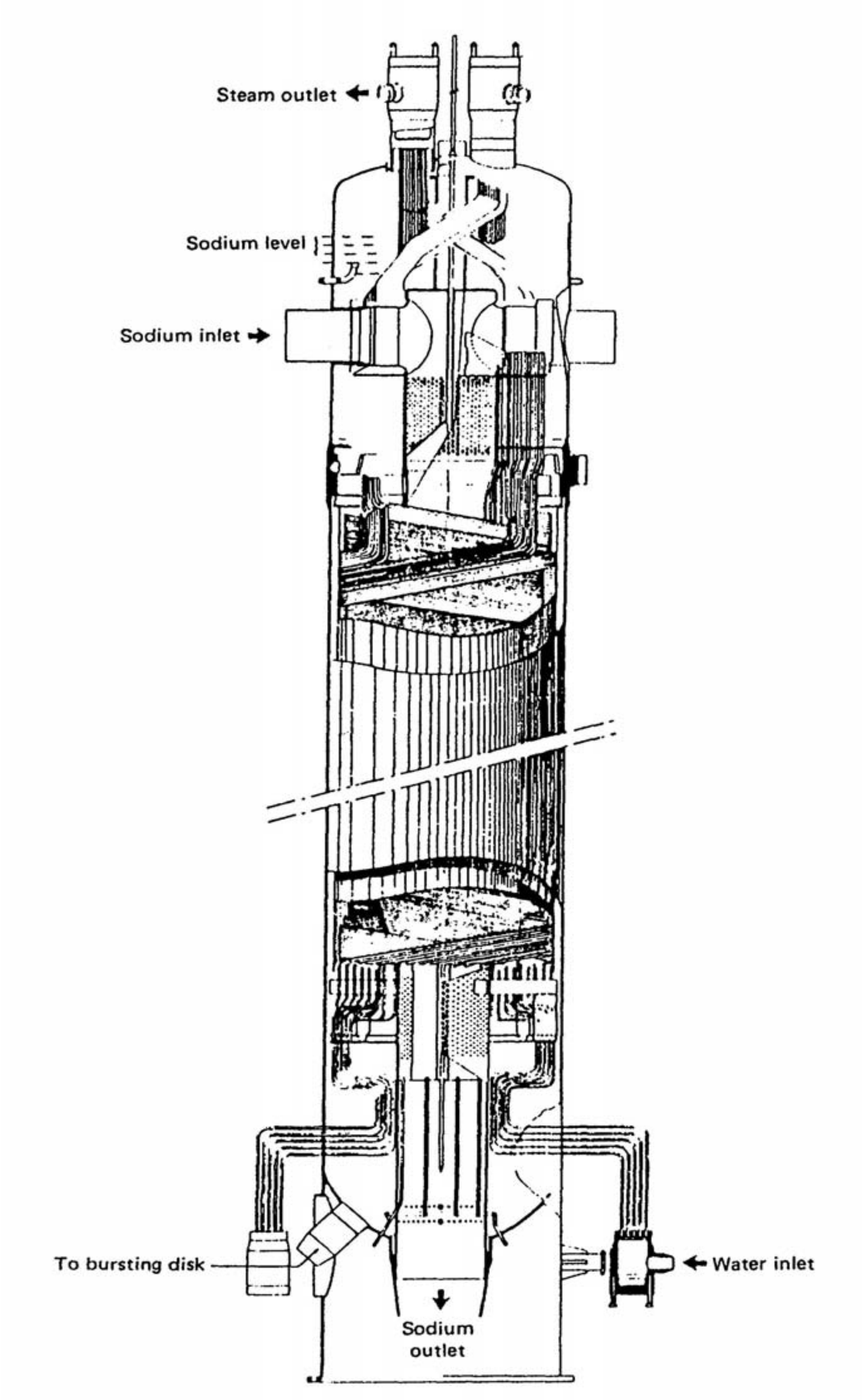


Super-Phénix 1 flow diagram.

Super-Phénix 1 turbine.

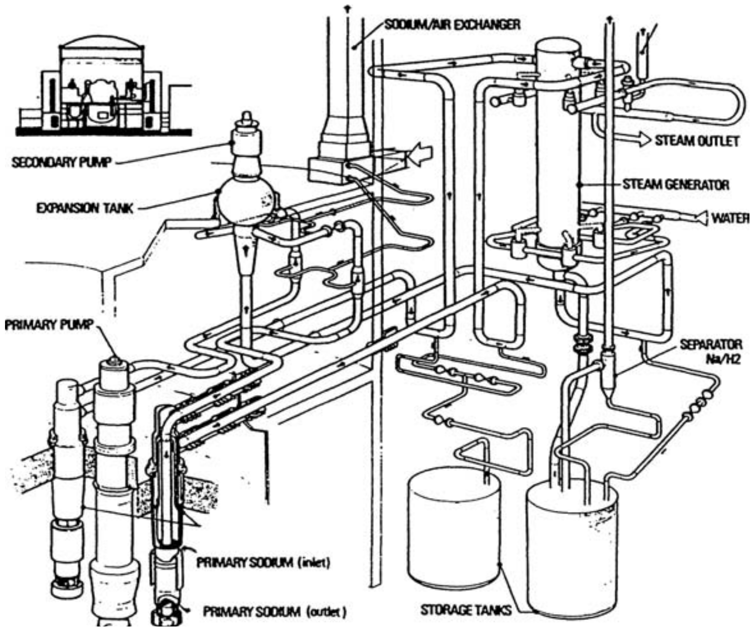


Super-Phénix 1 steam generator (1 of 2).

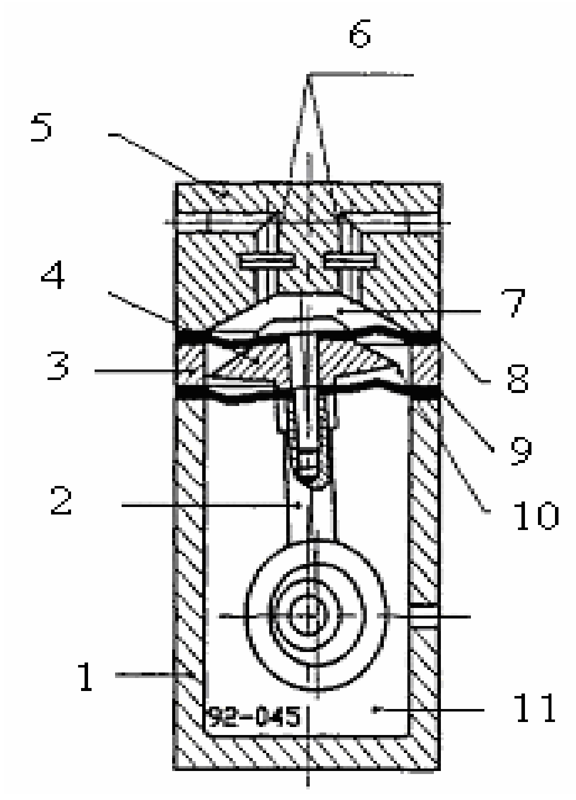


Super-Phénix 1 steam generator (2 of 2).[14]

[14] The outstanding success of the Super-Phénix 1 operation has undoubtedly been the demonstration of reliable operation of SGs with high self power (750 MW_{th}).



Super-Phénix 1 main secondary sodi circuits and steam generators together with the decay heat removal system.



1-compressor bode
2-main rod
3-intermediate ring
4-top of connecting rod
5-head
6-closures
7-compression chamber
8-neoprene working diagram
9-neoprene safety diagram
10-safety chamber
11-control unit

Compressor of the Super-Phénix 1 gas system.[15]

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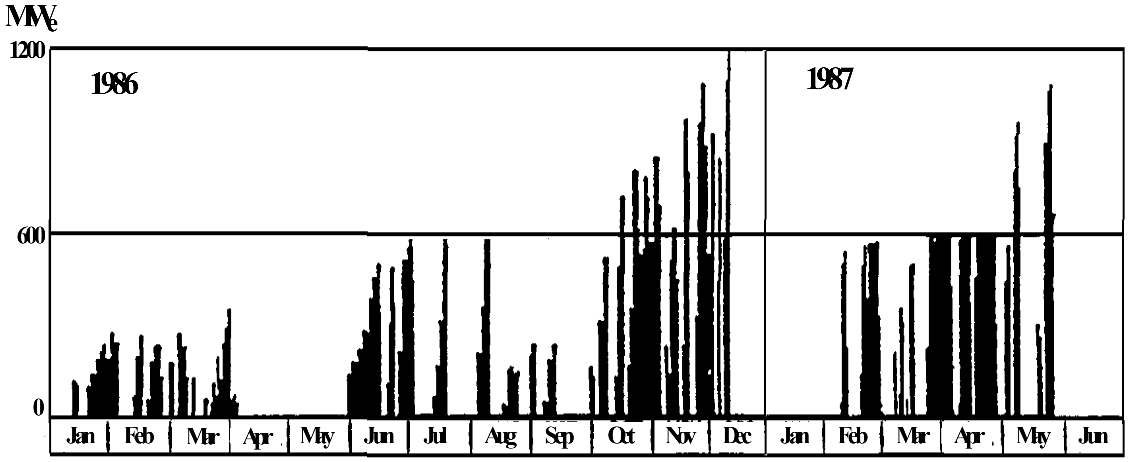
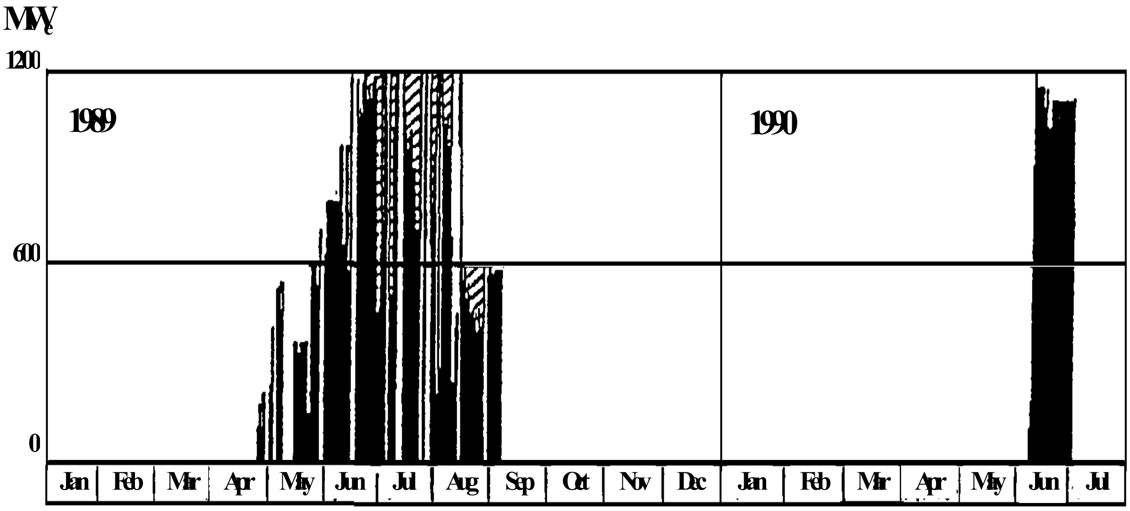
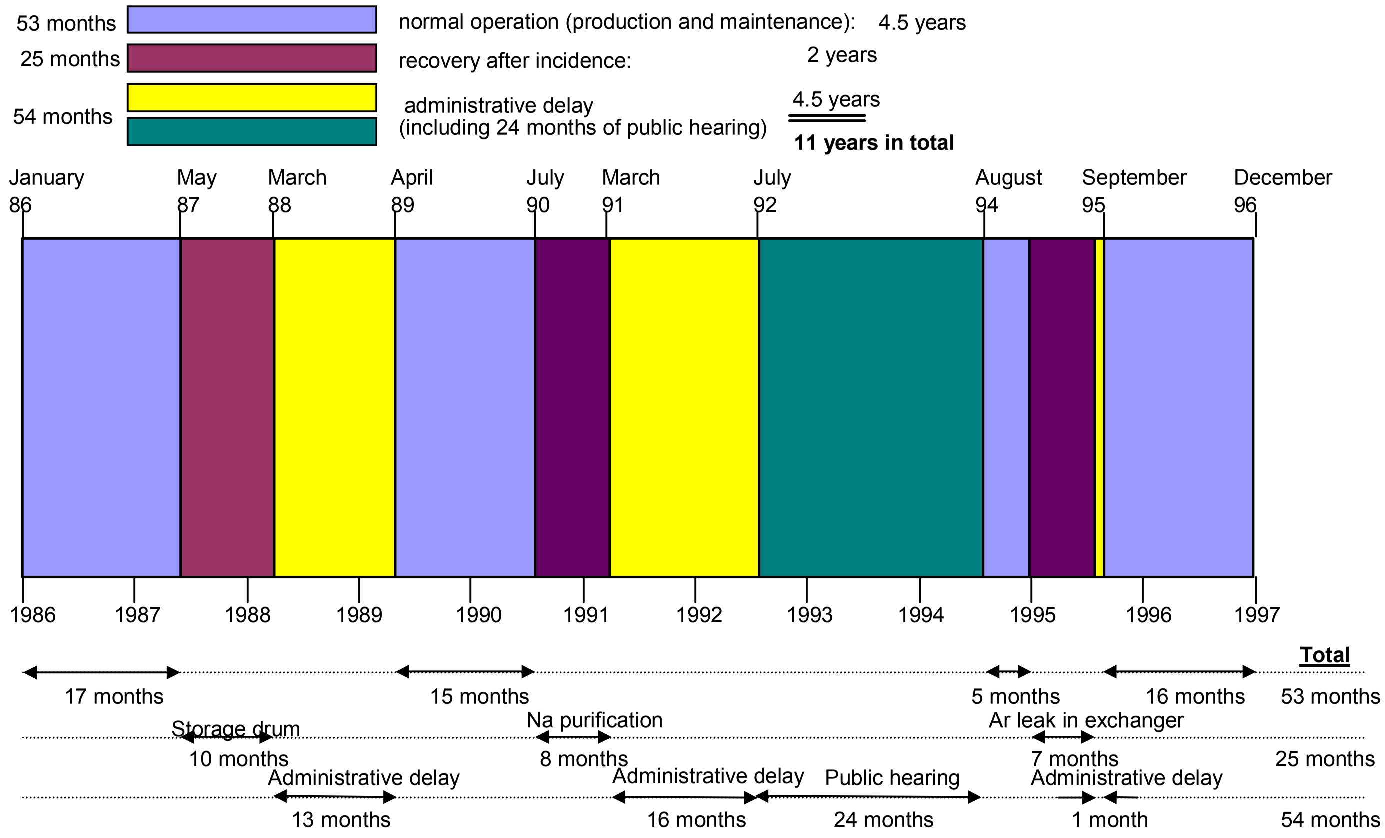
[15] The membrane of one compressor was defective for a long time, and about 600 L/hour of an argon and air mixture entered the reactor downstream of this circulation pump. The amount of sodium oxide produced was estimated to amount to 350-400 kg. Subsequent cleaning of the contaminated sodium took several months and was managed by the in-plant cold traps.



Super-Phénix 1 commissioning steps after link-up.



Super-Phénix 1 operation after fuel storage drum shutdown period (July-August 1989: limited power due to Rhone water temperature and flow and A turbine unavailable).

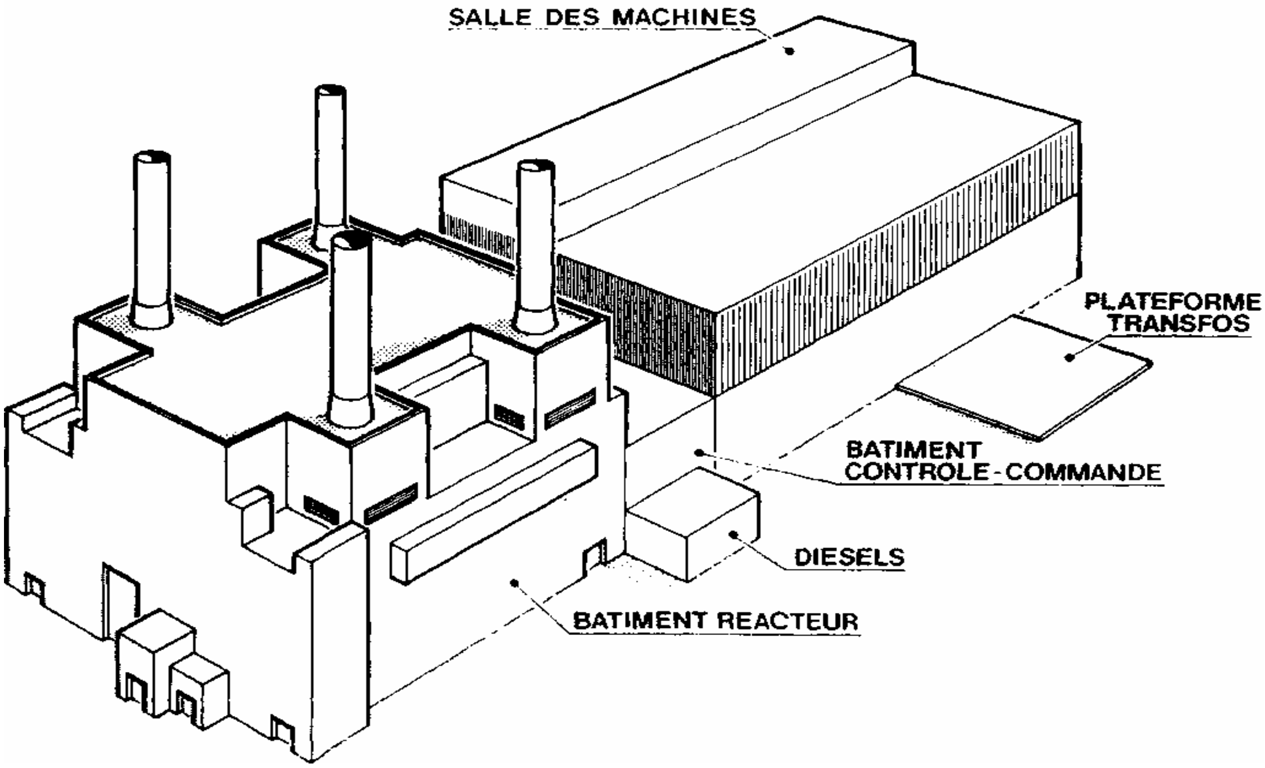


Super-Phénix 1 the operating and administrative history.[16]

[16] Three incidents marred the commissioning procedure and caused lengthy delays. A large social response on any incident existed because in the time of SPX commissioning anti-nuclear sentiments raised by Chernobyl in some social groups and governmental structures were too strong. With downturns in energy demand and political changes in 1998 the left French Government finally confirmed to discontinue it operation.

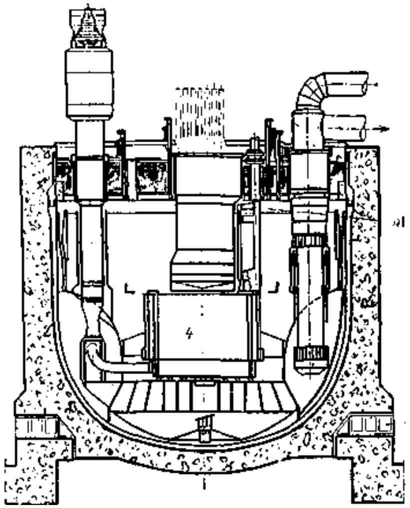
13.3.2. Super-Phénix 2

Super-Phénix 2 (SPX-2), project subsumed into EFR.

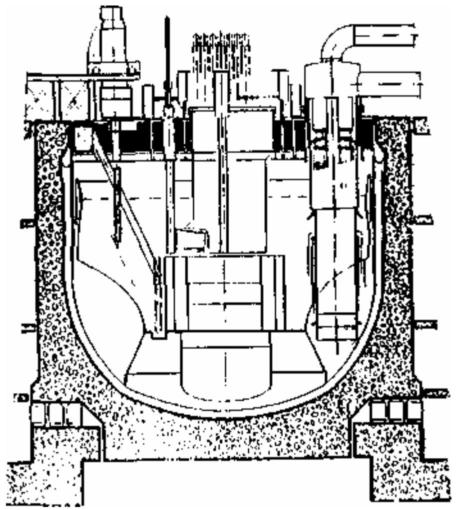


Super-Phénix 2 power plant building.

