IAEA-TECDOC-792

Management of research reactor ageing

INTERNATIONAL ATOMIC ENERGY AGENCY

The originating Section of this document in the IAEA was:

Engineering Safety Section
International Atomic Energy Agency
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna, Austria

MANAGEMENT OF RESEARCH REACTOR AGEING
IAEA, VIENNA, 1995
IAEA-TECDOC-792
ISSN 1011–4289

Printed by the IAEA in Austria
March 1995

FOREWORD

As of December 1993, about one quarter of the operating research reactors were over 30 years old. The long life of research reactors has raised some concern amongst research reactor operators, regulators and, to some extent, the general public. The International Atomic Energy Agency commenced activities on the topic of research reactor ageing by appointing an internal working group in 1988 and convening a Consultants Meeting in 1989. The subject was also discussed at an international symposium and a regional seminar held in 1989 and 1992 respectively.

A draft document incorporating information and experience exchanged at the above meetings was reviewed by a Technical Committee Meeting held in Vienna in 1992. The present TECDOC is the outcome of this meeting and contains recommendations, guidelines and information on the management of research reactor ageing, which should be used in conjunction with related publications of the IAEA Research Reactor Safety Programme, which are referenced throughout the text.

This TECDOC will be of interest to operators and regulators involved with the safe operation of any type of research reactor to (a) understand the behaviour and influence of ageing mechanisms on the reactor structures, systems and components; (b) detect and assess the effect of ageing; (c) establish preventive and corrective measures to mitigate these effects; and (d) make decisions aimed at the safe and continued operation of a research reactor.

Specialists from over twenty Member States have made contributions to the present publication either by participating in the early draft, preparing and submitting case studies, or reviewing the document. IAEA staff member M. Gazit collected most of the information in Appendix II and prepared the working paper for the Technical Committee Meeting. The resultant publication was finally reviewed and edited by F.A. DiMeglio and by F. Alcalá-Ruiz, who served as Scientific Secretary for all of the above meetings.

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1. INTRODUCTION

1.1. BACKGROUND

Since the first nuclear research reactor went critical in 1942, over 550 research reactors have been constructed worldwide and, of these, approximately 300 are currently in operation. Approximately 66% of the reactors currently in operation around the world are over 20 years old and 30% are over 30 years old.

These research reactors were designed and constructed using standards, materials and components meeting industrial practices in the country of origin at the time of construction. In general, these components and materials were required to satisfy acceptance tests. There was not sufficient experience to predict reliably the expected lifetime for most of the components and materials even if exposed only to benign environments and operating conditions. However, exposure to aggressive environments and operating conditions will cause unanticipated or accelerated degradation of some of the materials and components. In addition, new or revised standards are now available and these should be utilized when considering ageing related degradation. For all these reasons, an understanding of degradation mechanisms, assessment techniques and appropriate mitigation processes is necessary to develop corrective response and to maintain safety in the operation and utilization of these reactors.

The design, operation and utilization philosophy of nuclear research reactors is fundamentally different from that of nuclear power reactors. This is because the purpose of a research reactor is to be used as an experiment itself or to conduct separate experiments during its operation. In addition, utilization may also lead to frequent modifications of the reactor. These differences require that separate criteria be established for power and research reactors even though many age related degradation mechanisms are similar.

Many papers have been published and symposia and seminars held on the ageing of nuclear power reactors, and these works provide useful reference material for research reactors. In addition, some papers have been published and symposia and seminars held on the ageing of research reactors. The international experience has been reviewed for this publication, which will provide assistance in managing ageing problems in research reactors.

The IAEA began activities on research reactor ageing in November 1988 by appointing an internal working group which produced a preliminary report. A consultants meeting was then convened in Vienna in November 1989. The topic was also discussed at the IAEA International Symposium on Research Reactor Safety, Operations and Modifications, held in Chalk River, Canada, in October 1989 [1]. In addition, an IAEA Seminar for Asia and the Pacific on Ageing, Decommissioning and/or Major Refurbishments of Research Reactors was held in Bangkok, Thailand, in May 1992. Finally a Technical Committee Meeting (TCM) was held in Vienna in November 1992 to review a working paper on research reactor ageing. This working paper was prepared by the IAEA's staff and incorporated:

(1) The results of the Consultants Meeting held in Vienna in November 1988;
(2) The results of the Symposium held in Chalk River in October 1989 and of the Seminar held in Bangkok in May 1992; and
(3) Relevant material from other IAEA publications related to power reactor ageing [2], to research reactor design [3] and to research reactor operation [4].