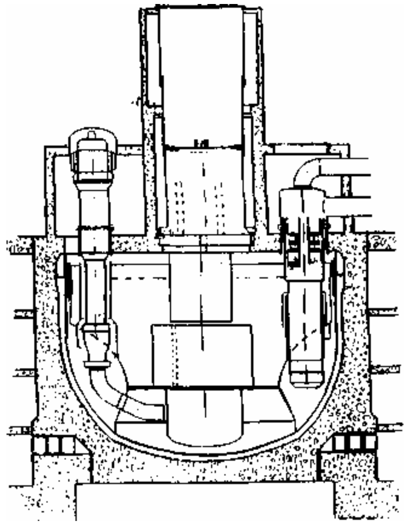
SPX-2 SHORT TERM



SPX-2 MEDIUM TERM



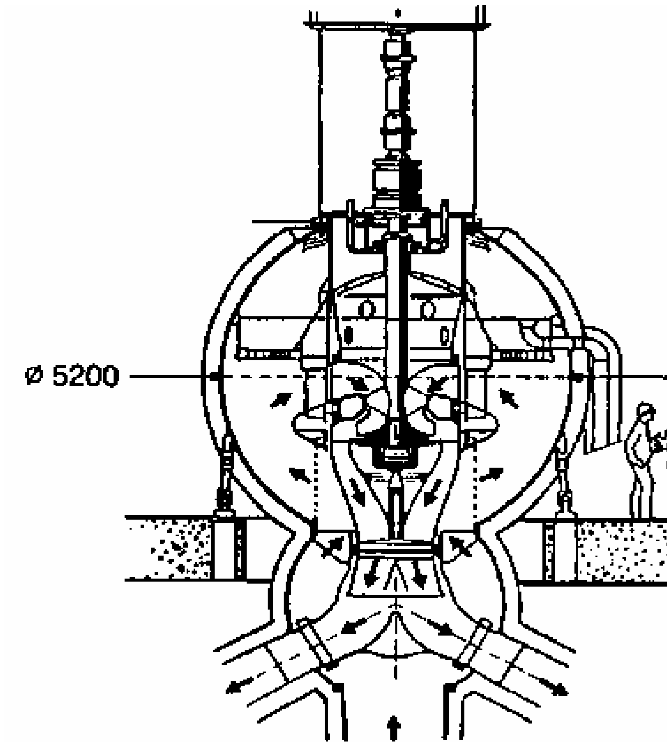
SPX-2 LONG TERM

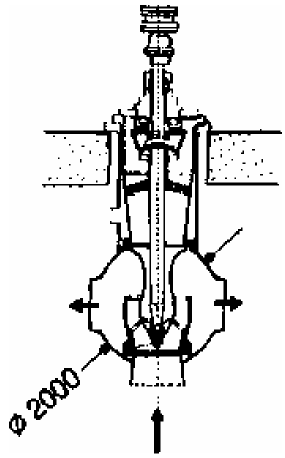


SPX-2 SHORT TERM
- 8 IHX+4 PP (sub critical shaft)
- under sodium tubesheet IHX
- in-core storage
- 2 rotating plugs, single transfer arm
- steel mass M_{st} = 3 400 tons (2.3 tons/MW(e))
- D_r = 20 m
- H_r = 18 m.

SPX-2 MEDIUM TERM
- 6 IHX+3 PP (super critical shaft)
- raised tubesheet IHX
- no in-core storage
- 2 rotating plugs, transfer arm and direct lift
- steel mass M_{st} = 2 800 t (1.85 t/MW(e))
- D_r = 17 m
- H_r = 17 m.

SPX-2 LONG TERM
- 6 IHX+3 PP (super critical shaft)
- raised tubesheet IHX
- no in-core storage-refuelling cell with fuel handling machine
- steel mass M_{st} = 2 500 t (1.65 t/MW(e))
- D_r = 16 m
- H = 15 m.





Super-Phénix 1 *Super-Phénix 2*

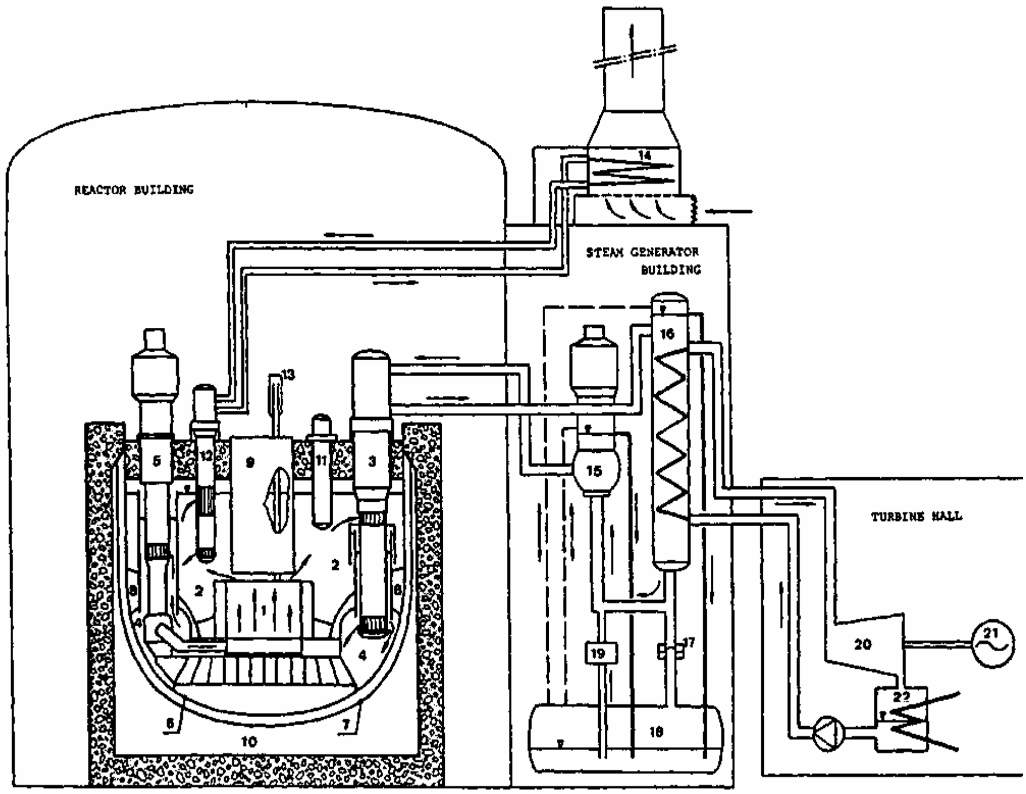
Sketch of the two secondary pump types.

	Super-Phénix 1	Super-Phénix 2
Type	Centrifugal	Mixed flow
Capacity	3.8 m^3/s	4.5 m^3/s
Head	28.1 m	28.9 m
Speed	500 rev/min	945 rev/min
Temperature	345°C	345°C
Total weight	24 500 kg	12 500kg
Relation of manufacturing costs	100	53
Expansion tank weight	40 500 kg	-

Overview: Super-Phénix 1 and Super-Phénix 2 secondary pumps.

13.3.3. SNR-2[24]

Project subsumed into EFR.



1) core
2) hot collector
3) intermediate coll
4) cold collector
5) primary pump
6) reactor vessel
7) guard vessel
8) intermediate collector
9) core cover plug
10) reactor pit
11) primary sodium purification
12) decay heat removal cooler
13) absorber
14) sodium-air heat exchanger
15) secondary pump
16) steam generator
17) burst disc
18) expansion tank
19) secondary sodium purification
20) turbine
21) alternator
22) condenser

General scheme of SNR-2 plant.

[24] Project subsumed into EFR.

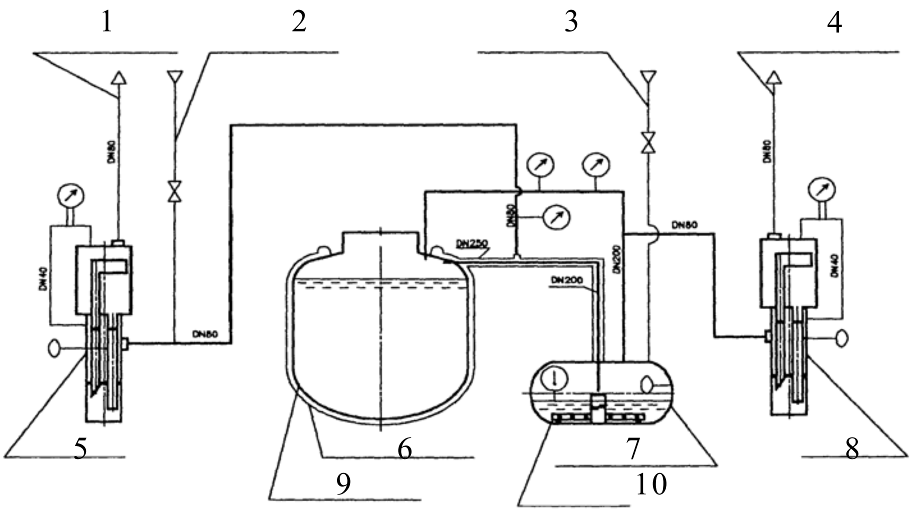
13.3.4. BN-800

A power unit with the BN-800 reactor was contemplated as an advanced version of its predecessor BN-600. It was assumed then that for the purpose of obtaining the largest economical effect it would be necessary, first, to retain most of the design solutions of the BN-600 reactor in the new one and, second, to create a small series of such plants with the whole complex of fuel cycle facilities.

A number of engineering and design solutions, based on the generalized experience in construction, commissioning, adjustment works, and the BN-600 plant operation were determined, aimed to improve economics and safety margins. Besides, the next step in the closed fuel cycle realization was to be taken. The main trends of work on improving economical characteristics were assumed to be as follows:

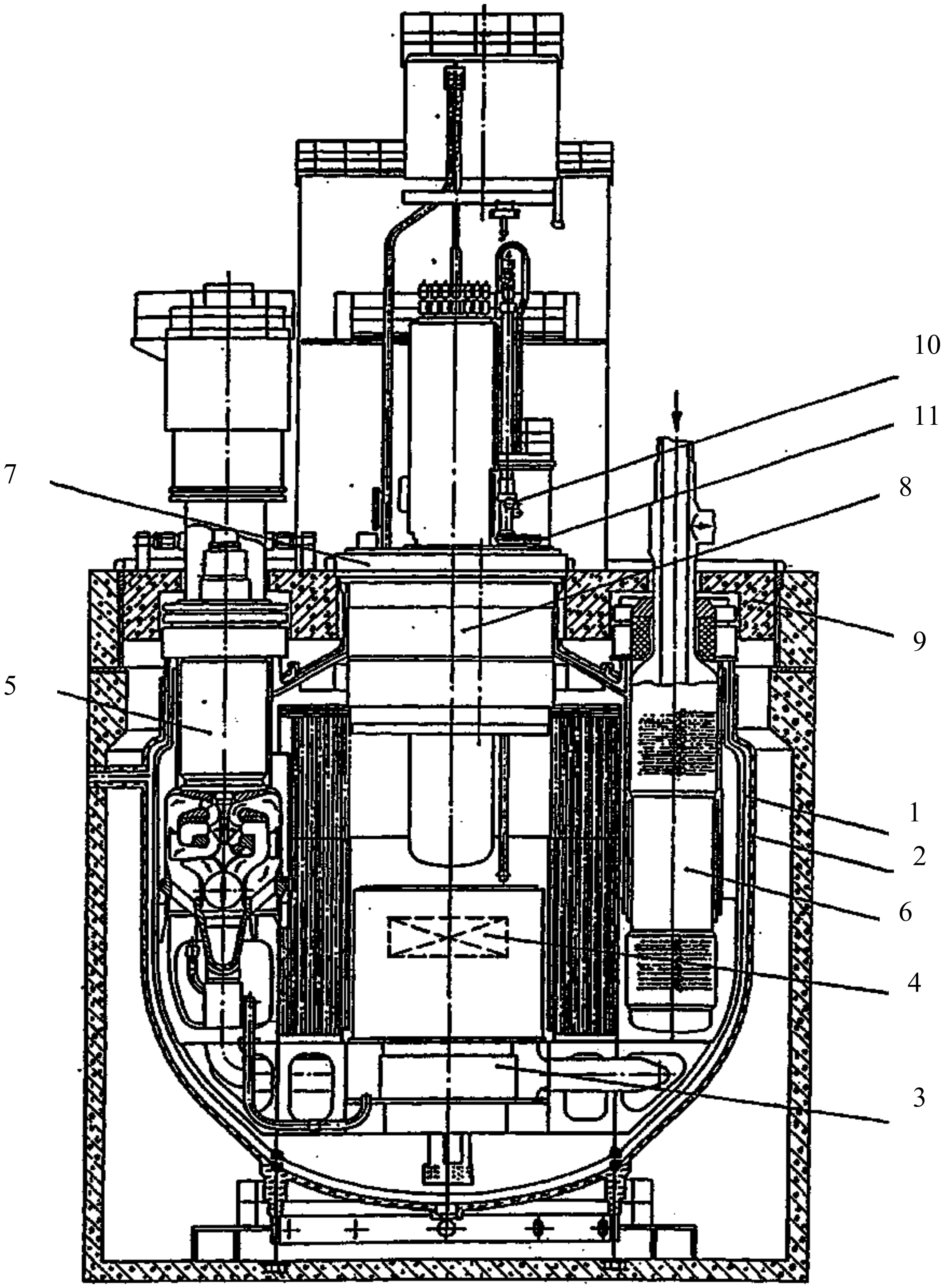
— Reduction of fuel cycle expenditures both by means of increasing the fuel burn-up and reducing fuel elements and fuel assemblies consumption as the result of the core heat rating and height optimization;
— Reduction of the specific material consumption through an optimization of engineering and design solutions.

In 1997 the license for renewal of the BN-800 construction was issued. The power plant is under construction.



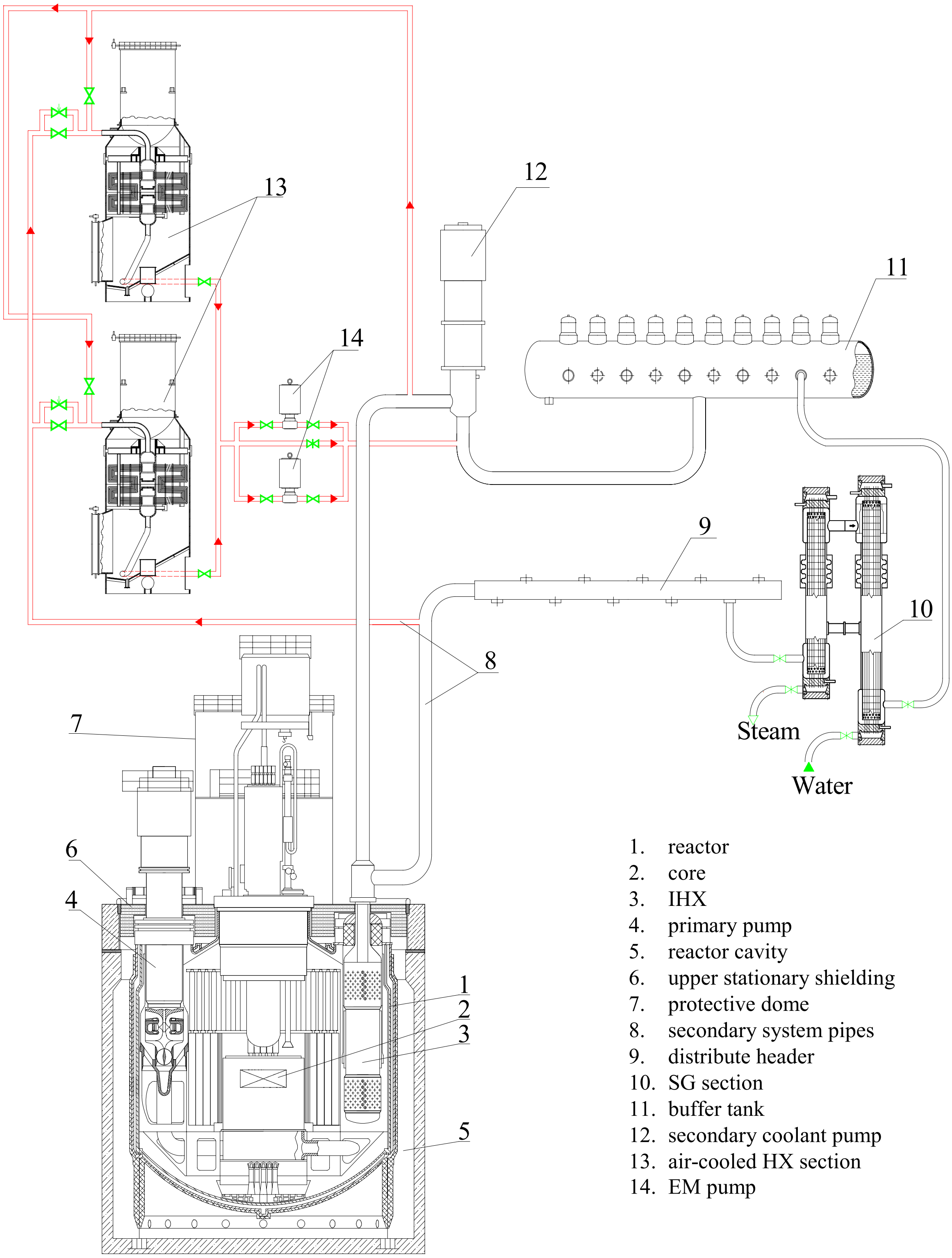
1 to 4-special ventilation system, 2, 3-from argon distribution system, 5-safety vessel hydraulic sea; 6-reactor safety vessel, 7-expansion tank; 8-safety vessel hydraulic seal, 9-main vessel, 10-mixing device

BN-800 main and guard vessels protection system of unprotected increase/decrease gas pressure.



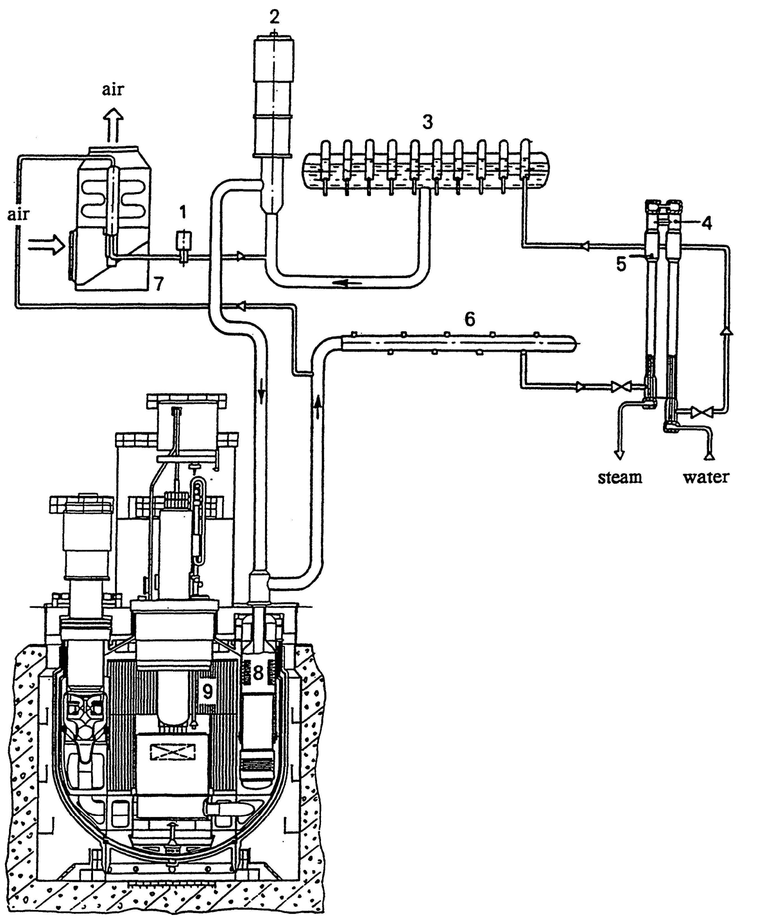
1-main reactor vessel, 2-guard vessel, 3-core diagrid, 4-reactor core, 5-reactor coolant pump, 6-intermediate heat exchanger, 7-large rotating plug, 8-above core structure, 9-upper stationary shield, 10-refuelling mechanism, 11-small rotating plug

BN-800 cross-section of the primary circuit.