This TECDOC is the outcome of the above TCM and contains recommendations, guidelines and information on the management of research reactor ageing. Because of its objectives, this TECDOC should be used in conjunction with other IAEA publications related to the safety of research reactors. A list of these publications is given at the end of this publication together with an overview of proposed publications on research reactor safety. In particular, this TECDOC is related to the Safety Guide on Safety in the Utilization and Modification of Research Reactors, IAEA Safety Series No. 35-G2 [5] and to a document on guidelines for safety reviews of research reactors under preparation.

1.2. OBJECTIVES

The objectives of this publication are to:

- State the ageing problem and explain its relationship to the safety of research reactors;
- Review ageing mechanisms for an understanding of their behaviour and influence on reactor components and systems;
- Provide guidelines to assist research reactor operators in the detection and assessment of the effects of ageing;
- Provide information which may be used for evaluating the safety of continued operation of an ageing research reactor;
- Recommend preventive and corrective measures to mitigate the effects of ageing; and
- Give guidance on the decision making process leading to a project for repairing, refurbishing and/or replacing a research reactor.

1.3. SCOPE AND FORMAT

With the exceptions noted below, this publication is applicable to any type of operating research reactor. It may also be applied to critical and subcritical assemblies (hereafter both included under the term research reactor) to the extent that is appropriate for these facilities.

In the context of this publication, the term research reactor covers the reactor core, experimental facilities and all other facilities relevant to either the reactor or its experimental facilities located on the reactor site.

The guidance given in this publication is applicable to research reactors with limited hazard potential to the public and typical characteristics. For addressing the topic in research reactors with several tens of megawatts of power, fast neutron spectrum research reactors or small prototype power reactors, etc., other similar IAEA publications prepared for power reactors may be more appropriate for a number of aspects (see References). No specifications for such a transition to other guidance are presented.

There may be research reactors (including critical assemblies) for which some of the guidance given in this publication may not be appropriate. One example is the core cooling system for a low power reactor or a critical assembly. Since the power output is small, there may be no dedicated core cooling system.

An ageing problem with obvious manifestations (e.g. leakage of corroded primary coolant piping) will evoke a corrective maintenance response from the operating organization. This publication, however, also concerns ageing degradation problems which are not so obvious. It discusses not only the assessment of the degradation which occurs through ageing but also its effect on safety and the actions which should follow. In addition, it discusses the role of inspection and preventive maintenance in detecting and delaying degradation of components and materials and minimizing the number of obvious manifestations.

Human resources are an important aspect of the safe operation and utilization of the reactor facility. The ageing of the operating and research staff at research reactor installations should be considered. However, because of the specialized nature of this problem, it is beyond the scope of this publication.

This TECDOC has been structured as follows: Section 2 defines the ageing problem in a broad sense and introduces the ageing management methodology. Section 3 deals with implications of ageing on the safety of research reactors, introducing the conditions, mechanisms, effects of ageing and current trends and future activities in research on ageing. A short comment on post-service inspection and testing is also included, since the possibility of shutting down an ageing reactor exists. Section 4 suggests ways to detect ageing problems and to collect, record, review and assess data. Section 5 provides methodology and guidelines for prevention and mitigation of the consequences of ageing. Section 6 provides guidelines for assessment of the conditions for continued operation of existing research reactors.

2. DEFINITION OF AGEING AND AGEING MANAGEMENT

2.1. DEFINITION OF AGEING

Ageing is defined as a general process in which characteristics of components, systems and structures gradually change with time or use. This process eventually leads to degradation of materials subjected to normal service conditions[1]. These include normal operation and transient conditions under which the component, system or structure is required to operate. Postulated accident and post-accident conditions are excluded [2] and should be evaluated on a case-by-case basis for the effect on the reactor safety and utilization.

In a research reactor facility, the effects of such degradation may result in the reduction or the loss of the ability of components, systems and structures to function within accepted criteria. Safety and utilization of the facility may be affected unless preventive measures have been taken, and corrective measures have been established.