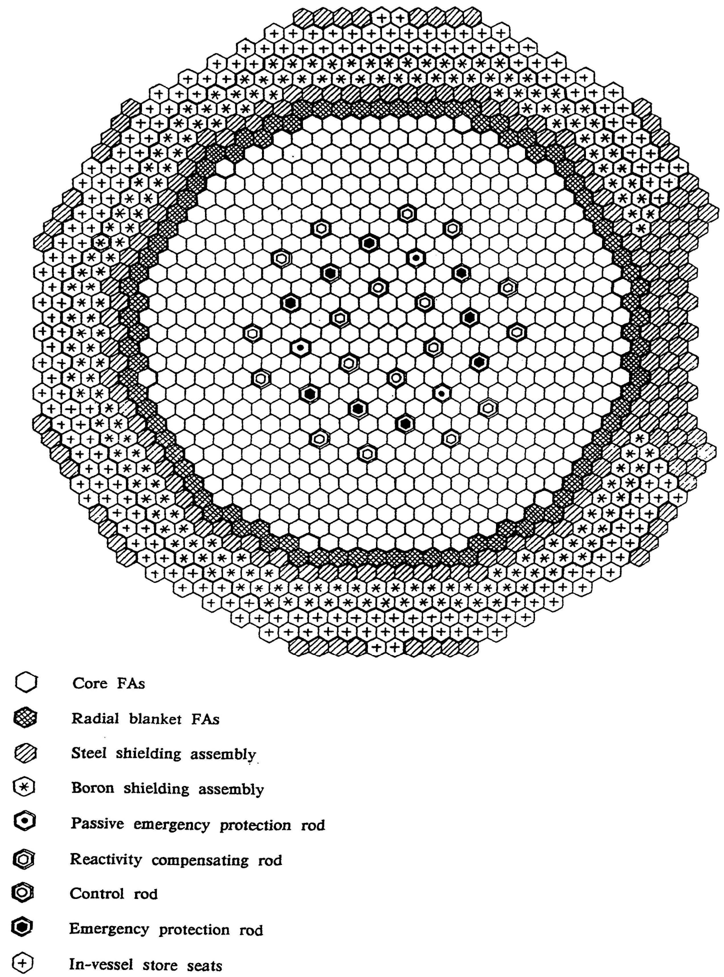
1. reactor
2. core
3. IHX
4. primary pump
5. reactor cavity
6. upper stationary shielding
7. protective dome
8. secondary system pipes
9. distribute header
10. SG section
11. buffer tank
12. secondary coolant pump
13. air-cooled HX section
14. EM pump

BN-800 flow sheet (1 of 2).

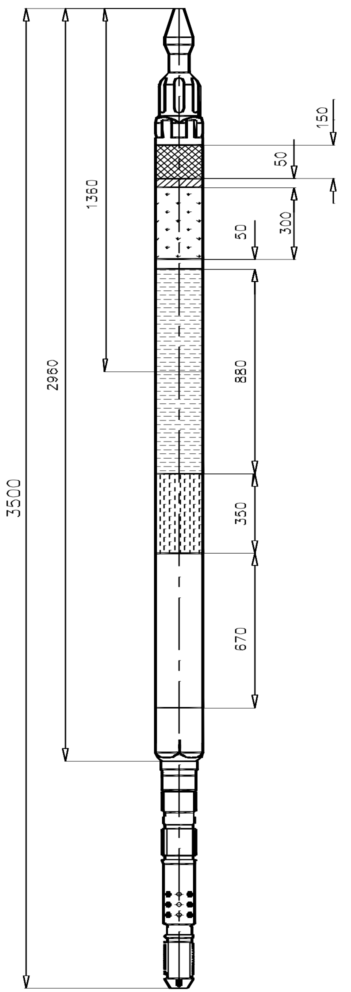


1-electromagnetic pump, 2-secondary coolant pump, 3-secondary coolant expansion tank, 4-evaporator module, 5-superheater module, 6-secondary sodium distributing header to SG, 7-air cooler, 8-intermediate heat exchanger, 9 -reactor

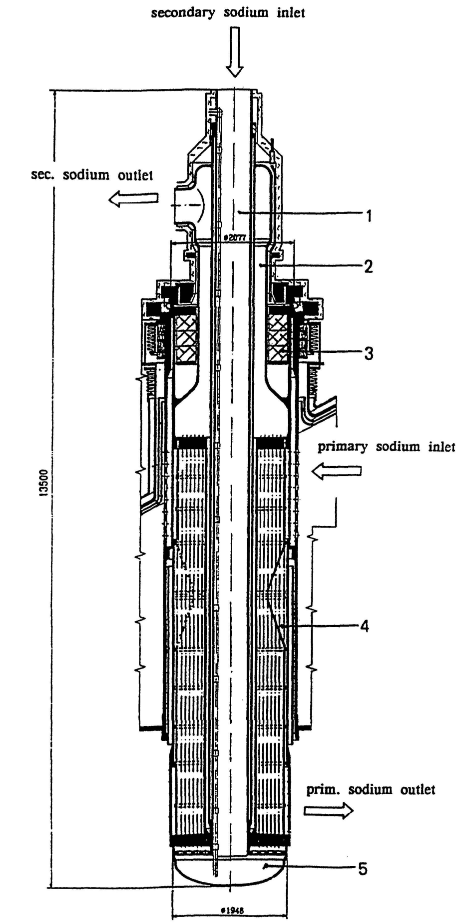
BN-800 flow sheet (2 of 2).



BN-800 core layout.



BN-800 core fuel assembly with MOX-fuel [dimensions in mm, from the top: boron screen (50), Na (300), core (880), blanket (350), gas (670)].



1-central downcomer tube, 2-secondary sodium outlet chamber, 3-shielding block, 4-heat exchange tube, 5-bottom

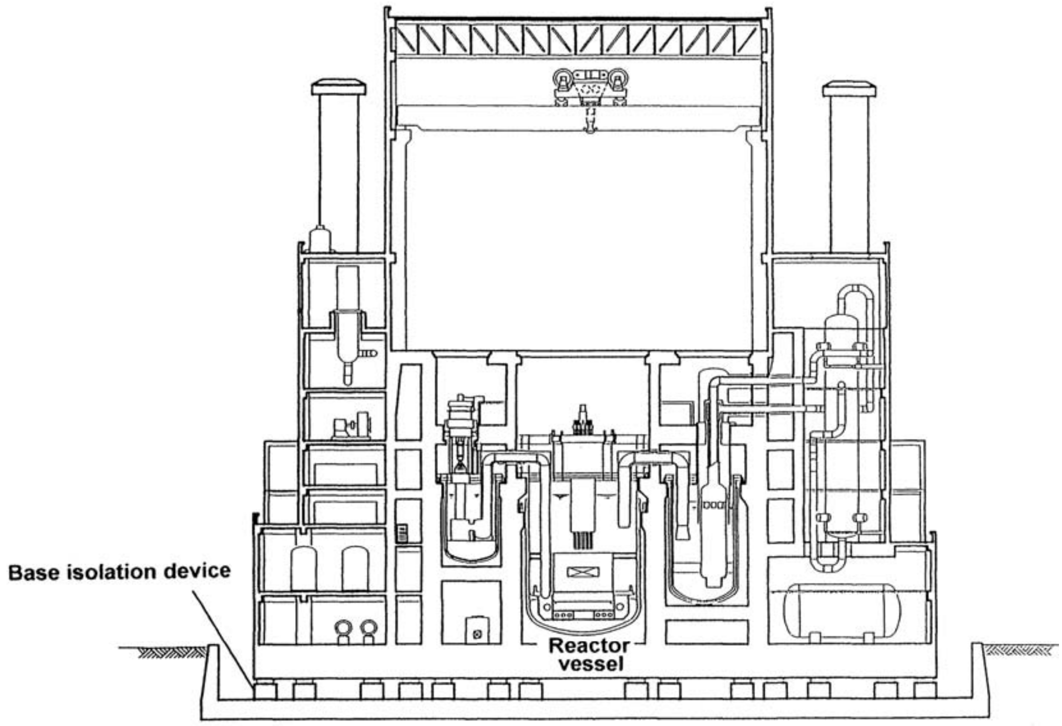
BN-800 intermediate heat exchanger.

13.3.5. DFBR

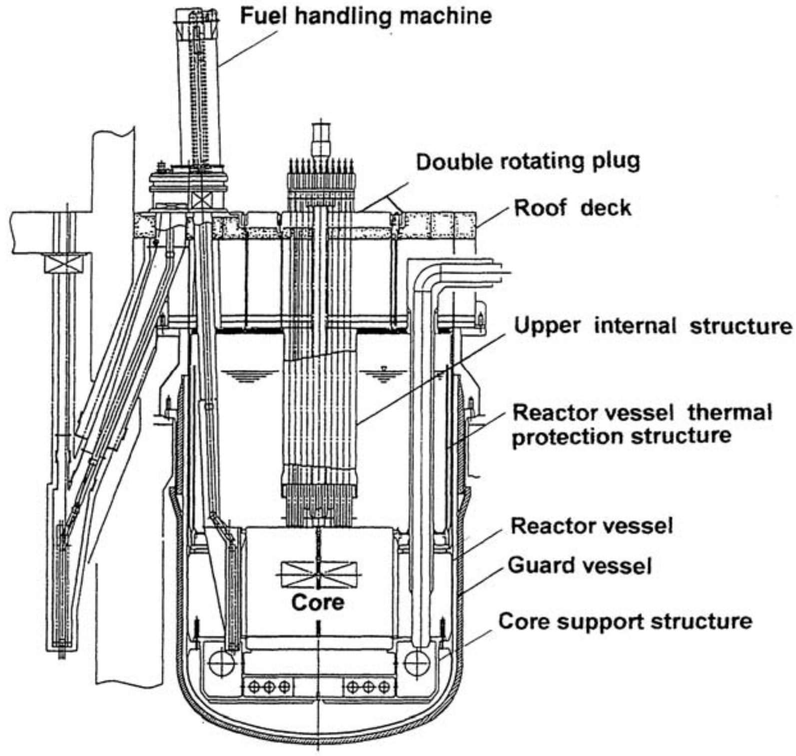
The top entry loop type design was selected for the Japanese DFBR because of the following considerations:

- Major primary components such as the intermediate heat exchanger (IHX) and the pumps are outside of the reactor vessel, and this facilitates maintenance and repair;
- The system has flexibility to introduce such innovative technologies as the electromagnetic pump integrated component, which is needed for commercialization of the FR; and
- Experience gained at the prototype MONJU must be fully utilized;

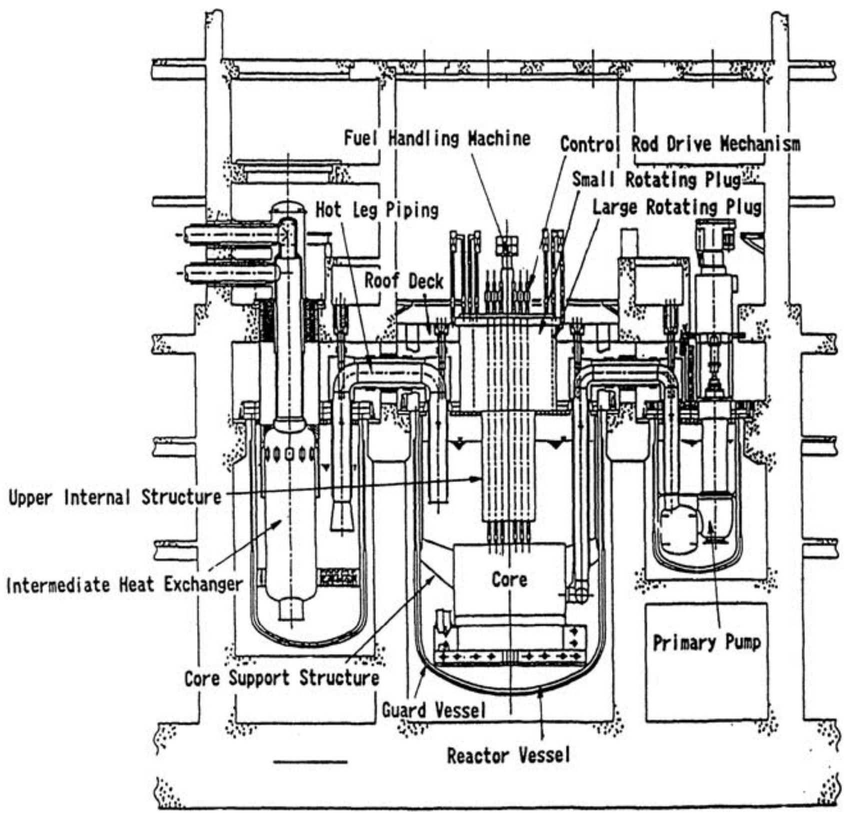
Considering that the top entry system is quite a new concept, the conceptual design study, the evaluation study of commercialization prospects and the water hydraulic tests using models of thermal-hydraulic properties specific to the top entry system were conducted.



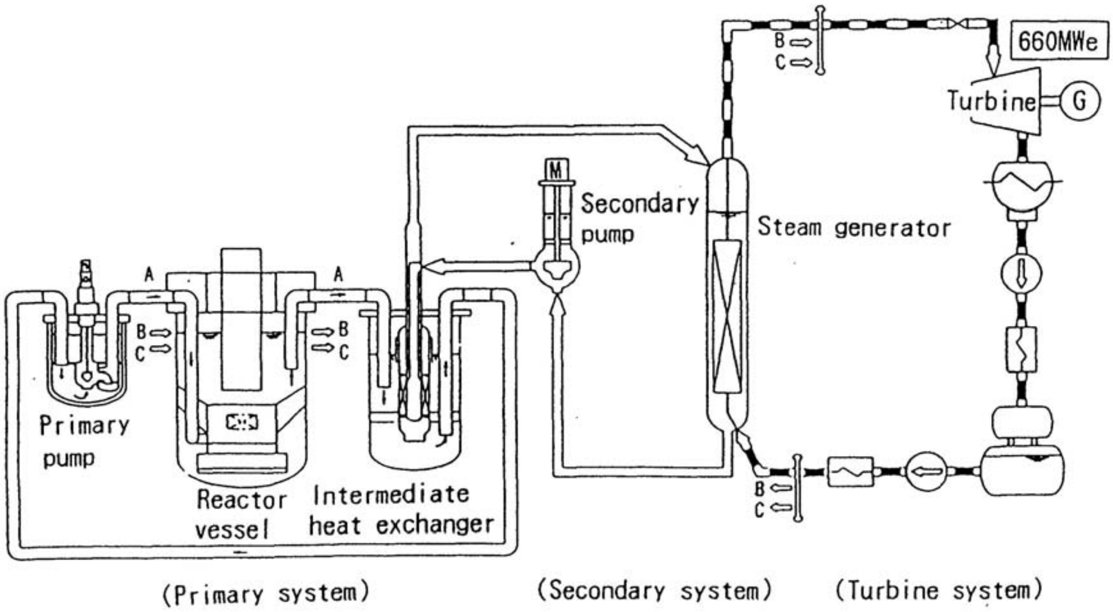
DFBR seismically isolated reactor building.



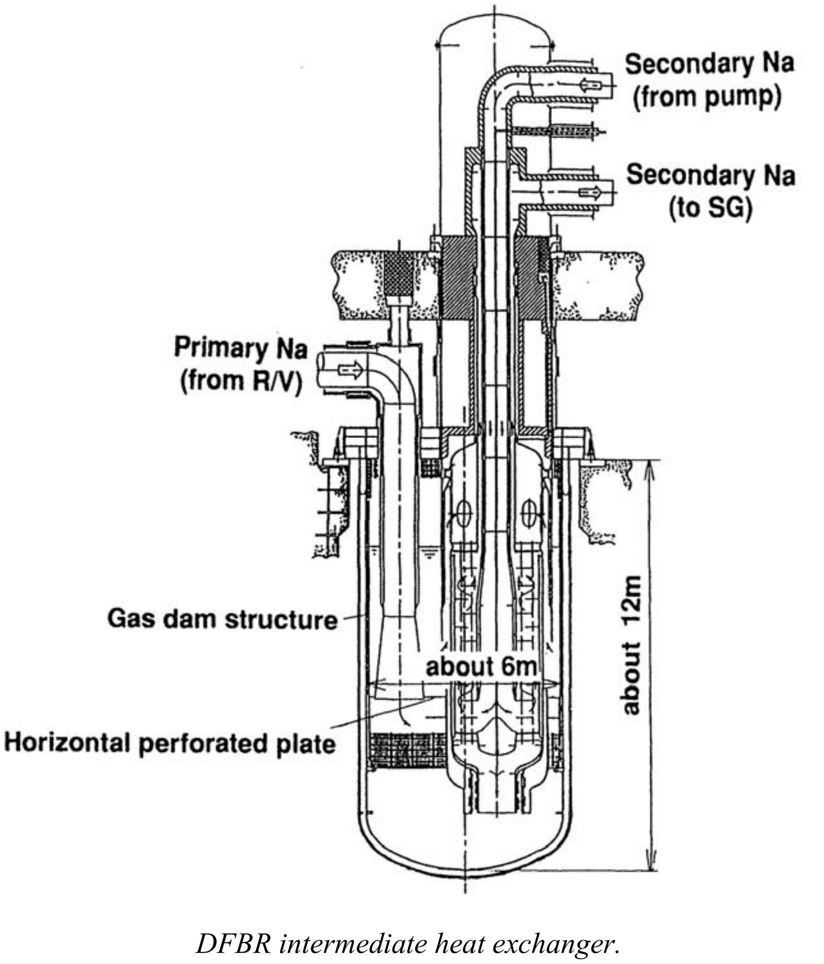
DFBR reactor.



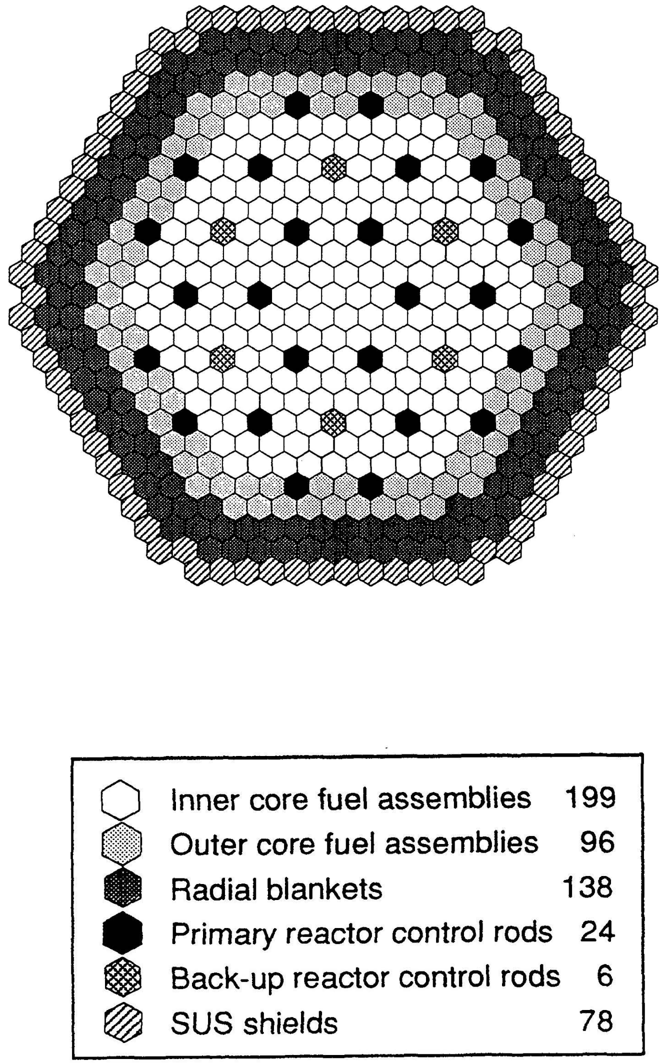
DFBR reactor system.



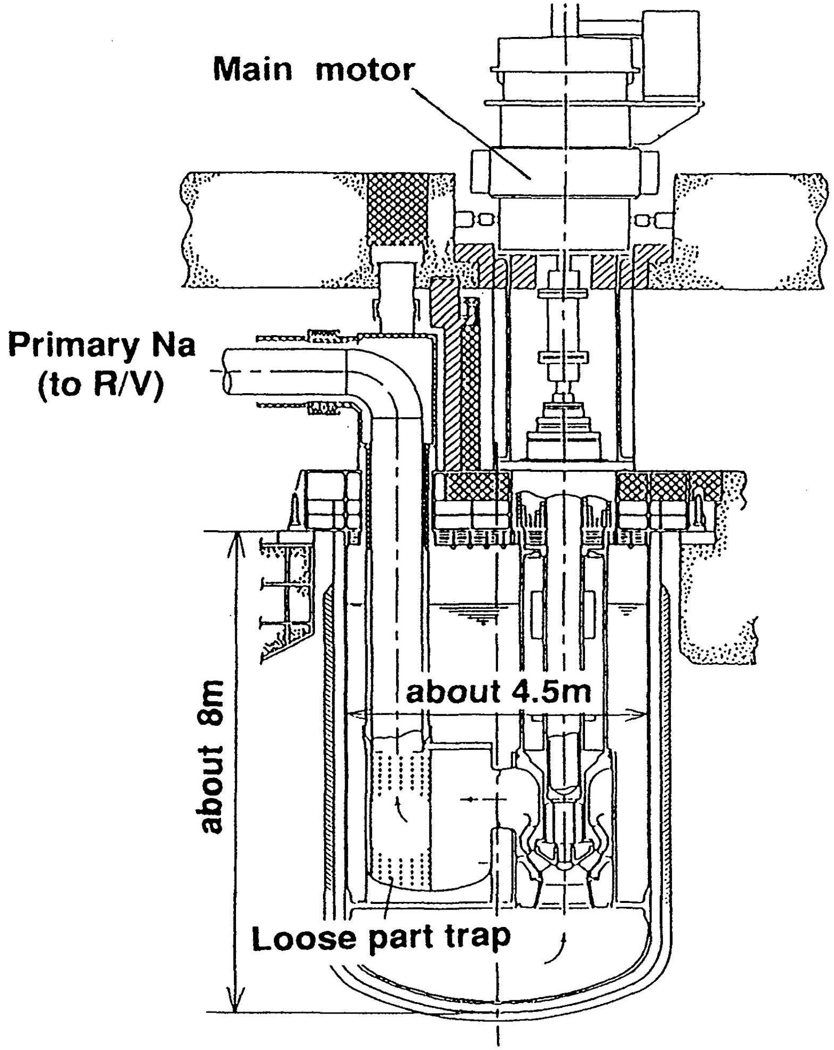
DFBR flow diagram.