2.1.1. Service conditions

Service conditions which contribute to ageing act through chemical and physical processes that affect material properties or functional capabilities. These are:

- Stress and/or strain;
- Temperature;
- Environmental factors such as radiation, high humidity or the presence of chemically active liquids or gases (before or during operation);
- Service wear and corrosion, including changes in the dimensions and/or the relative position of individual parts of assemblies;
- Excessive testing;
- Inadequate design, improper installation or maintenance.

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[1] Normal service conditions encompass all operational states of the research reactor plus all those specific circumstances surrounding them. Such circumstances may be related to the service environment for the performance of experiments (which may change the normal service environment), to the operating schedule which may consider cycles of different duration), etc.

In addition to these service conditions, there are conditions not related to chemical or physical processes which can lead to obsolescence and affect reactor safety. These are:

- Technology changes;
- Safety requirements changes;
- Obsolescence of documentation;
- Inadequacies of design;
- Improper maintenance or testing.

These non-chemical or non-physical service conditions are also considered in this document. Further discussion of service conditions for ageing may be found in Section 3.2.

2.1.2. Degradation of materials

The main effect of ageing is degradation of materials. This degradation may be:

- A change in physical properties (e.g. electrical conductivity);
- Irradiation embrittlement;
- Thermal embrittlement;
- Creep;
- Fatigue;
- Corrosion, including corrosion erosion and corrosion assisted cracking;
- Wear (e.g. fretting) and wear assisted cracking (e.g. fretting fatigue).

The effects of ageing are discussed in Section 3.3.

2.2. MANAGEMENT OF AGEING

The probability of a component, system or structure failure resulting from ageing degradation normally increases with the time of exposure to service condition unless countermeasures are taken. The objective of the management of ageing is to determine and apply these countermeasures. The management of ageing includes activities such as protection, repair, refurbishment or replacement, which are similar to other activities carried out at a reactor facility during routine maintenance and testing or when a modification project takes place. However, it is important to distinguish between these different activities, because the management of ageing requires the use of methodology which will detect and evaluate deficiencies produced by the service conditions and will lead to the application of countermeasures for prevention and mitigation of the deficiencies. One approach to this methodology is a determination that the reactor systems and components can perform their safety functions during their service life and under the service conditions. This can be achieved through appropriately selecting systems and components which should be subjected to surveillance activities and included in a long term ageing detection programme, through data collection and through evaluation of the potential ageing effects. The above activities will be accompanied by countermeasures for prevention and mitigation of the ageing effects to ensure an adequate level of safety for the reactor facility.

To manage ageing it is necessary to understand how ageing affects the components and materials which are used to achieve overall safety of the reactor. This topic is discussed in detail in Section 3 along with an overview of the current trends and future activities in research on ageing. The management of ageing and related activities are discussed in Sections 4 and 5.

3. AGEING AND SAFETY OF RESEARCH REACTORS

3.1. GENERAL SAFETY REQUIREMENTS AND AGEING

The overall safety objective for a research reactor is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological hazards. In order to achieve this objective, a number of safety principles and requirements are utilized in the design stage and these as well as additional measures are utilized during reactor operation. These are, inter alia, defence in depth, reliability, safety analysis, quality assurance and regulatory supervision, including the review and assessment of the relevant associated safety documentation prepared by the operating organization [3, 4].

Because of ageing, full compliance with the above safety principles and requirements may be compromised. Examples follow of the areas where ageing may reduce the level of compliance with the safety principles and requirements.

3.1.1. Ageing and defence in depth

Defence in depth is usually achieved by a system of multiple barriers. The integrity of such a system can be impaired by failure of one or more of these barriers. The ageing process may lead to an increase in the probability of failure of a barrier component and ultimately to the failure of the barrier. An example of the effect of ageing on defence in depth follows.

Release of fission products from the fuel to the environment is prevented by the fuel matrix, the fuel cladding, the reactor pool and the reactor building (confinement). Cracking of the concrete of a confinement building, due to environmental conditions over a long period of time, may reduce its ability to confine a radioactive release.

3.1.2. Ageing and reliability

The ageing of components may lead to an increase in failures of these components and a decrease in the availability of the reactor. In most instances, the use of redundancy in the safety related systems will help to prevent that the safety of the system is compromised.

However, even those systems which incorporate redundancy may, of course, age and effect reliability.

For example, the reactor nuclear instrumentation system, which is designed to shut down the reactor, may be a three channel system which requires the simultaneous action of two for shutdown with a required reliability of 1×10^{-4} failures per demand. Ageing of the components may reduce the reliability of the system to 1×10^{-3} which may not comply with the safety requirements.

3.1.3. Ageing and safety related documentation

Along with components and materials, safety related documentation may also age in the sense that over time it may become out of date or even obsolete. Research reactors are frequently modified to incorporate new experimental facilities and the modifications require updating of documentation. This fact and the fact that testing and repair may also need to be changed with ageing is particularly important for the maintenance programme which is the basis for managing the ageing problem. Improper maintenance in conjunction with other service conditions may accelerate ageing.

Safety in operation requires that the operating personnel be knowledgeable of modified systems and the associated documentation. Therefore, training and retraining of responsible people at all levels is necessary in order to address the fact that systems, programmes and documentation have changed or may need to be changed.

3.1.4. Ageing and advances in technology and safety requirements

During the lifetime of a research reactor, technological advances will occur resulting in the introduction of new components and techniques. This may lead to difficulties in getting spare parts. Advances in safety concepts may require changes in hardware or software and may interfere with routine operation of the reactor. Sometimes, remedial activities related to the above changes are identified as "backfitting" activities (for further details see Ref. [5]).

3.2. SERVICE CONDITIONS AND AGEING

Ageing effects are normally discussed in terms of undesirable effects or failures. However, the basic causes of ageing phenomena are frequently service conditions which support the actuation of the particular ageing mechanism leading to these effects. In brief it can be said that:

SERVICE CONDITIONS
+
AGEING MECHANISMS
lead to
UNDESIRABLE EFFECTS OR FAILURES.

The following subsections present general considerations associated with three broad categories of service conditions.

3.2.1. Normal operation conditions

Levels of radiation, temperature or pressure in normal operation conditions will affect the physical properties of a material. Radiation affects components in and outside the reactor core. Other components may be affected by radiation from radioactive materials circulating with the coolant. While the effects of temperature and pressure are more noticeable in power reactors, they are also present in research reactors in materials such as gaskets. Cycling temperature or pressure variations may accelerate deterioration. Table I provides summary information on specific ageing mechanisms. Additional information on these topics is given in Appendix IV which lists 12 case studies. Further information on material ageing mechanisms related to nuclear power plants but sometimes applicable to materials used in research reactors can be found in Ref. [2].

3.2.2. Anticipated operational occurrences conditions

Following anticipated operational occurrences (e.g. fire, flooding, overheating or power excursions) acceleration of ageing effects may occur. It is advisable to investigate and to take corrective actions to stop accelerated ageing. Table II summarizes information on these conditions and induced ageing mechanisms.

TABLE I. EFFECT OF AGEING FOR SEVERAL SERVICE CONDITIONS

Conditions	Ageing mechanism	Consequence/failure
Radiation	Change of properties	- chemical decomposition - strength change - ductility change - colour change - swelling - resistivity change - burnup
Temperature	Change of properties	- strength change - resistivity change - ductility change - colour change
Stress (pressure)	Creep	- changes of geometry (e.g. break, collapse)
Cycling of temperature, flow and/or load Flow induced vibrations	Motion	- displacement - change of position or set point - loose connections
	Fatigue	- break, collapse - deformation
	Wear	- deterioration of surface - change of dimensions
Flow	Erosion	- strength change
Fluids chemistry	Corrosion/galvanic cells	- release of radioactive material - strength change - deposition of particles - short circuits - leakage conditions

TABLE II. EFFECT OF AGEING FOR ANTICIPATED OPERATIONAL OCCURRENCES

Conditions	Ageing mechanism	Consequence/failure
Power excursion	Thermal and mechanical damage	- deterioration of systems - accelerated ageing
Flooding	Deposition and chemical contamination	- Corrosion
Fire	Heat, smoke, reactive gases	- reduction of strength - corrosion

TABLE III. EFFECT OF AGEING FOR SEVERAL ENVIRONMENTAL SERVICE CONDITIONS

Conditions	Ageing mechanism	Consequence/failure
Humidity, salinity	Corrosion/galvanic cells	- leakage - release of radioactive material - strength reduction - deposition of particles - short circuits
Chemical agents	Chemical reactions	- undesirable chemical products - deterioration of structures
Wind, dust, sand	Erosion and deposition	- strength change - deterioration of surface - malfunction of components

3.2.3. Environmental conditions

Environmental conditions include climatic conditions such as humidity, frost and winds as well as site conditions such as salinity, sand, dust or chemical agents. The effects of these conditions are in general corrosion, erosion or undesirable chemical reactions occuring to the equipment exposed to such conditions. Table III summarizes information on these ageing mechanisms and conditions.