DFBR intermediate heat exchanger.



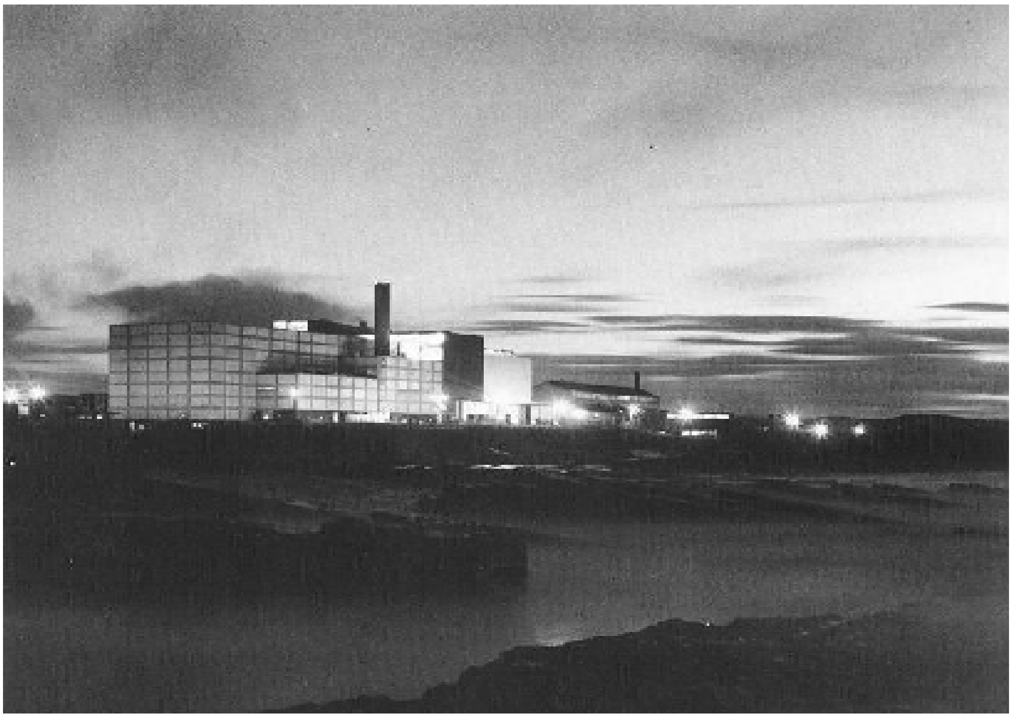
DFBR core configuration.



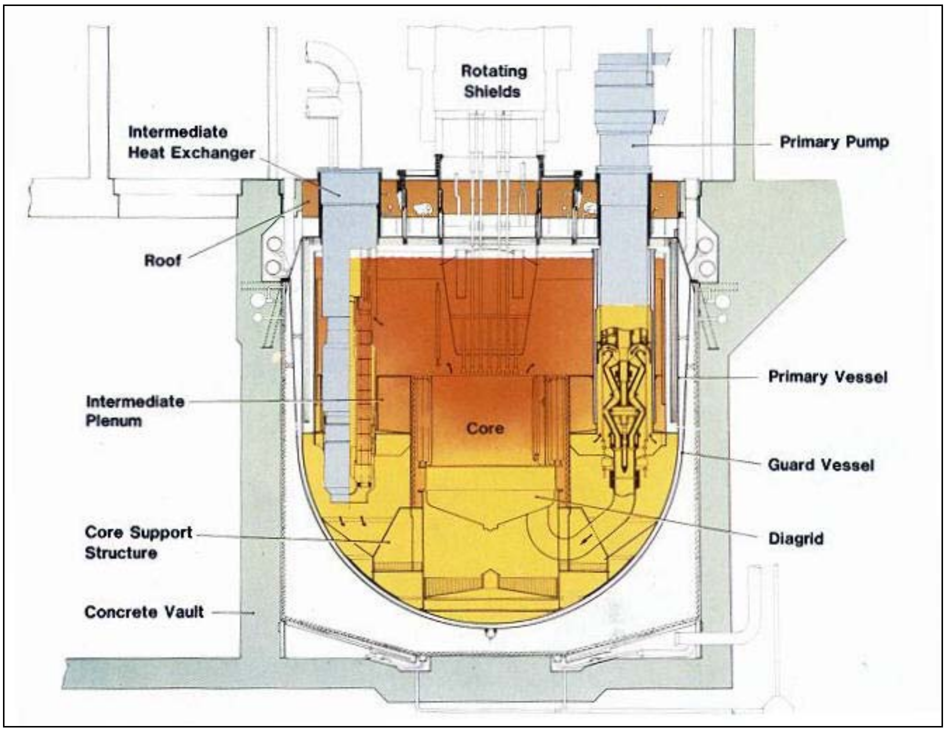
DFBR primary pump.

13.3.6. CDFR[25]

Project subsumed into EFR.

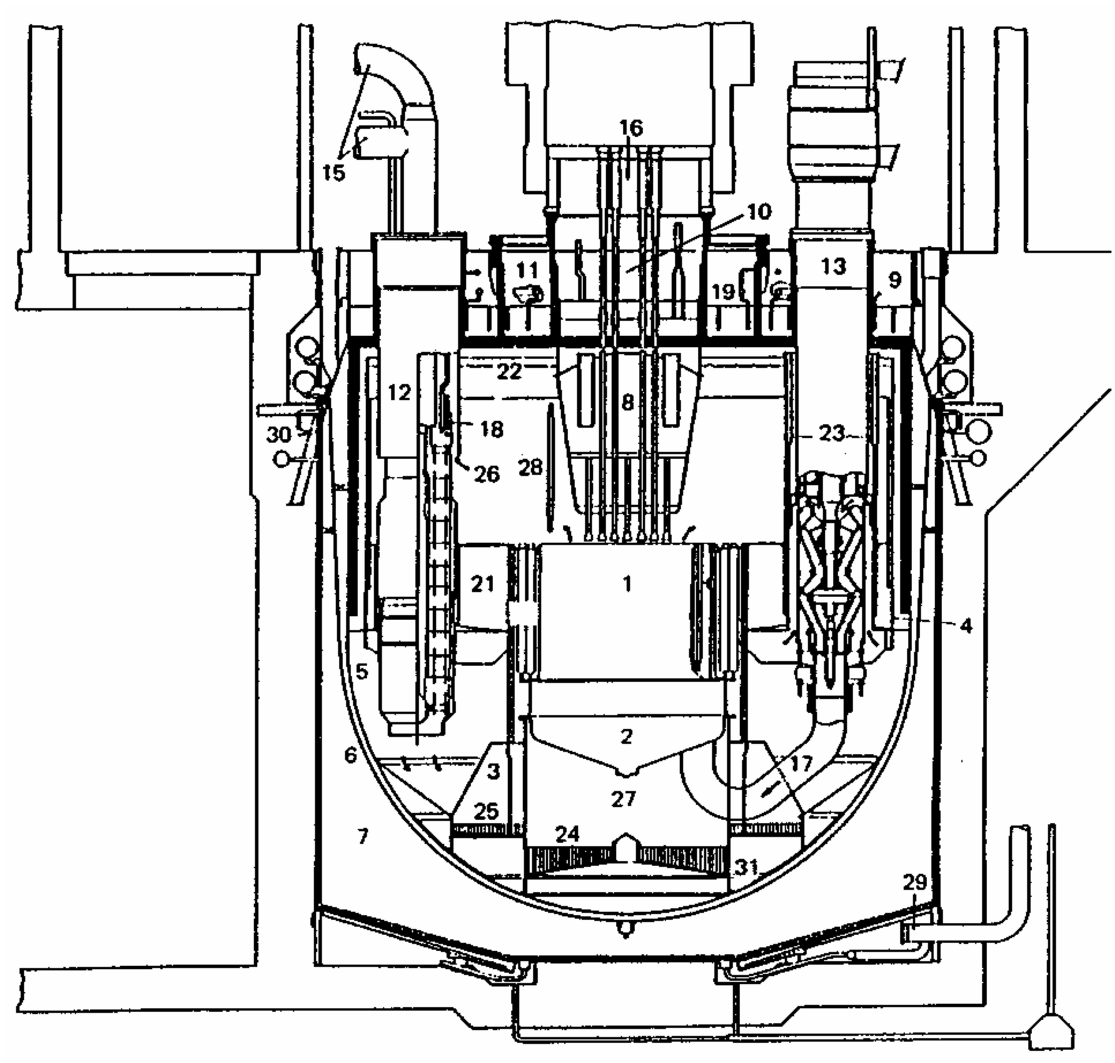


CDFR overall survey.



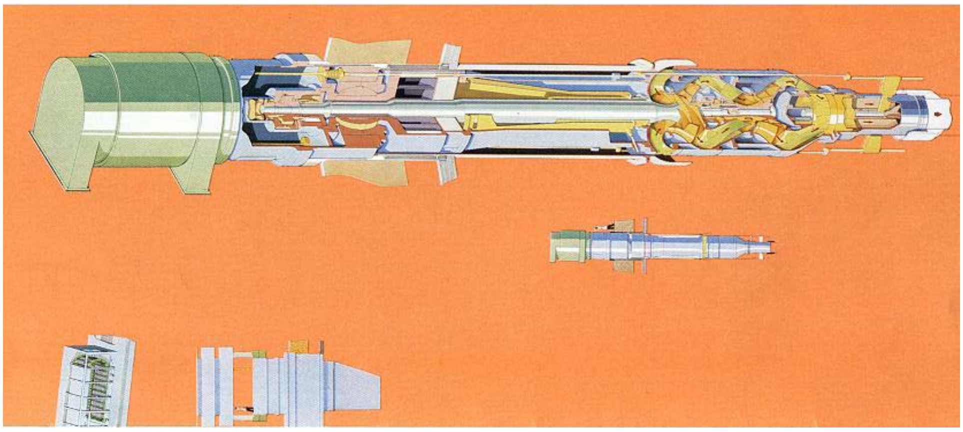
CDFR reactor arrangement (1 of 2).

[25] Project subsumed into EFR.

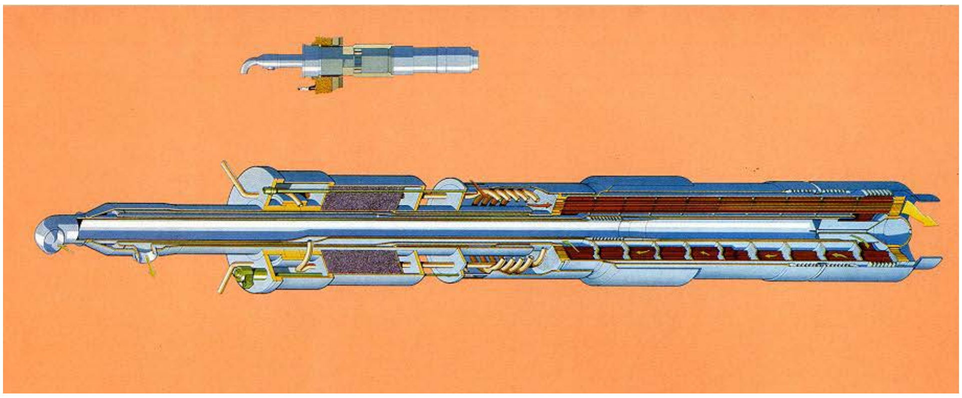


1 Core
2 Diagrid
3 Strongback
4 Inner tank
5 Primary vessel
6 Guard vessel
7 Vault
8 Above core structure
9 Roof
10 Rotating shield
11 Rotating shield inner/outer
12 Intermediate heat exchanger
13 Primary pump
14 Outer neutron shield
15 Secondary sodium pipework
16 Control rod mechanism
17 HP pipework
18 Decay heat coils
19 Roof cooling gas inlet
20 Roof cooling gas outlet
21 Intermediate plenum
22 Dynamic level 540°
23 Dynamic level 370°
24 Debris tray
25 Debris tray in./out.
26 Hot pool
27 Cold pool
28 Fuel subassembly
29 Vault cooling inlet
30 Vault cooling outlet
31 Secondary support gap

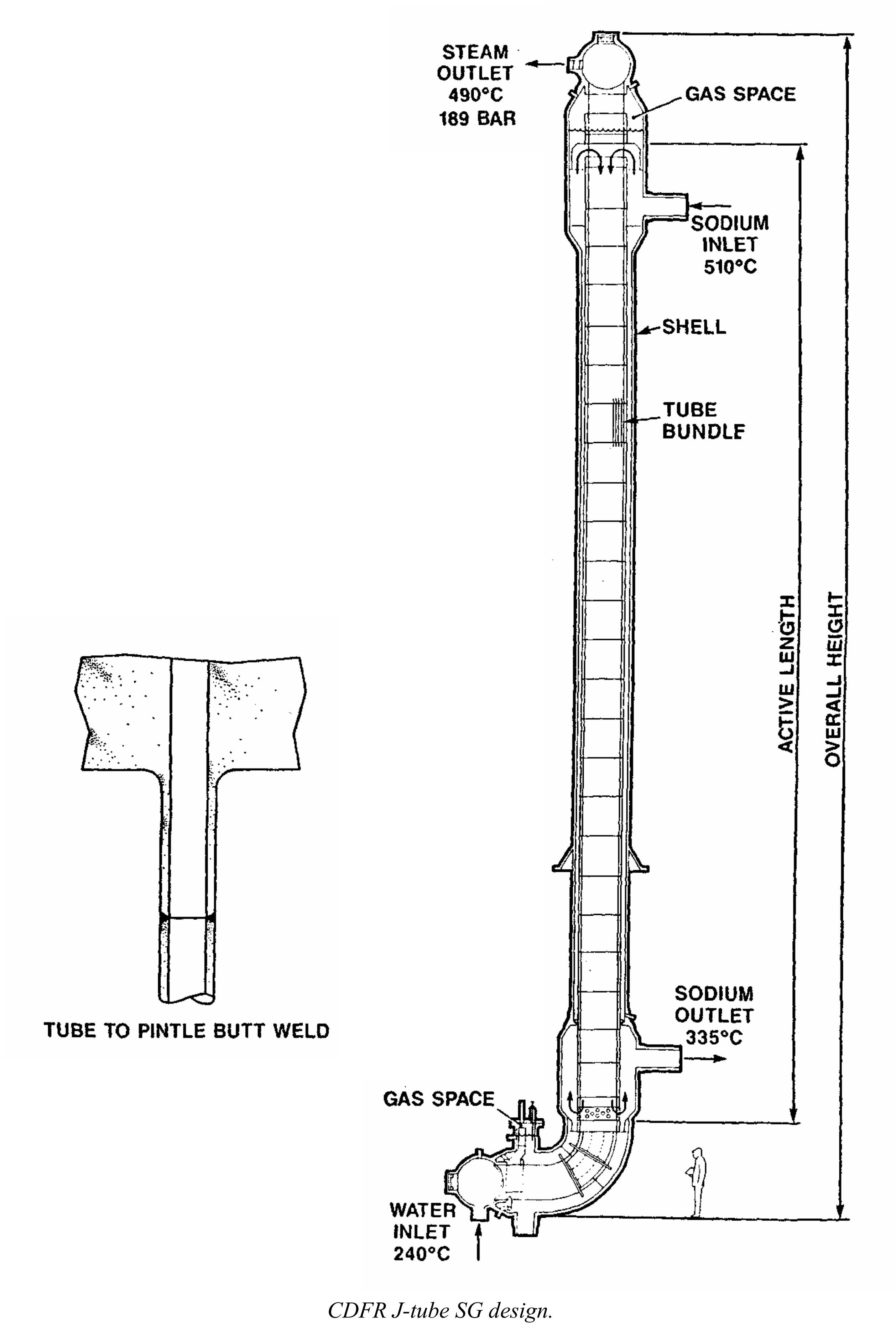
CDFR reactor arrangement (2 of 2).



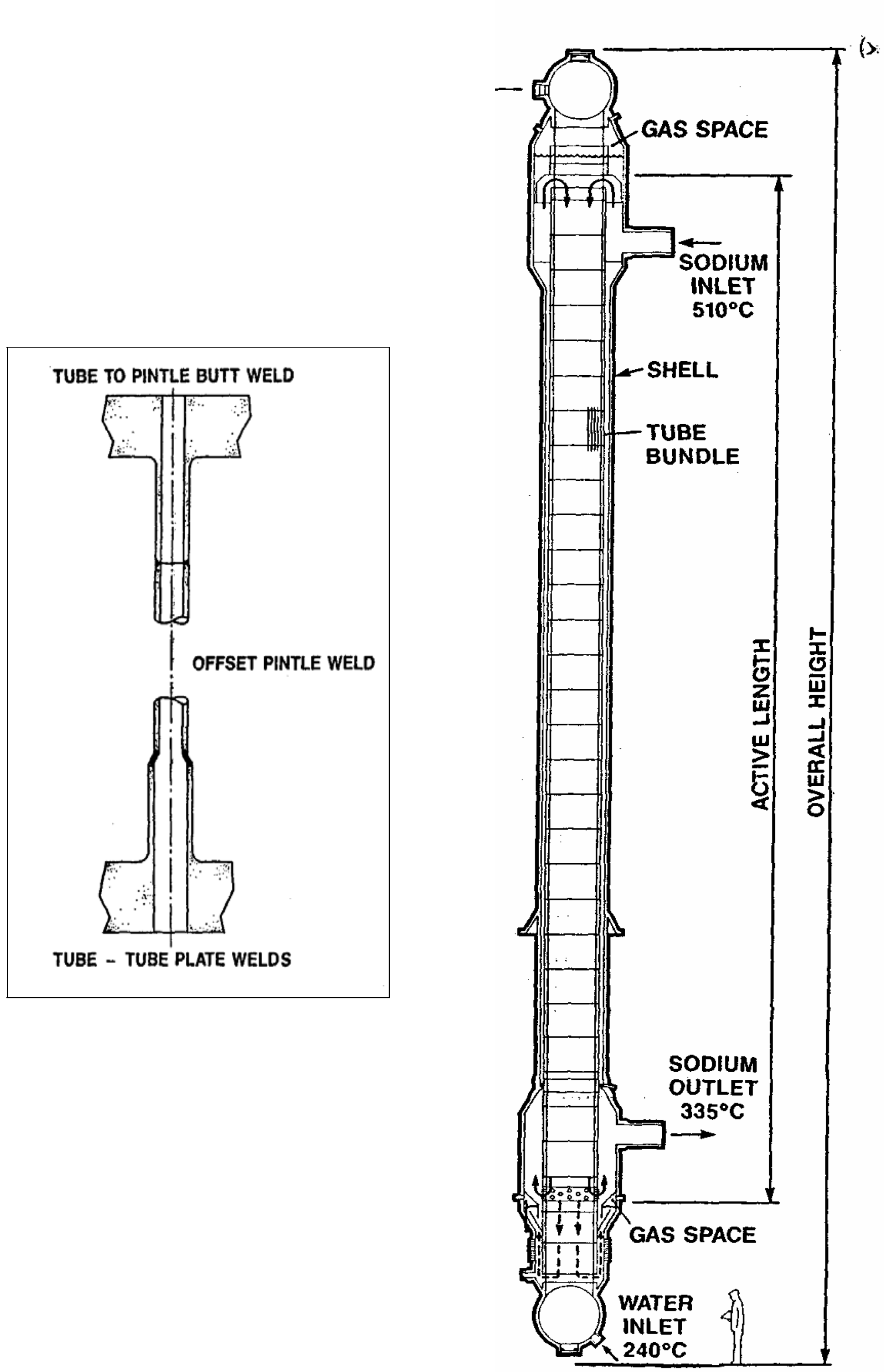
CDFR primary sodium pump.