3.3. PHYSICAL CONDITIONS OR MECHANISMS AND EFFECTS OF AGEING

The following subsections which follow deal with the general effects (physical changes) of ageing by several mechanisms, which may be induced by specific service conditions on materials, components and systems of a research reactor. These subsections deal with a number of ageing related problems which would be expected for different service conditions. If several of these service conditions or mechanisms exist simultaneously, the ageing process may be accelerated.

3.3.1. Radiation

The effect of neutron irradiation on metals is mainly to increase the yield and the ultimate strength and to reduce the toughess. Helium or fission gas production within the metal matrix leads to changes in material properties and also to swelling. Swelling is particularly important in reactor control devices made of boron compounds.

Fast neutron irradiation of graphite causes displacement of lattice atoms and leads to graphite growth and distortion. The Wigner effect in graphite is also a problem in some high power research reactors. For these reactors, embrittlement of beryllium components must also be considered.

Concrete is traditionally used as a shielding material. However, severe damage from radiation is not expected under most research reactor operating conditions because the concrete is usually not in a high radiation field.

Electrical and electronic equipment (e.g. coaxial and other cables) is generally located in low radiation level fields. Where that is not possible, proper action should be taken to inspect and renew equipment.

All organic materials and glass are radiation sensitive and they should be carefully selected and monitored during use.

3.3.2. Temperature

Attention should be paid to proper cooling of experimental facilities and reactor structures such as thermal columns and concrete shields, as well as to electrical and instrumentation cables which may be located in unventilated hot areas. A temperature above 60°C may cause degradation of concrete by dehydration with a corresponding loss of integrity and neutron shielding effectiveness.

Elevated temperature in polymers results in hardening or a loss in tensile strength and elastic qualities even at the temperatures associated with research reactors.

3.3.3. Pressure

Research reactors operate at much lower pressure than power reactors. Therefore, pressure alone usually does not impose high stress on components in these reactors. Local high stress areas should be considered separately. Special care should be taken with experimental devices operated at high temperature and/or pressure.

3.3.4. Vibrations and cycling

Vibrations and cycling of pressure, flow, or temperature develop loading stresses which may cause cracking of material and eventually a fatigue fracture. Vibrations may cause degradation of electronics components and instrumentation. Vibration associated with the integrity of bonds and seals may be an important factor in their integrity. Change of position or of a set point is another phenomenon connected to vibration. Repeated relative motion of adjacent parts may result in fretting or wear.

3.3.5. Corrosion

Corrosion is the reaction of metal with its environment. Corrosion leads to material loss with surface degradation and loss of strength. Some types of corrosion (e.g. intergranular corrosion, stress/strain corrosion, corrosion fatigue) lead to loss of strength through crack enhancing. Another effect of corrosion is deposition of particles (corrosion products) in vulnerable places (e.g. valve seat) to impair the function of a component. These particles may contain radioisotopes, which complicate maintenance work. As corrosion products occupy a larger volume than that of the metal itself, fill up of crevices and narrowing of passages can also be expected. Corrosion of reinforcing bars in concrete should be taken into account. Although there are many types and appearances of corrosion, it can generally be divided into three types, as follows:

Corrosion without mechanical loading

- Uniform corrosion attack;
- Local corrosion attack (galvanic cells);
- Selective corrosion attack, especially intergranular corrosion.

Corrosion with additional mechanical loading

- Stress/strain corrosion cracking;
- Corrosion fatigue.

Corrosion erosion

While the service environment is the main cause of corrosion, many service conditions such as those causing erosion will enhance the process.

3.3.6. Other chemical reactions

Some environmental conditions may cause deterioration of structure or equipment through chemical reactions other than corrosion, e.g. reaction of the structure or equipment with ozone or NO_2. Use of chemicals may cause damage to equipment. Special care should be taken when irradiating capsules containing materials such as copper or mercury which may cause strong corrosion in aluminium alloys.