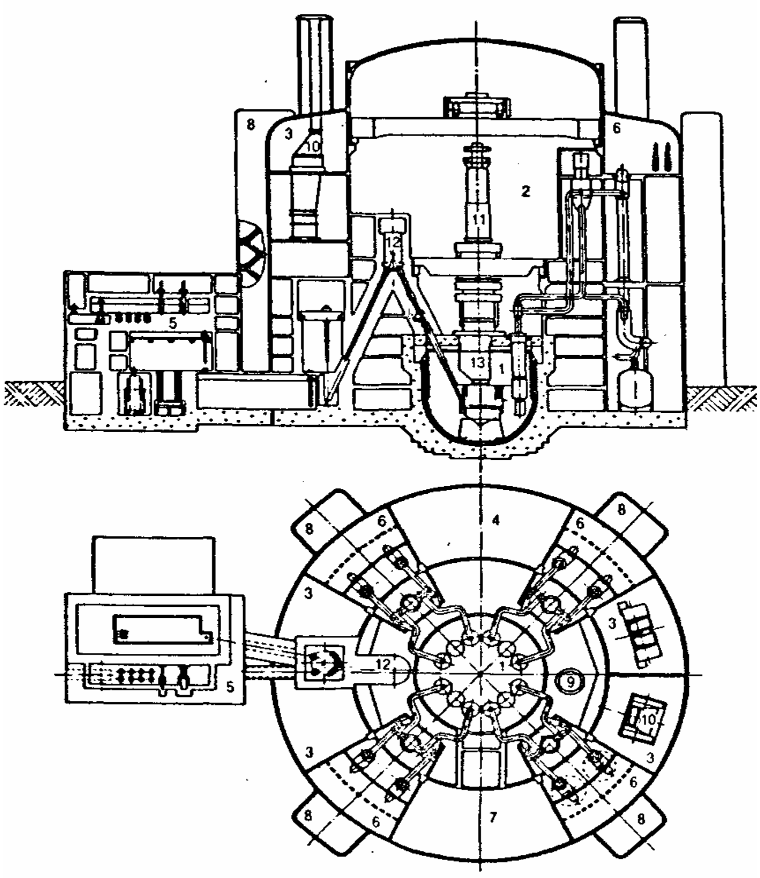
CDFR intermediate heat exchanger.



CDFR J-tube SG design.

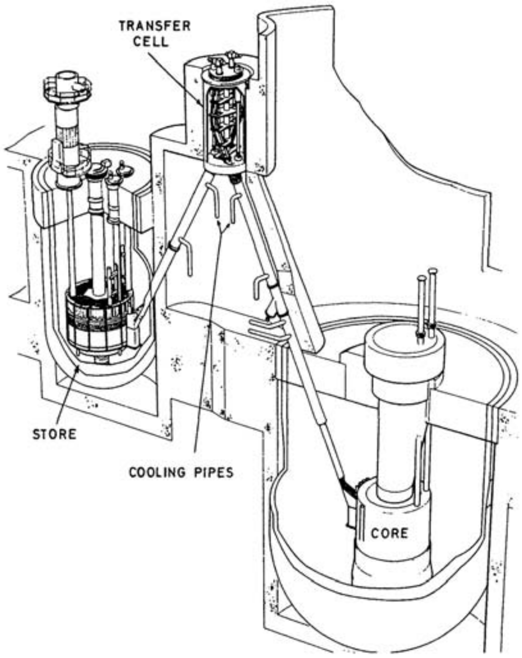


CDFR straight tube SG design.

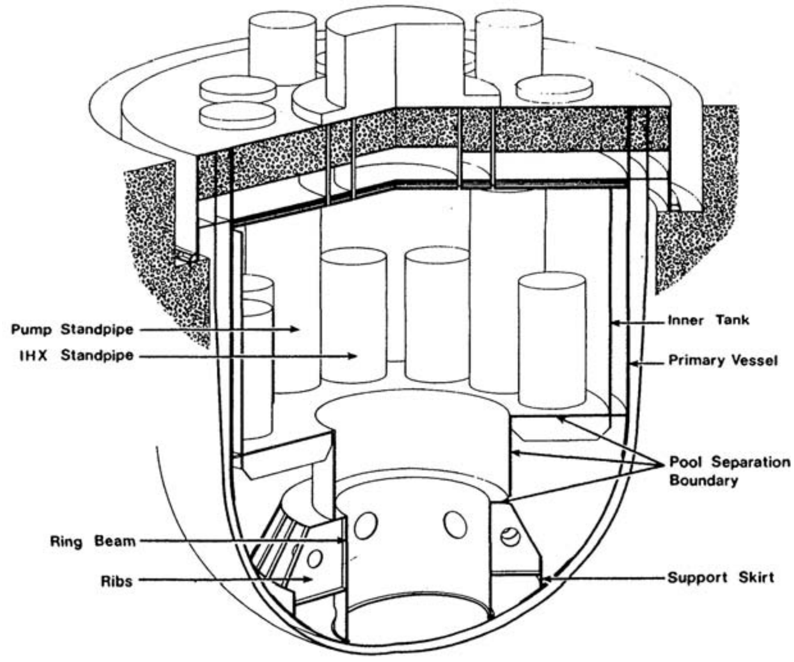


1-reactor, 2-containment building, 3-reactor services, 4-main control block, 5-fuel building, 6-SG blocks, 7-maintenance transfer block, 8-service, tower 9-primary cold trap, 10-decay heat rejection system, 11-active handling flask, 12-fuel transfer cell, 13-above core structure and rotating shields

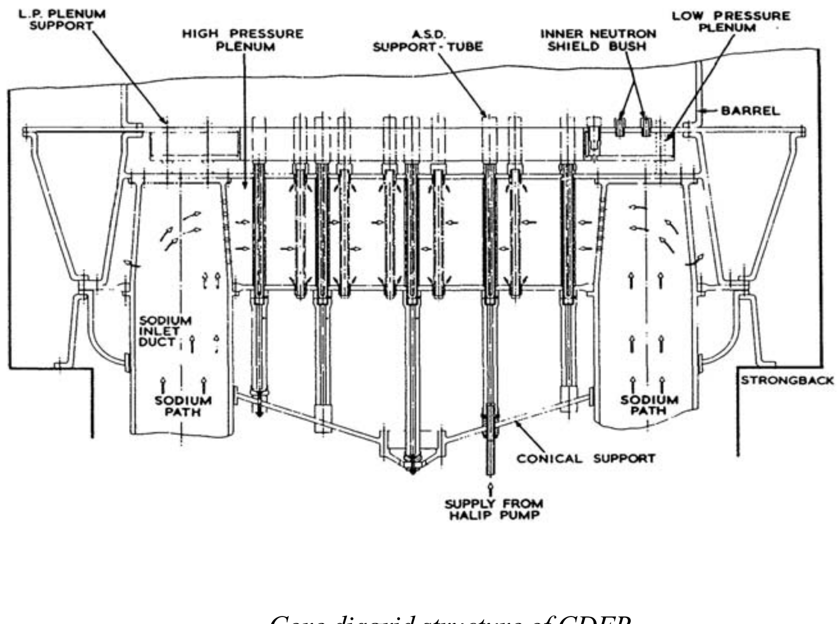
Reactor building cross-section of the CDFR design.



CDFR fuel handling system.



Bottom support 'strong-back' of CDFR.

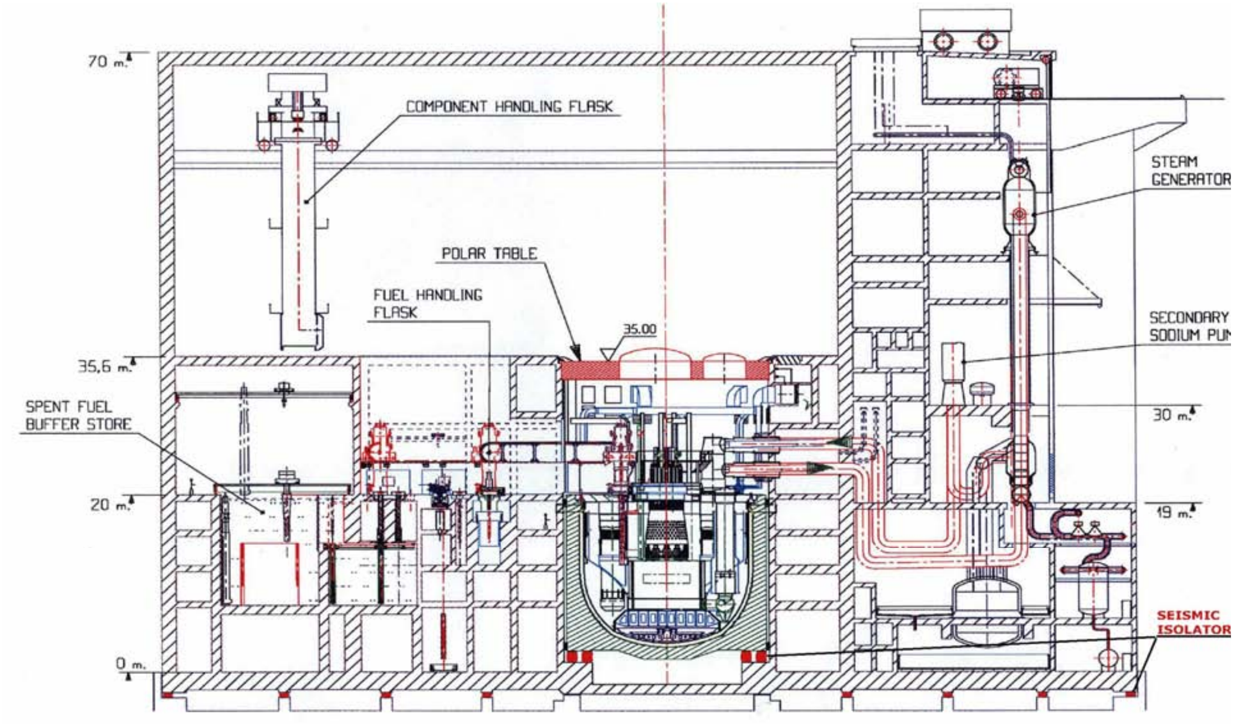


Core diagrid structure of CDFR.

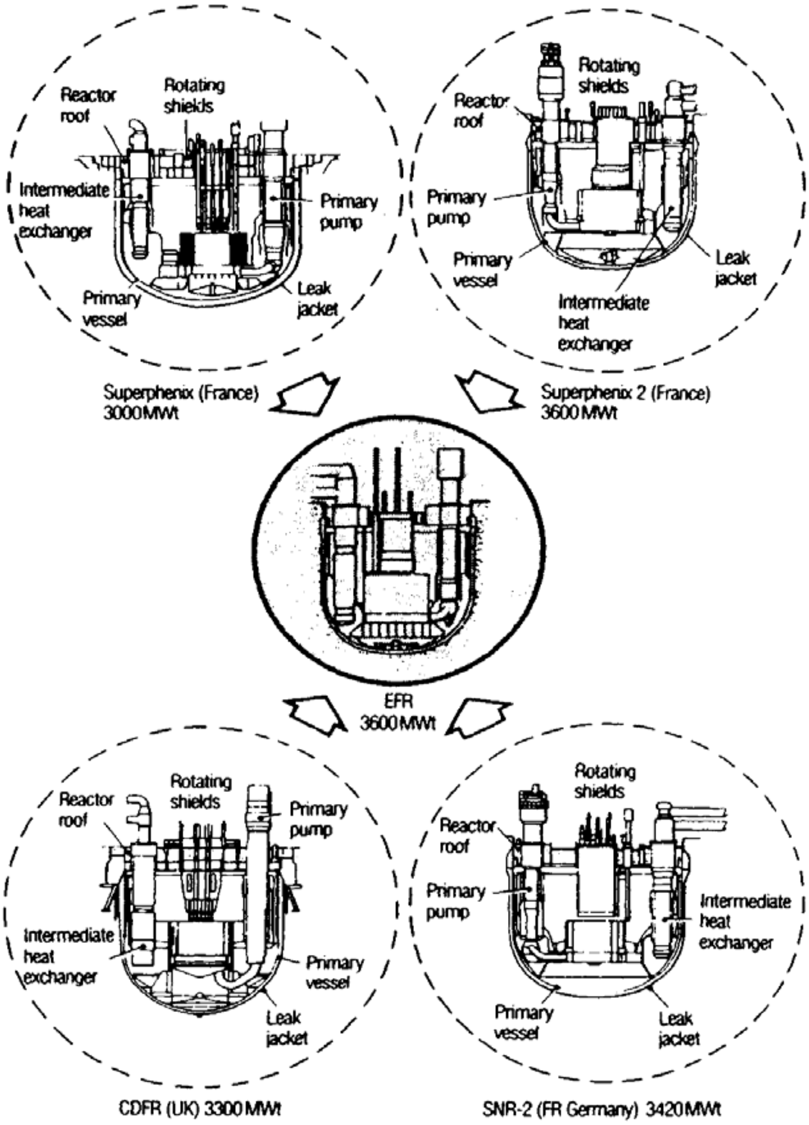
13.3.7. EFR

With France in the leading role, the European fast reactor (EFR) design has been completed. This is synthesis of the extensive experiences from France, Germany and the United Kingdom with large pool-type oxide-fuelled reactors. One of the outstanding achievements of the EFR programme has been to make firm and reliable cost estimates. The construction of a reactor to the EFR design may not be possible in the near future, but a well-validated way forward to commercial utilization of fast reactors has been established. This way is generally consistent with other studies, and indicates that the goal of competitive fast rectors may be within reach.

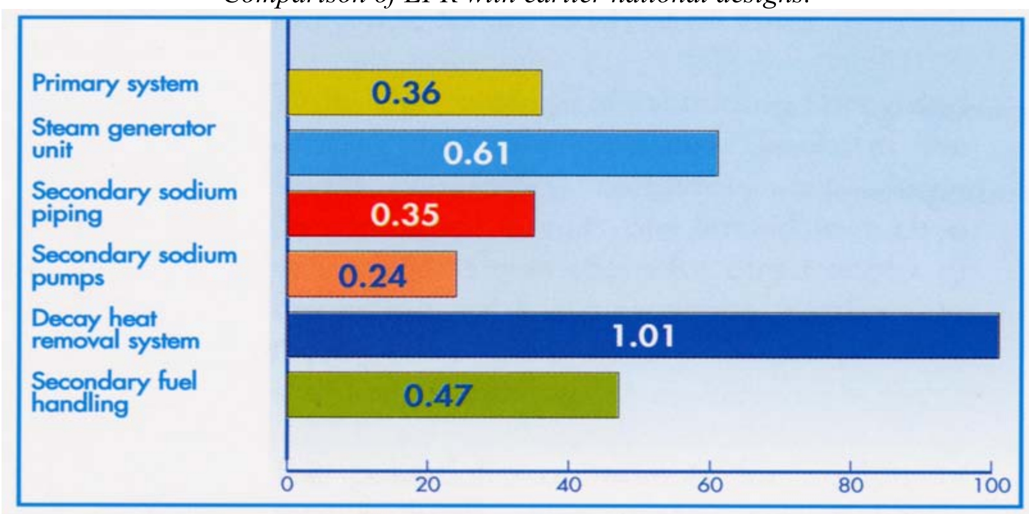
EFR overall survey.



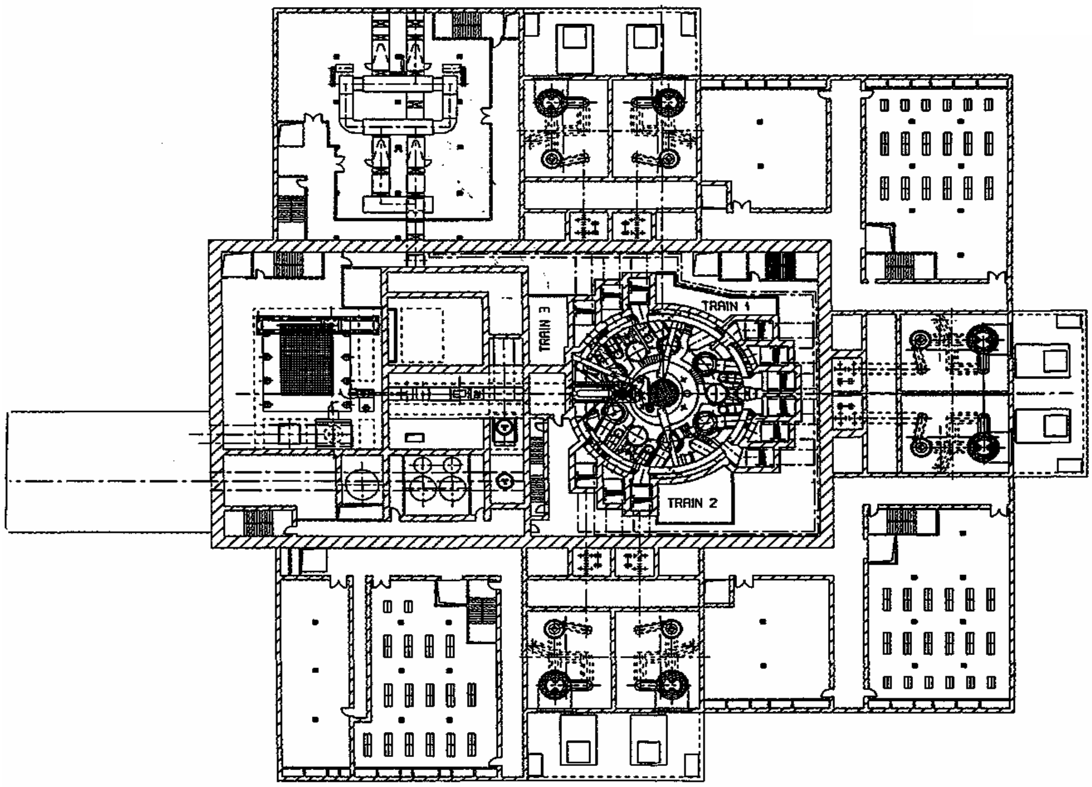
EFR nuclear island layout – elevation (1 of 2).



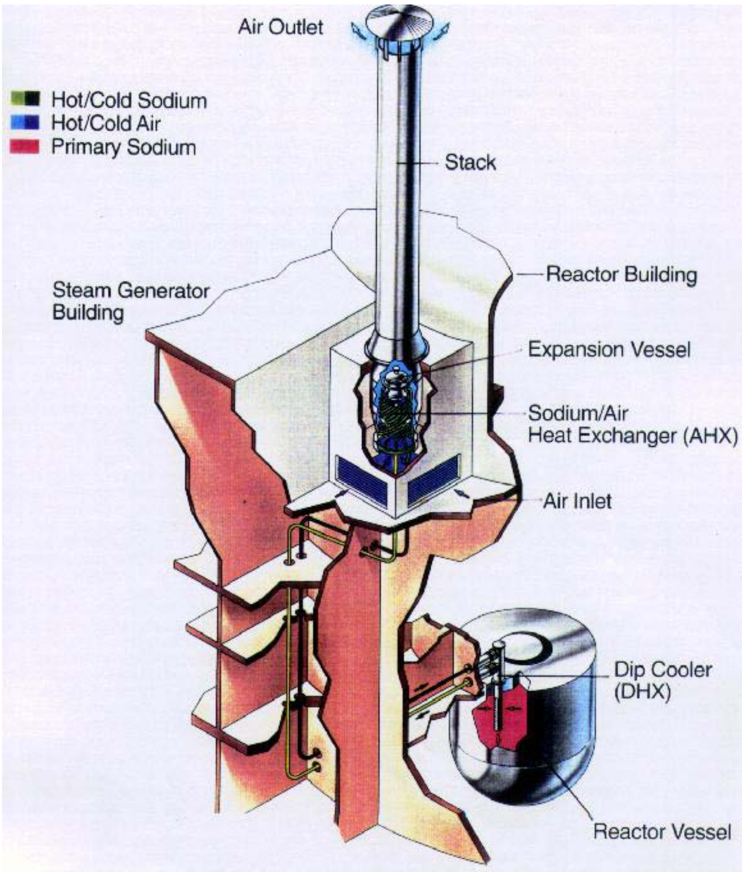
Comparison of EFR with earlier national designs.



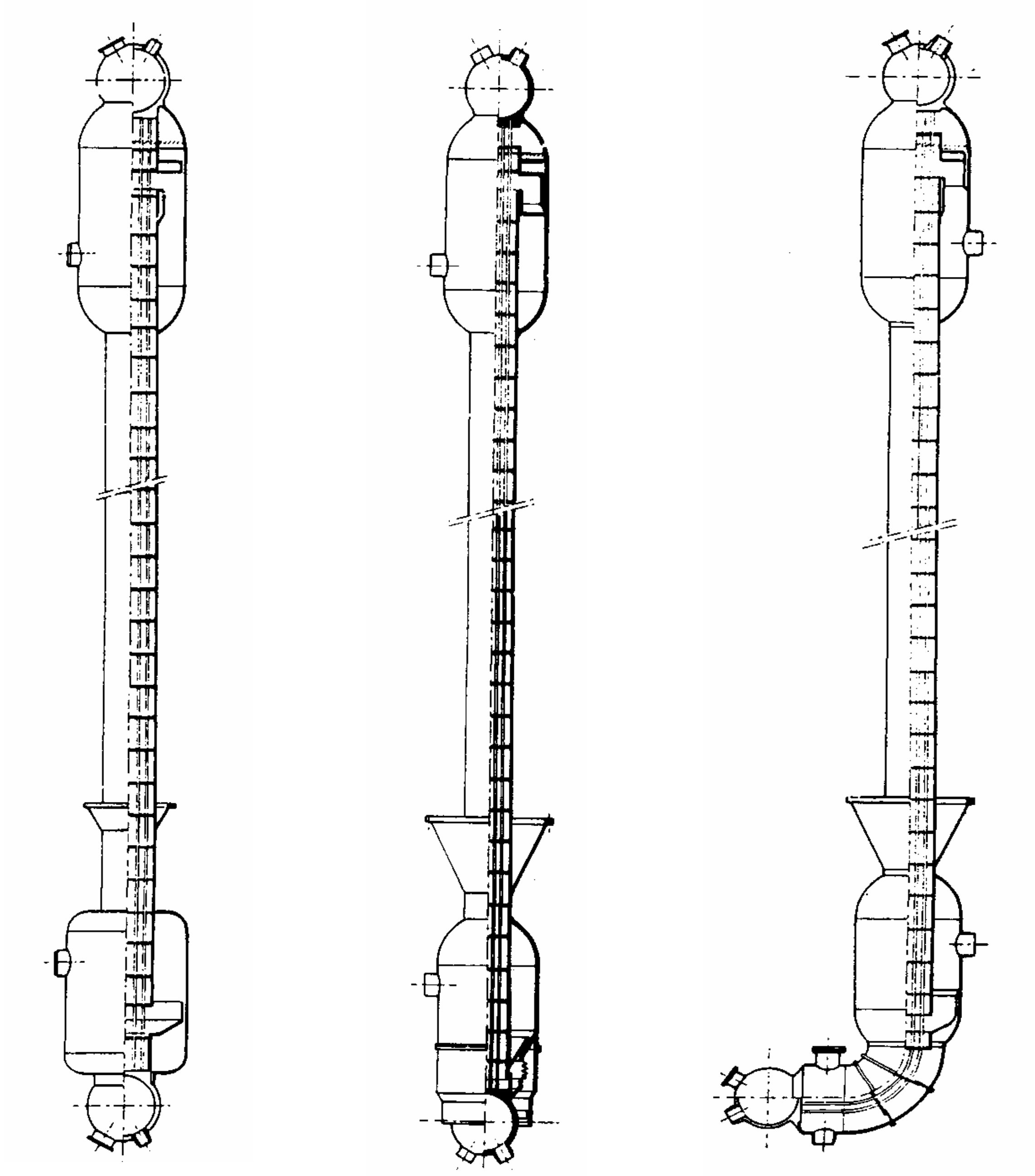
EFR vs Super-Phénix 1 (100%) comparison of the specific steel weight (steel only) in t/MW(e).



EFR nuclear island layout – plan view).



EFR direct reactor cooling system.

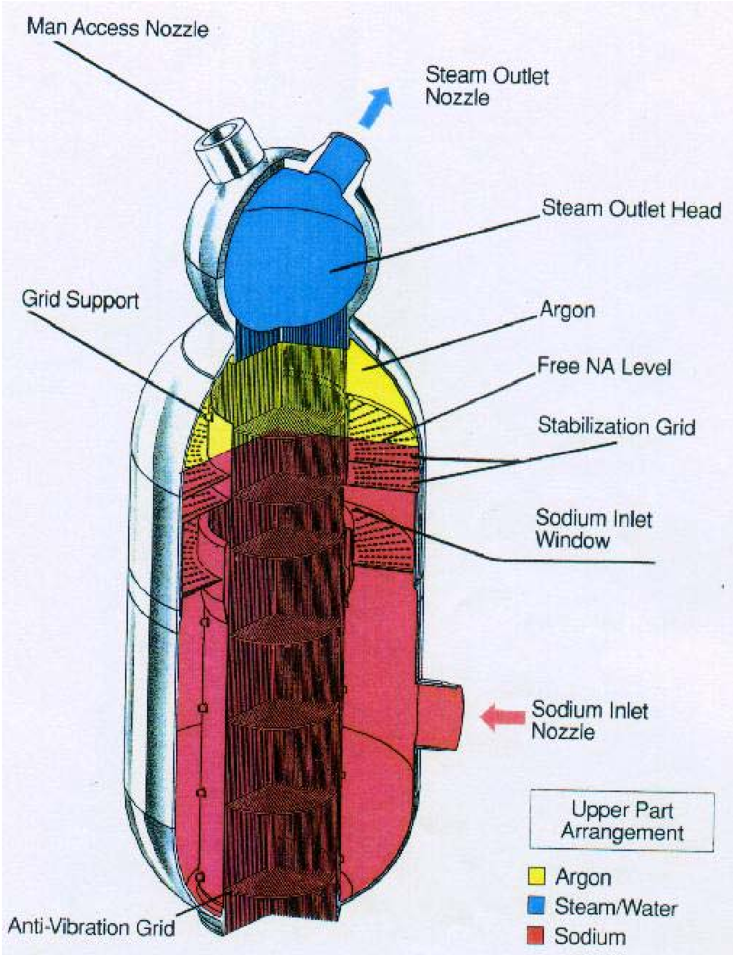


a) Designwith flexible shell

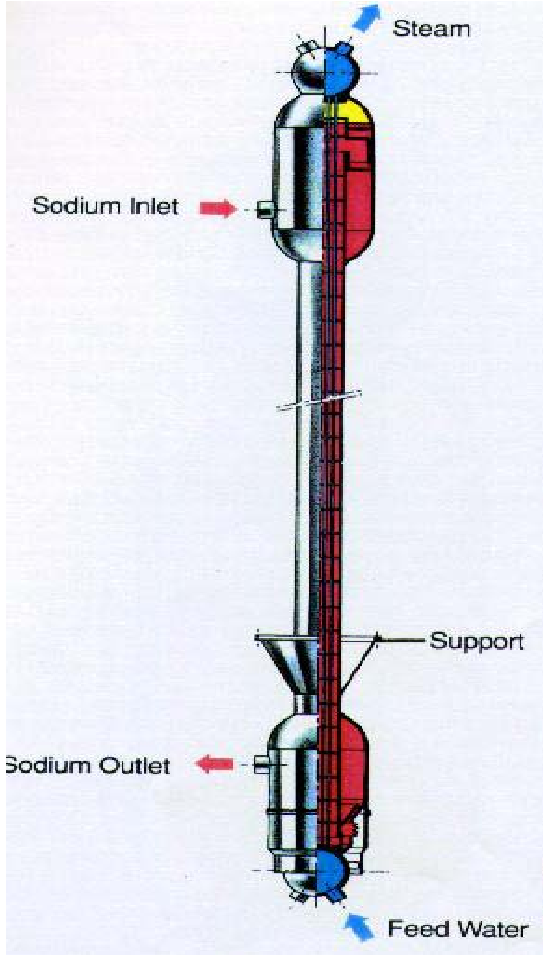
b) Design with bellows into the shell

c) Design with flexible tubes

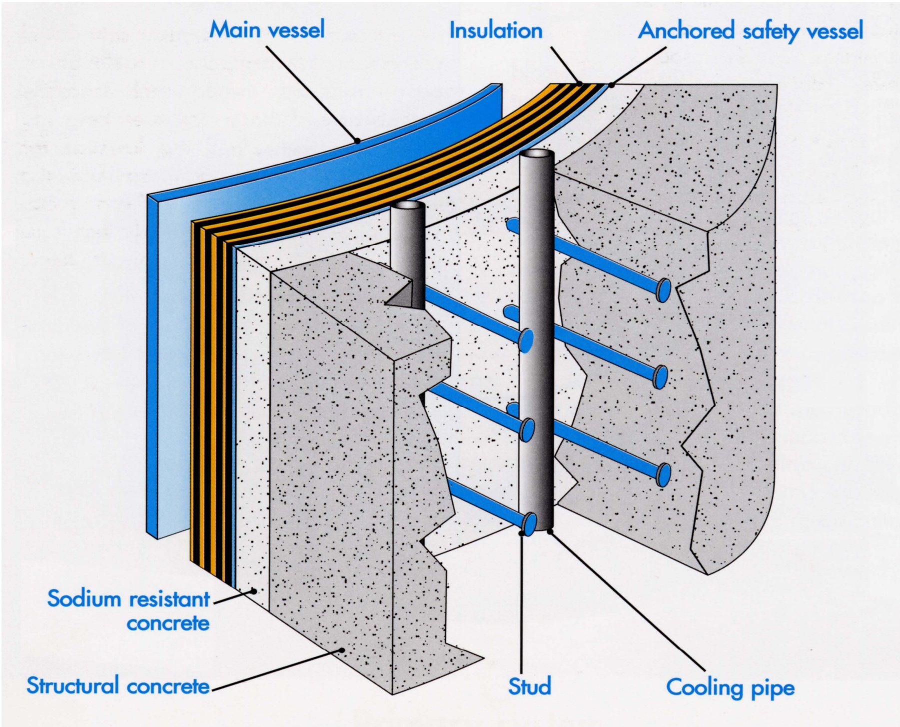
EFR steam generator options.



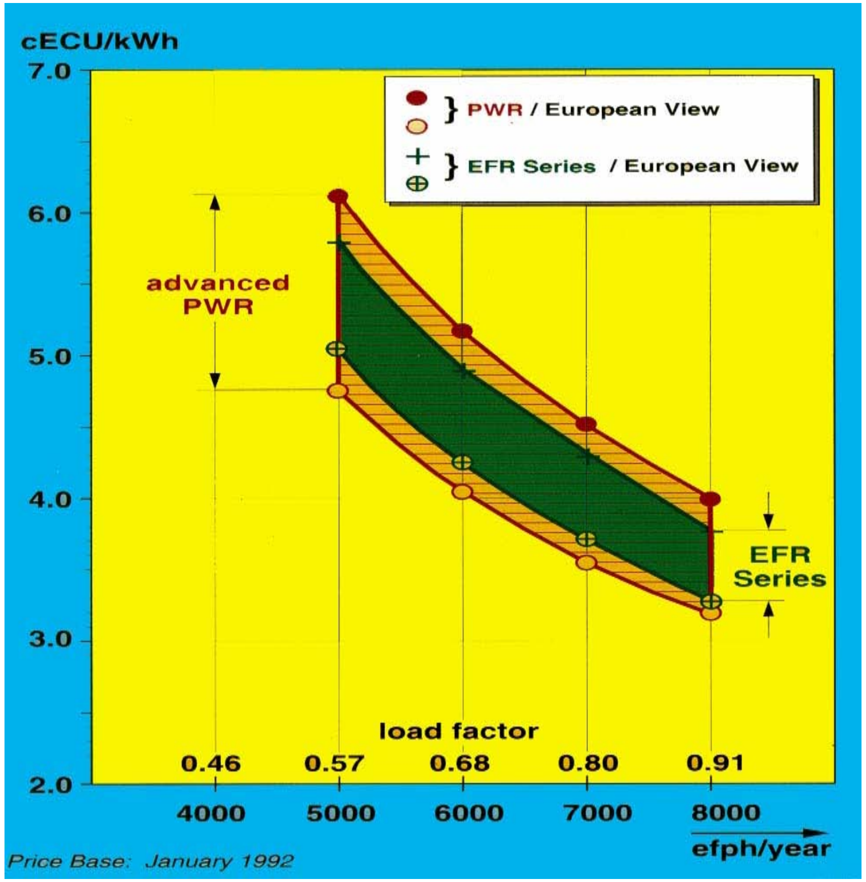
EFR SG upper part.



EFR SG design with bellows in the shell.



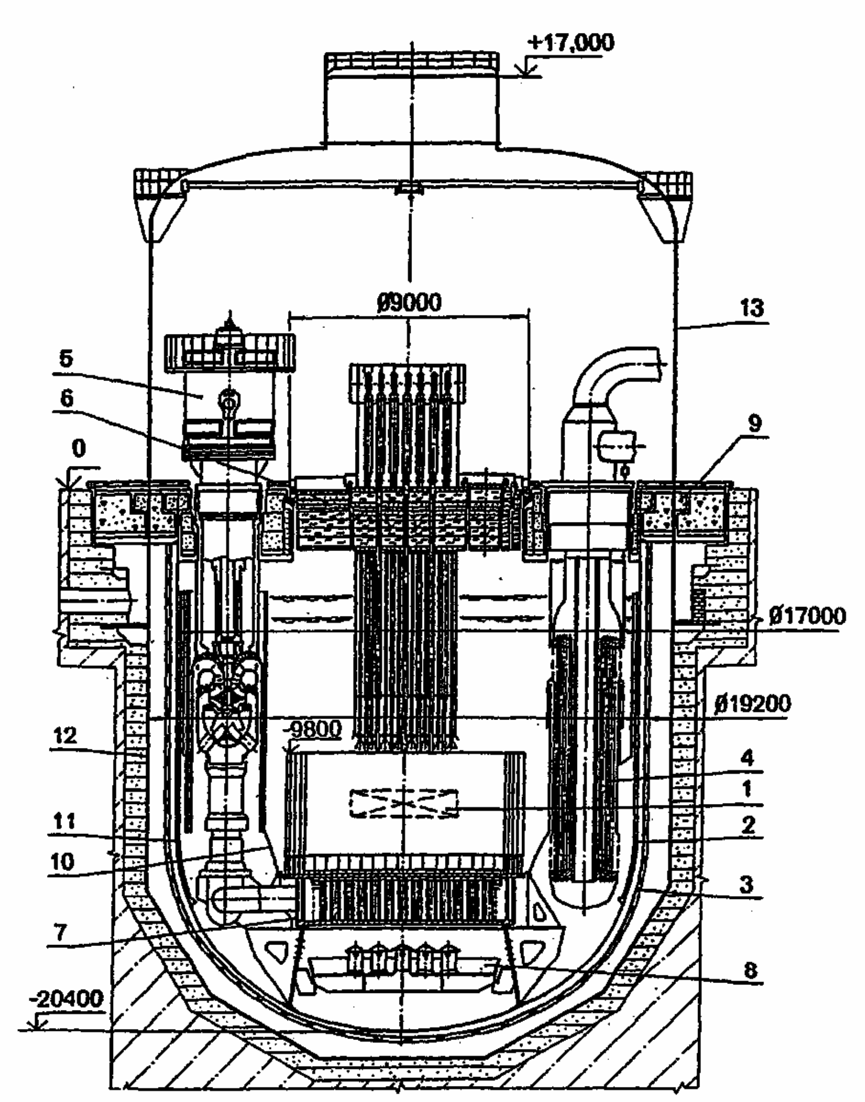
EFR safety vessel and vault.



Generating cost comparison EFR vs. advanced PWR.

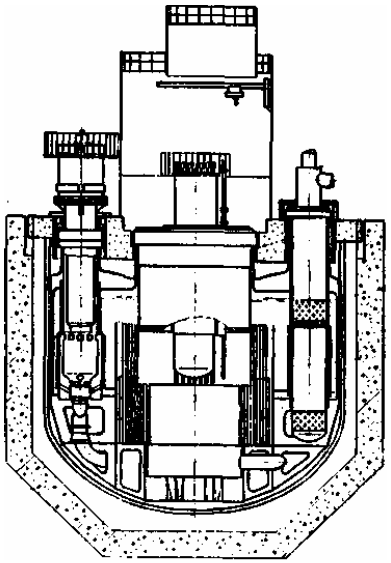
13.3.8. BN-1600

The conceptual design of the advanced reactor plant BN-1600 was completed in 1992, in full compliance with the up-to-date requirements for safety and economic efficiency of the new generation NPPs. It is expected that this design can be realized in Russian Federation not earlier than 2020, taking into account the fact that in the near future the fast reactor development programme in this country will be primarily focused on construction of the pilot BN-800 reactors, and creation of the closed nuclear fuel cycle production plants. This phase is of exceptional importance for the subsequent development of fast reactors and should precede their wide incorporation into the nuclear power park.

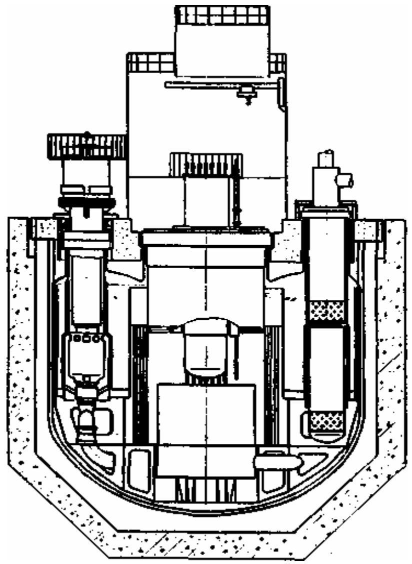


l-reactor core, 2-main reactor vessel, 3-guard vessel, 4-submerged heat exchanger for decay heat removal, 5-cold filter-trap, 6-rotating shield plug, 7-core diagrid, 8-core catcher, 9-upper stationary shield, 10-"hot" sodium collector, 11-thermostabilizing baffle, 12-well liner, 13-containment, 14-refuelling mechanism, 15-elevator, 16-refuelling cell, 17-FAs transfer mechanism

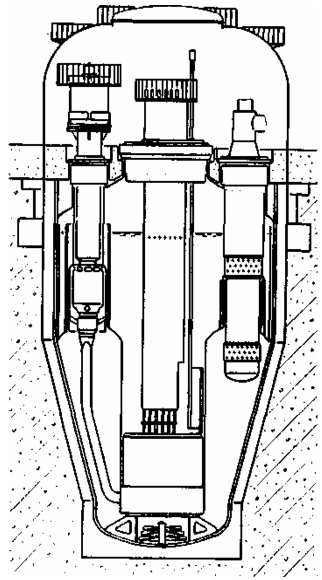
BN -1600 reactor block design option (4 IHX+4 PP).



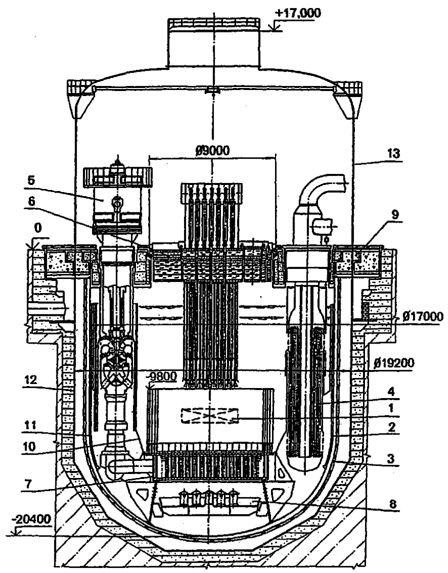
- 8 IHX + 4PP
- reactor vessel roof cooled by sodium
- steel radial shielding
- vertical tube refuelling device
- M_{0t} = 6 400 t (4.0 t/MW_{el})
- D/H = 18.9/19.5 m



- 8 IHX + 4PP
- reactor roof has no cooling
- steel and boron carbide radial shield
- vertical tube refuelling device
- M_{gt} = 4 700 t (3.0 t/MW_{el})
- D/H = 19.9/19.5 m

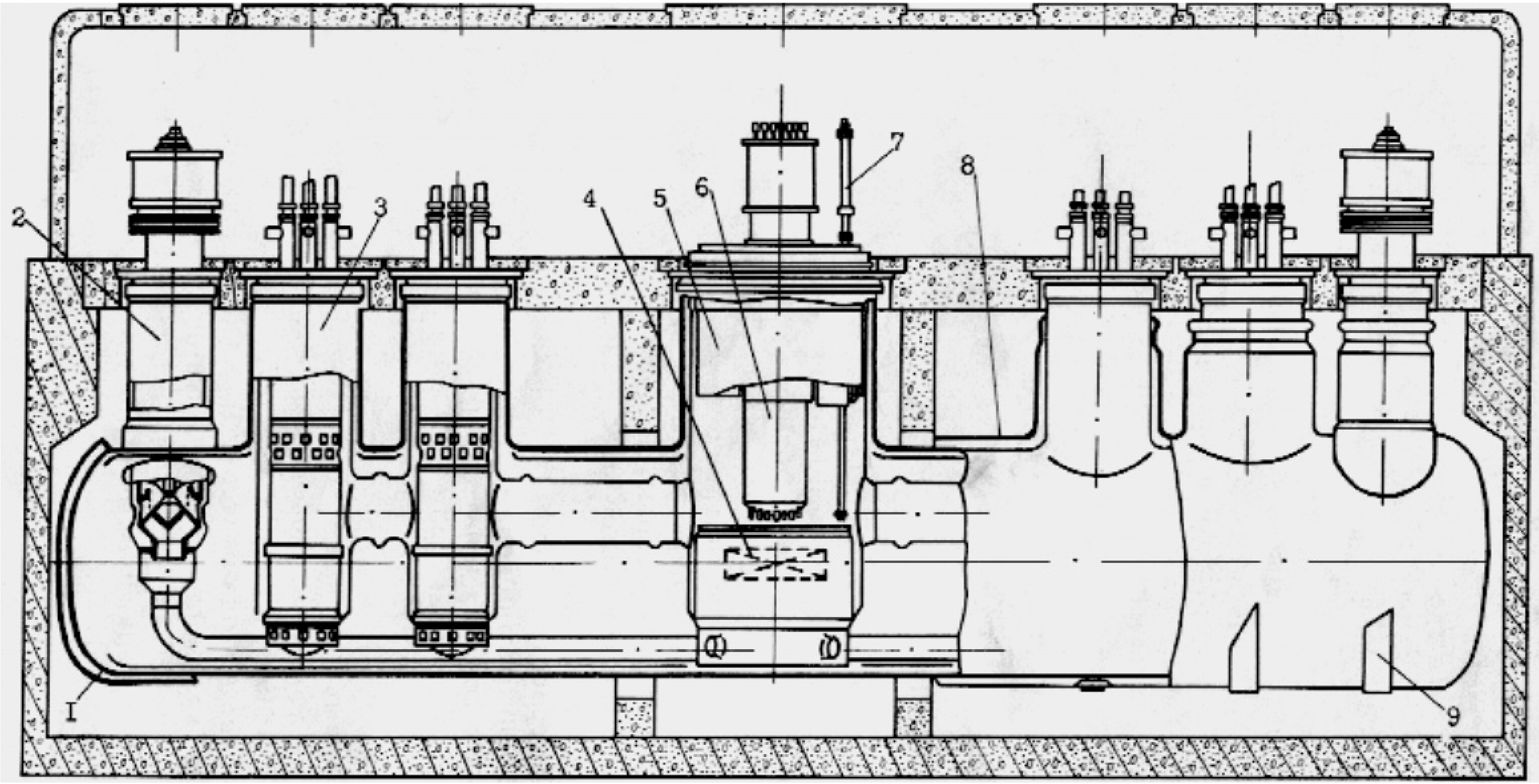


- 4 IHX + 4 PP
- reactor vessel roof has no cooling
- no radial shielding
- single transfer arm
- M_{st} = 2 700 t (1.7 t/MW_{el})
- D_r = 17.0 m, H_r = 28 m



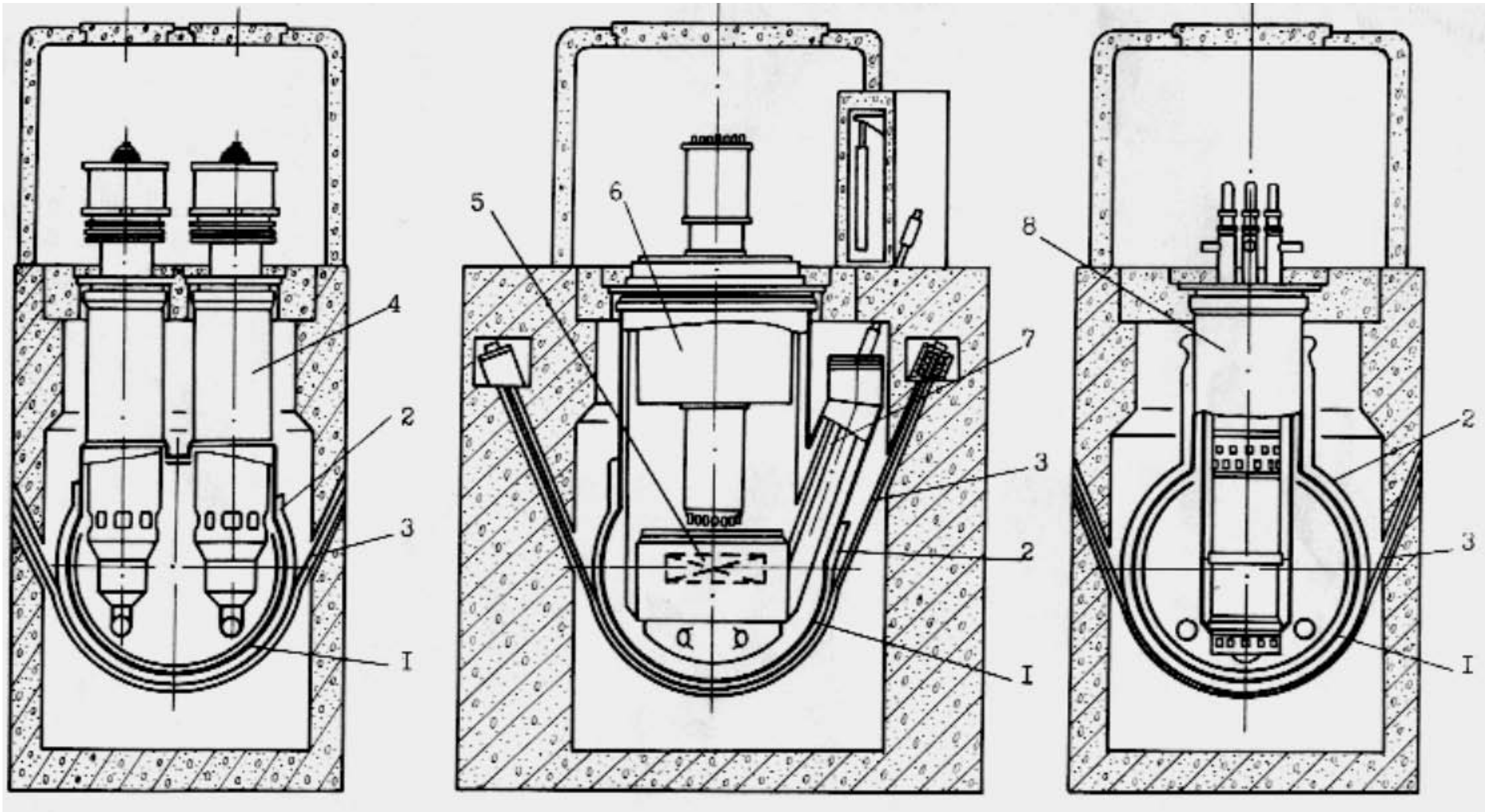
l-reactor core, 2-main reactor vessel, 3-guard vessel, 4-submerged heat exchanger for decay heat removal, 5-cold filter-trap, 6-rotating shield plug, 7-core diagrid, 8-core catcher, 9-upper stationary shield, 10-"hot" sodium collector, 11-thermostabilizing baffle, 12-well liner, 13-containment, 14-refuelling mechanism, 15-elevator, 16-refuelling cell, 17-FAs transfer mechanism

BN-1600 design options optimization.



1-reactor vessel, 2-primary pump, 3-intermediate heat exchanger, 4-reactor core, 5-rotatable plug, 6-central column with control assemblies, 7-refuelling mechanism, 8-safety vessel, 9-suspension (hang) structures

Layout of the BN-1600 reactor horizontal pool type design.



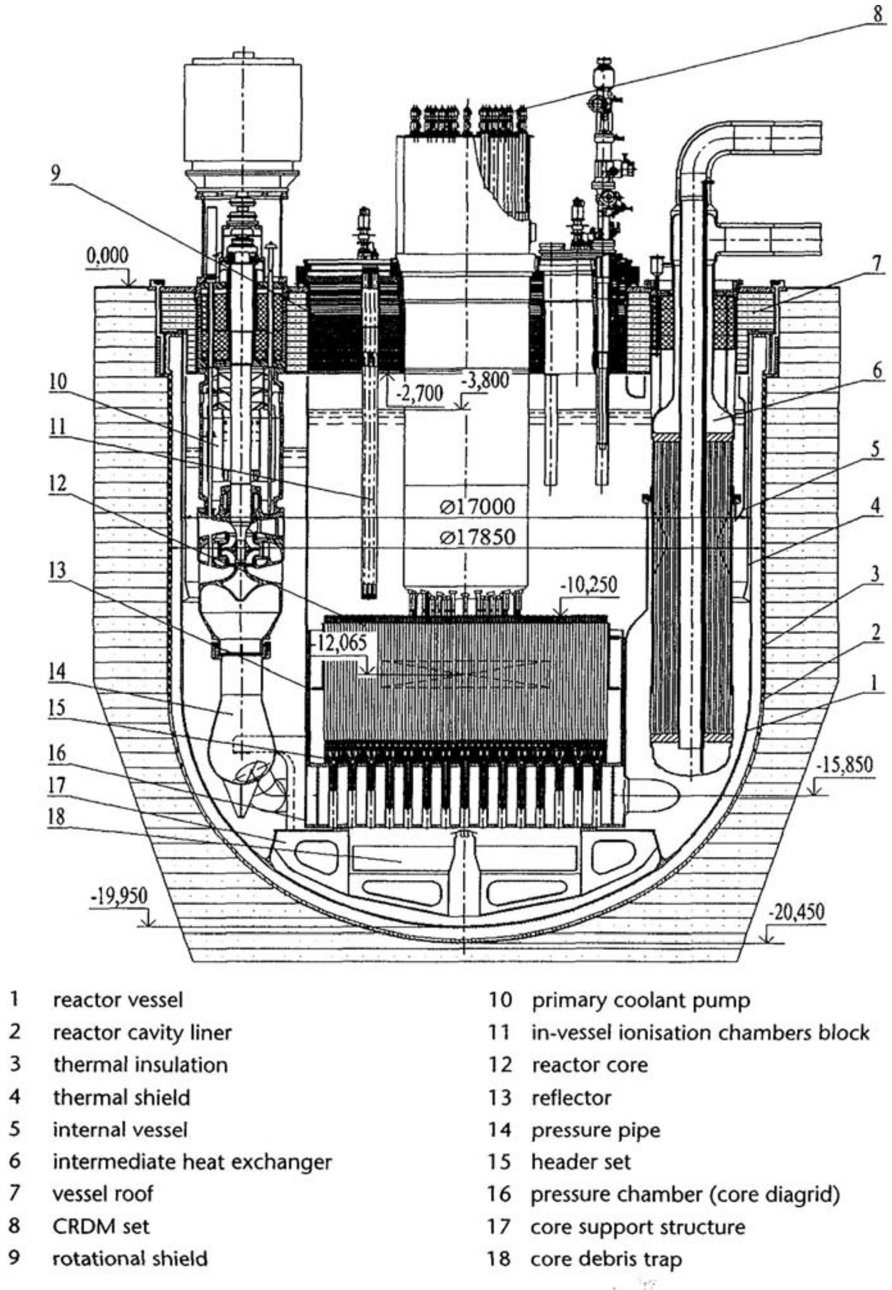
1-reactor vessel, 2-safety vessel, 3- suspension (hang) structures, 4-primary pump, 5- reactor core, 6- rotatable plug, 7-elevater, 8-intermediate heat exchanger

Cross-section view through pump and IHX of the horizontal pool type BN-1600 design.

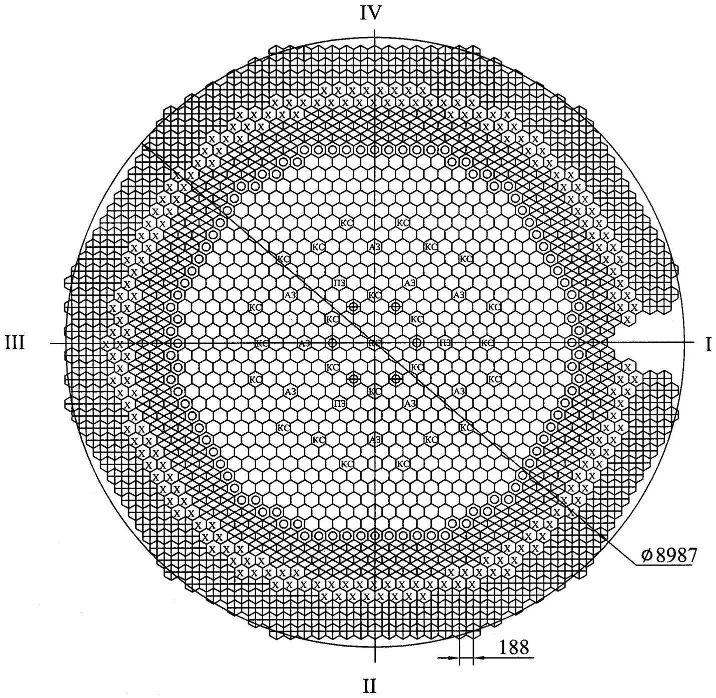
13.3.9. BN-1800

At the present time efforts to analyse an additional measures to reduce the capital cost are continued. A successful operation of BN-600 NPP testifies to the fact that the parameters and steam cycle efficiency of large reactor could be improved in comparison with BN-800 NPP. From the time the basic decision on this plant was taken, more than 20 years have passed. During this period, the steam parameters in fossil fuelled plants were increased (24 MPa, 560°C) and industry has started turning out turbines and generators from 500–800 to 1000–1200 MW(e). The main steam temperatures are 540 to 560°C is achieved. The decision on the use of such steam cycle and standard turbines is studied.

The design work on BN-1600 and BN-1800 has achieved substantial investment cost reductions for the reactor and NSSS.



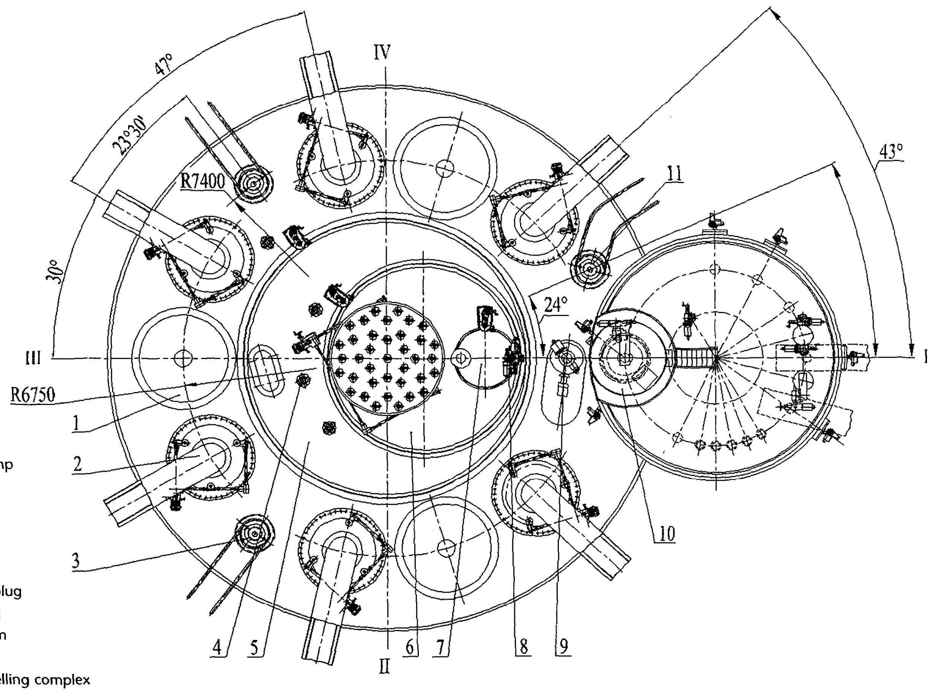
BN-1800 cross-section view through pump and IHX.



- FA-643 pcs.
- SSA 1st-type-6 pcs.
- SSA 2nd-type-96 pcs.
- BSA 1st-type-287 pcs.
- BSA 2nd–type-414 pcs.
- Scram rods-9 pcs.
- Preventive protection rods-3 pcs.
- Reactivity compensation rods-25 pcs.
- Spent FA in storage-204 pcs.

Total number of cells-1697

BN-1800 reactor core layout.

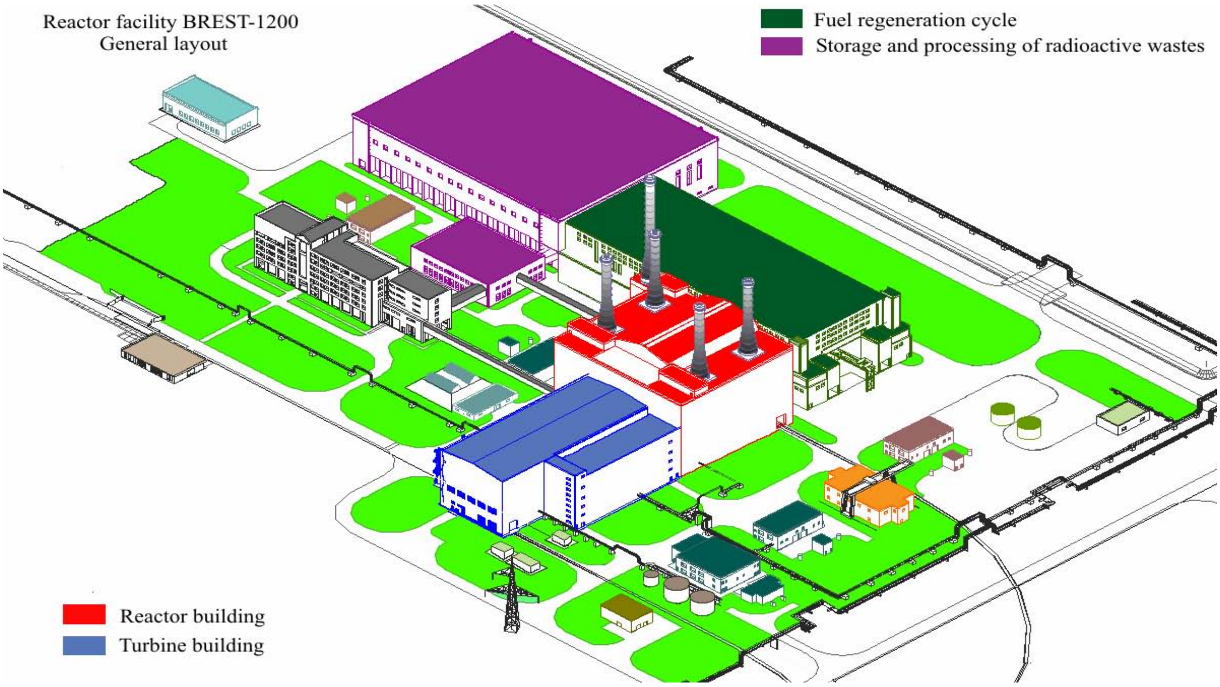


1 primary coolant pump
2 IHX
3 filter-trap
4 in-vessel ionisation chambers block
5 large rotational plug
6 medium rotational plug
7 small rotational plug
8 refuelling mechanism
9 elevator
10 reactor outside refuelling complex
11 sodium impurities control system

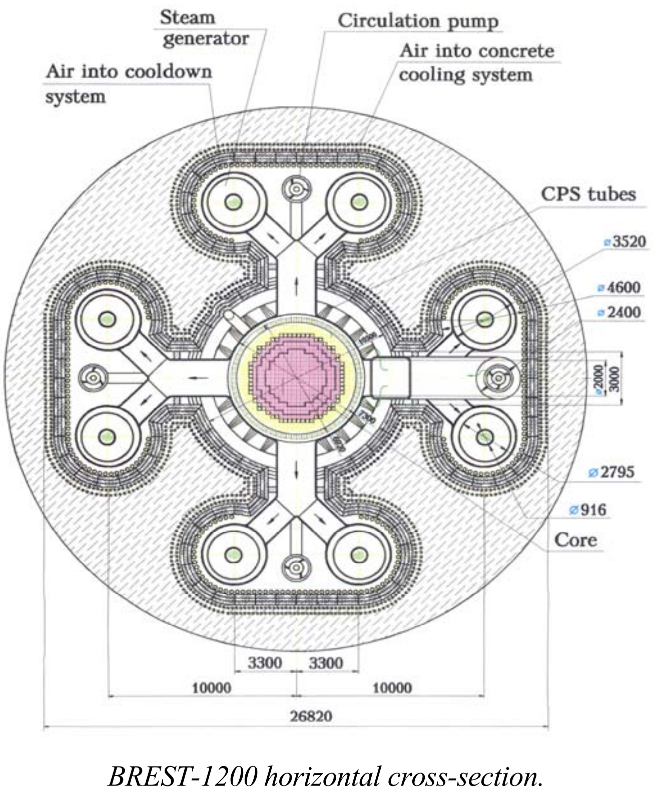
BN-1800 plan view.

13.3.10. BREST-1200

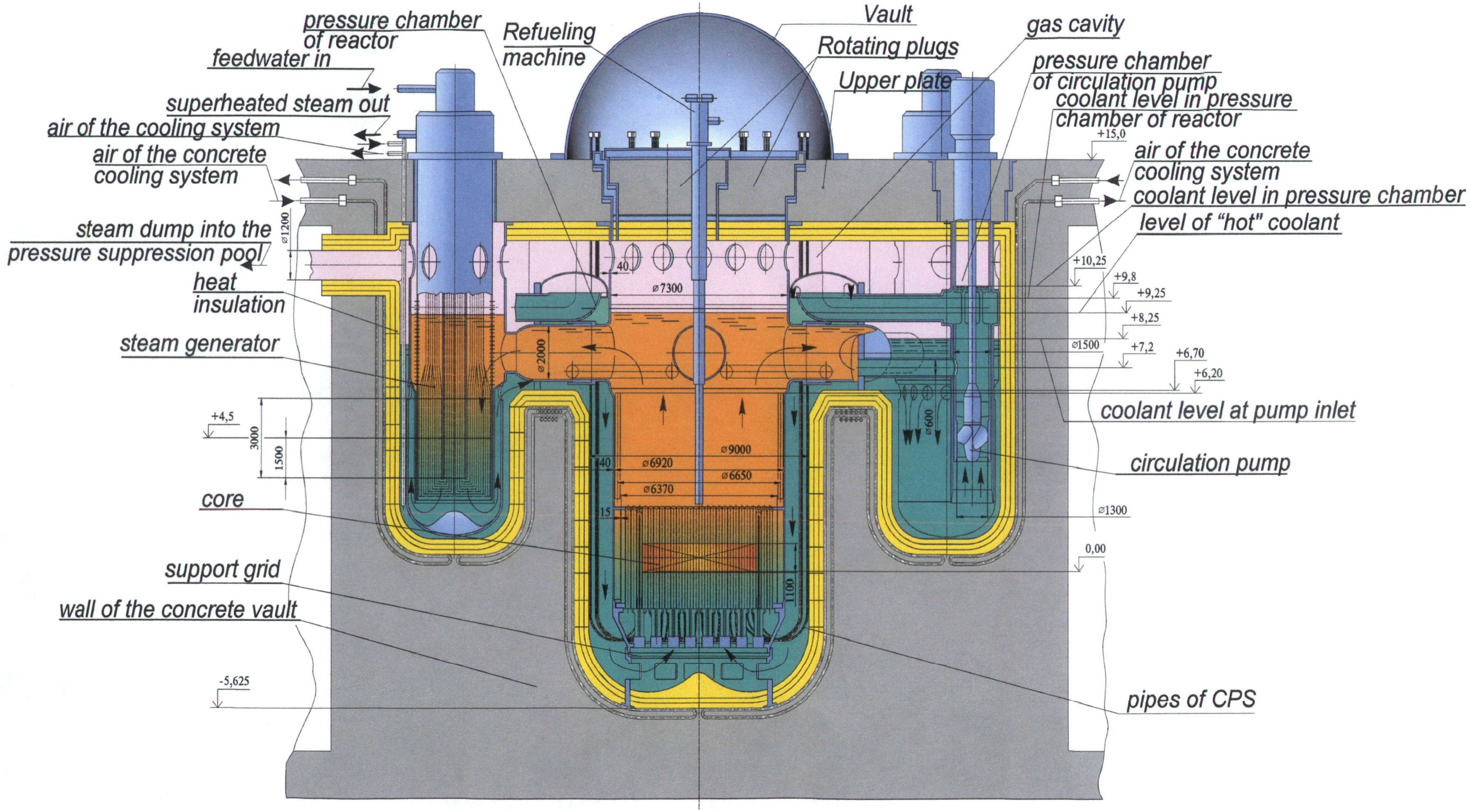
Activities in the FR area in Russian Federation include design studies of fast reactors with alternative coolants including lead (BREST-OD-300 and BREST-1200).



BREST-1200 overall survey.



BREST-1200 horizontal cross-section.



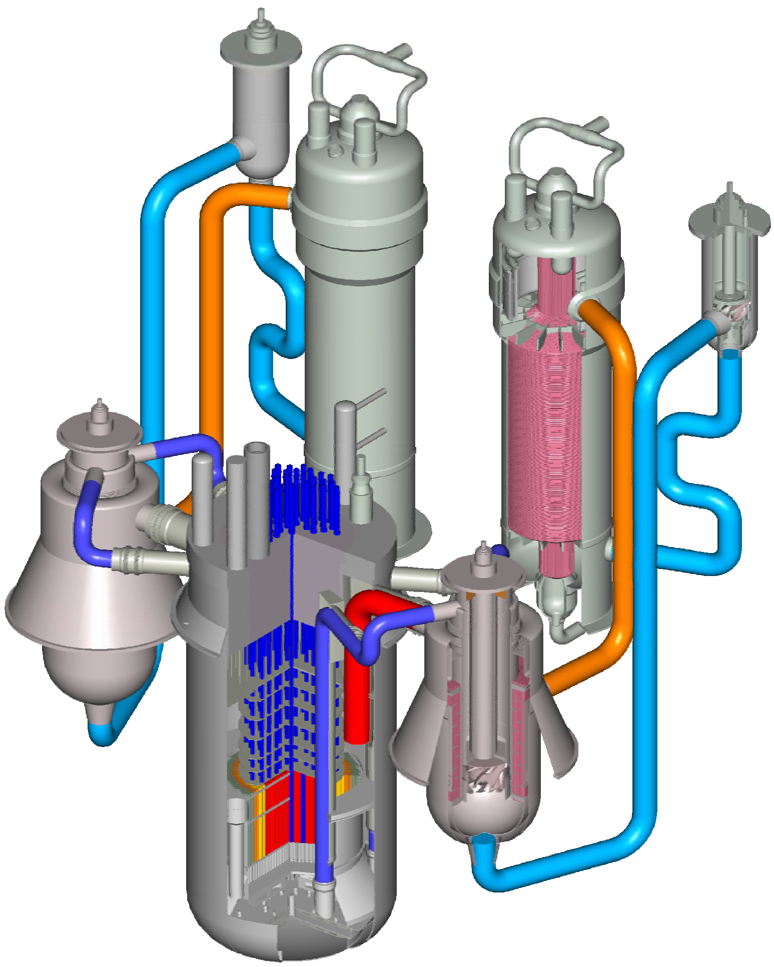
BREST-1200 vertical cross-section.

13.3.11. JSFR-1500

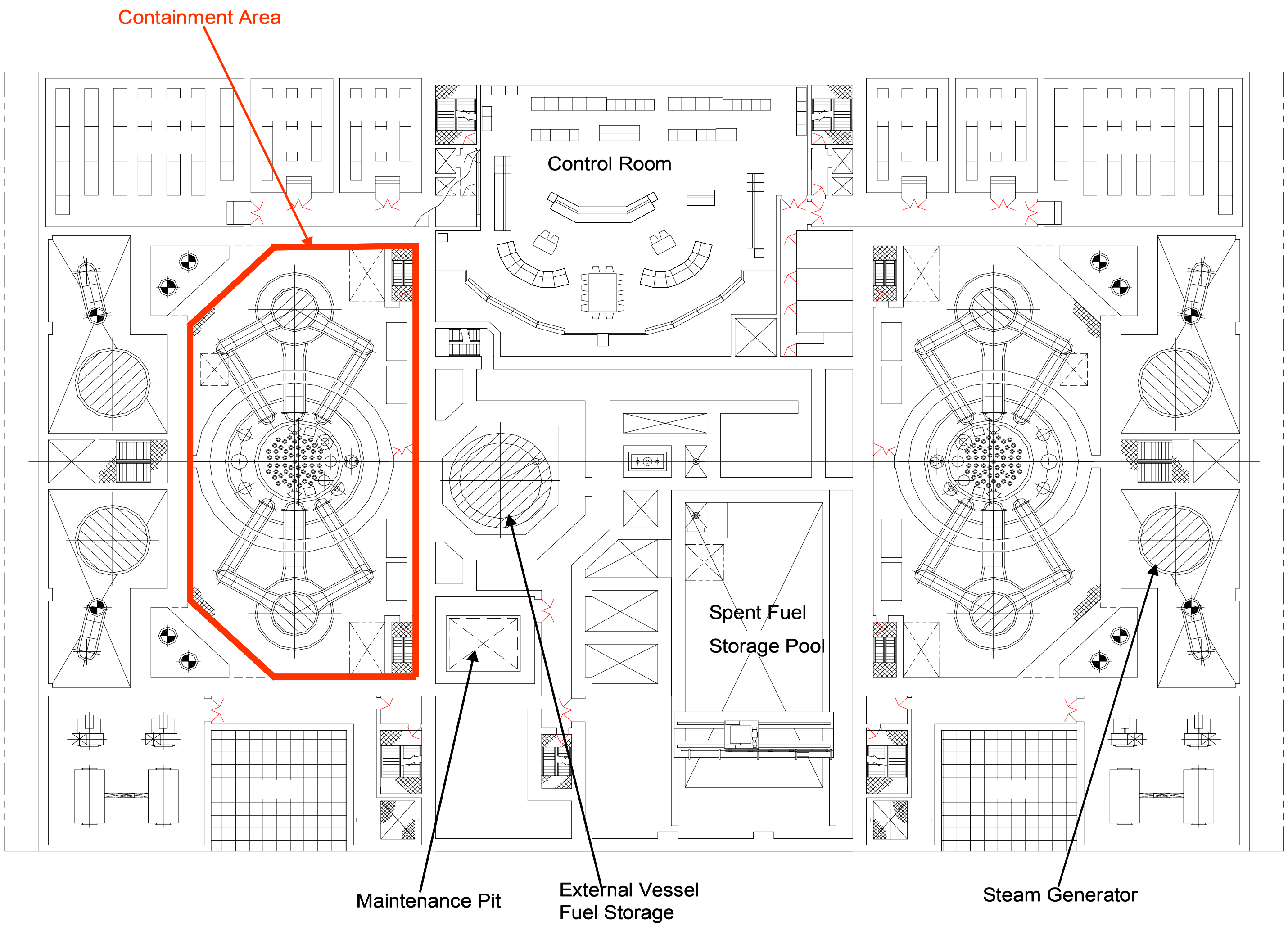
The fast reactor development programme is a key part of the Japanese policy for greater energy independence. The feasibility studies on commercialised fast reactors cycle systems are in progress. The Japanese R&D are being focused on the design of the candidate concepts and on fundamental tests of key technologies.

In progress of the loop type LMFR design development, Japan is now in a position to embark on an in-depth study of an advanced plant configuration - a compact loop type LMFR design: JSFR. To achieve the economic target, several innovative technologies and LMFR design improvement measures have been adopted. The reduction of plant material is accomplished by adopting the following technologies:

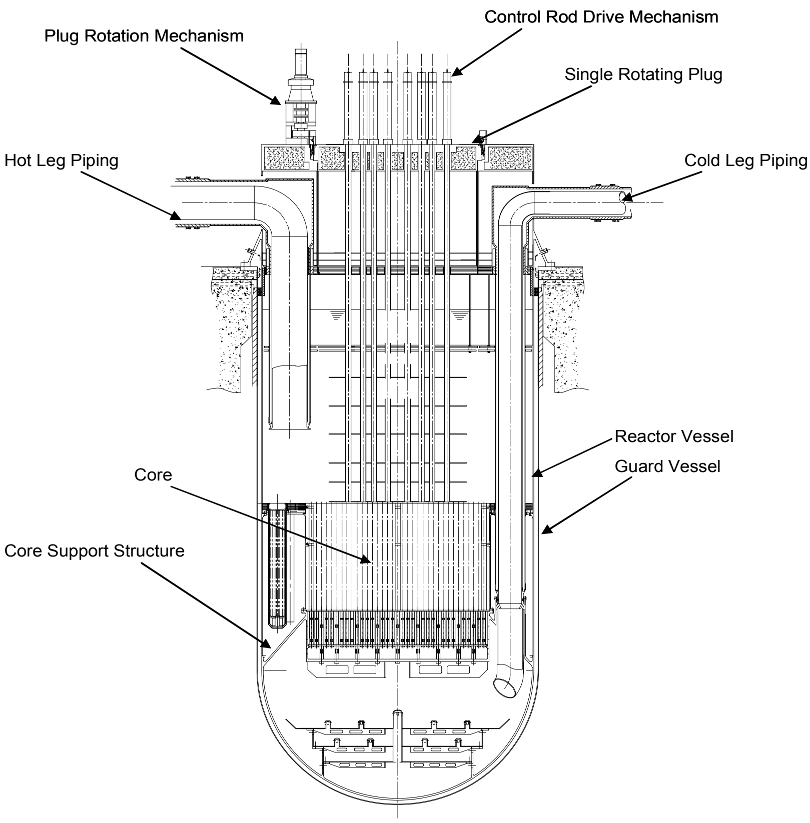
- Shortening the piping length and reduction of the number loops by adopting 12 Cr steel which has low thermal expansion with high strength;
- Development of integrated intermediate heat exchanger (IHX) with mechanical pump.



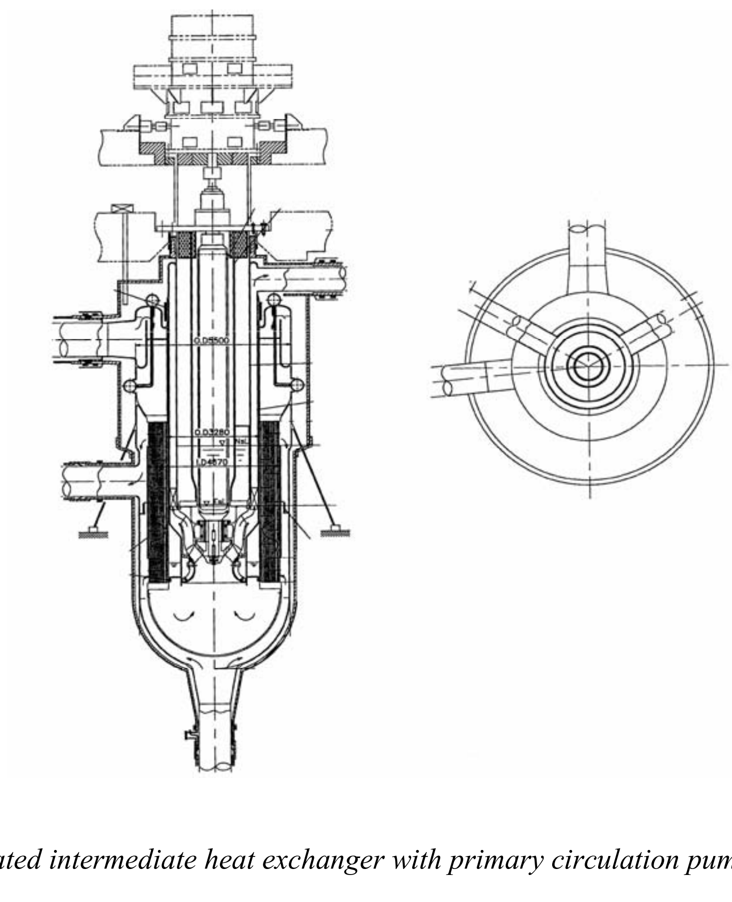
Bird's eye view of JSFR-1500 NSSS.



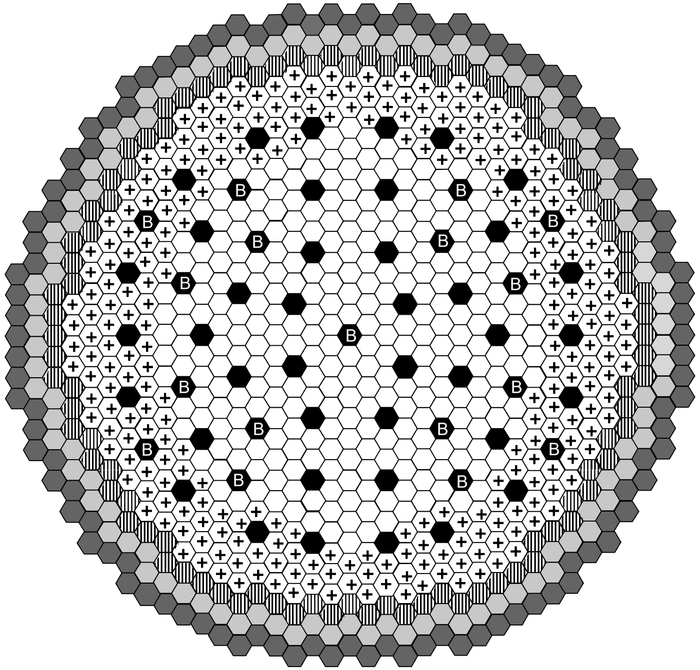
JSFR-1500 reactor building plan.



JSFR-1500 reactor.

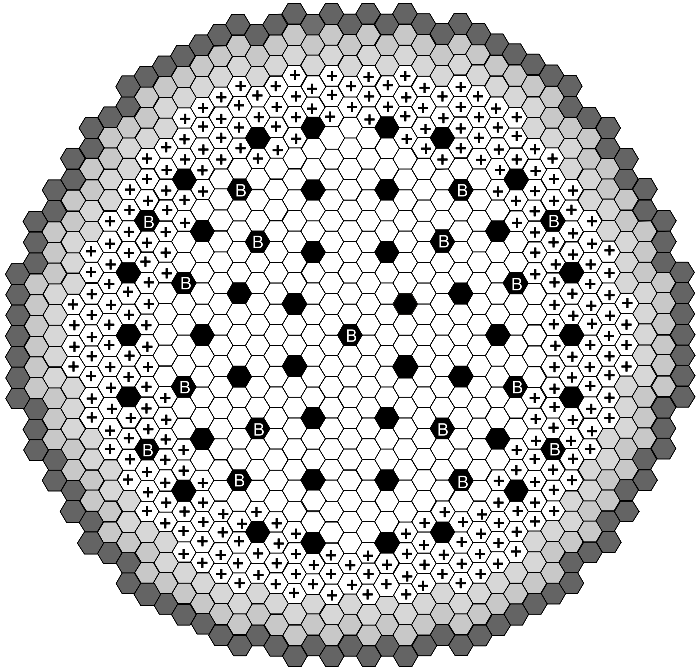


JSFR-1500 integrated intermediate heat exchanger with primary circulation pump.



Core Zone	Inner Core		288
	Outer Core		274
Radial Blanket			96
Control Rod	Primary Control Rod		40
	Buckup Control Rod		17
Radial Shield	SUS		102
	Zr-H		108

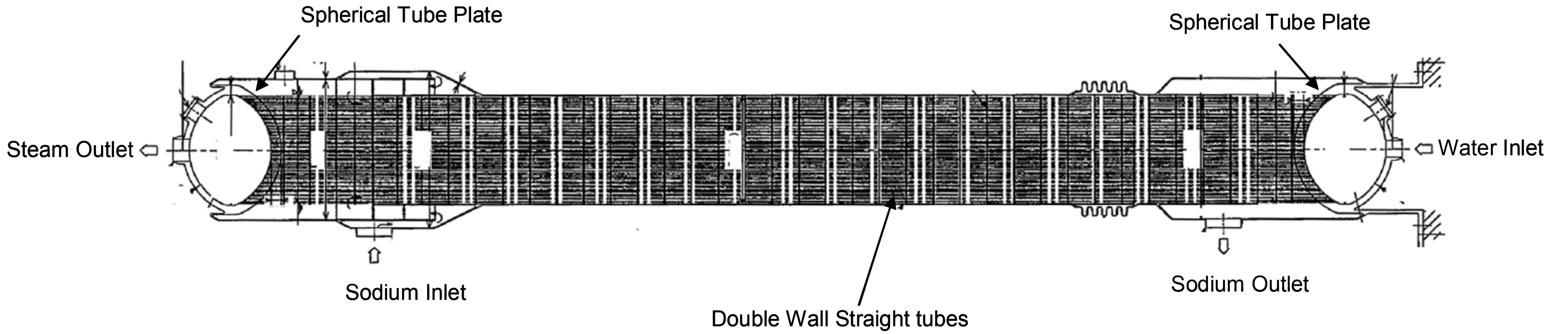
Breeding core



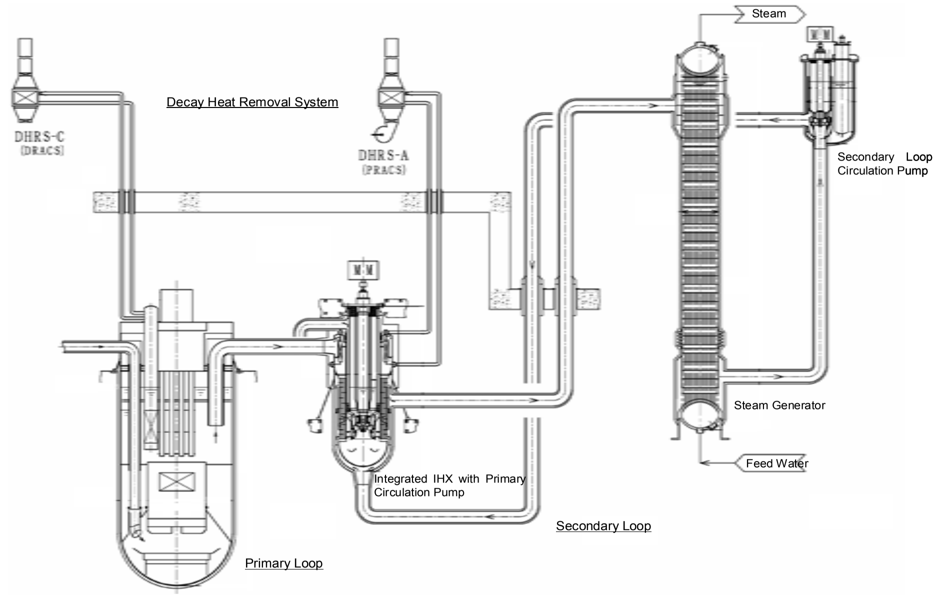
Core Zone	Inner Core		288
	Outer Core		274
Radial Blanket			0
Control Rod	Primary Control Rod		40
	Buckup Control Rod		17
Radial Shield	SUS		198
	Zr-H		108

Break even core

JSFR-1500 core configuration.



JSFR-1500 double-wall-straight-tube steam generator.



JSFR-1500 flow diagram.

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