3.3.7. Erosion

Operational conditions such as high velocity of coolant fluid may cause erosion in equipment such as pipes and heat exchangers. Erosion results in deterioration of surfaces and reduction in strength.

Environmental conditions such as high winds and sand storms may cause erosion in outside structures.

3.4. NON-PHYSICAL CONDITIONS AND EFFECTS OF AGEING

3.4.1. Changes in technology

Research reactors were built according to the standards and with the equipment available at the time of construction. Since then progress in technology, especially in electronics has been made. Even if the original instrumentation and control systems of the reactor still function well, getting spare parts becomes difficult. This may make it necessary to replace the entire instrumentation and control system in order to facilitate a proper maintenance programme.

3.4.2. Changes in safety requirements

For many research reactors, the time elapsed since their construction has brought many new safety requirements. The modification of the hardware and the updating of the documentation of the reactor should be considered accordingly. Such modifications are usually called "backfitting" activities.

3.4.3. Obsolescence of documentation

The utilization of the reactor demands modifications and changes of experiments which tend to make the reactor documentation obsolete. A good ageing management programme should include the updating of operational manuals, drawings, specifications and other documentation.

TABLE IV. EFFECT OF AGEING FOR SEVERAL NON-PHYSICAL CONDITIONS

Conditions	Ageing mechanism	Consequence/failure
Technology progress	Shortage of spare parts, disappearance of suppliers	- maintenance difficulties
Change of safety	Obsolescence of existing safety components & systems	- interference with operation - modification of safety related components and systems
Lack of administrative procedures, obsolescence of documentation	Incomplete updating	- incomplete information
Inadequate design	Various	- accelerated ageing - may cause or support other undesirable operating conditions
Improper maintenance and periodic testing	Various	- deterioration of systems

3.4.4. Inadequacies in design

Inadequate design includes selection of wrong materials and inaccessibility for inspection and repair. The consequences may be accelerated physical ageing. To overcome the effects of inadequate design it may require a decrease of reactor power to lower the rate of ageing or the need for more frequent inspections and tests.

3.4.5. Improper maintenance and testing

Improper maintenance and testing may increase the physical effects of ageing in various ways. For example, increased pressure on bearings and breaking as a result of excessive tensioning of retaining bolts will accelerate wear. Testing too frequently or using procedures which do not accord with design and the manufacturer's recommendations could have detrimental effects on components, systems or structures. The use of a trained staff is important. Records should be appropriately generated and retained. Table IV summarizes information on the conditions and ageing mechanisms related to the above conditions or circumstances.

3.5. CURRENT TRENDS AND FUTURE ACTIVITIES IN RESEARCH ON AGEING

Much information is available on ageing problems of NPPs. Extensive programmes are being conducted in the IAEA and in its Member States. The objectives of many of the studies are metal ageing (mostly steels) and degradation of concrete structures, electrical equipment, electronic components, elastomers and lubricants. Most of this research has been carried out in research reactors, some of them almost exclusively dedicated to material testing (see Appendix IV).

Some of these research activities may also apply to nuclear research reactors. Operators of research reactors may benefit from the experience gained in preparing management programmes for ageing in NPPs. Methodological approaches as well as specific results of research on topics such as corrosion and ageing behaviour of electrical components and electronics can be adapted to research reactors (see, for example, Refs. [6] and [7]).

Areas have been identified [2] where further development is needed in the methods to detect and mitigate ageing effects. Some of these areas, applicable to research reactors, are as follows:

- Better understanding of ageing mechanisms.
- Engineering studies on individual components which may be identified as having ageing related impact on the reliability of safety related systems.
- Refining techniques for reliability predictions.
- Improving methods for predicting remaining service life.
- Improving guidelines for service condition monitoring.

3.5.1. Issues specific for research reactors

Nuclear research reactors have unique problems which should be specifically dealt with. Operators of research reactors have been dealing with such problems for many years initially as a response to actual problems in specific reactors and more recently as systematic research programmes.

The main items of research reactor programmes related to ageing are:

- The aluminium reactor tank and other components
- The effects in graphite and beryllium (reflector and moderator materials)
- Obsolescence of electronic equipment
- Corrosion of cooling and other systems components
- Deterioration of heat-exchanger tubes
- Degradation of cooling towers
- Degradation of concrete structures
- New safety requirements.

The first item, ageing effects in aluminium components, is unique to research reactors and little information may be found in the NPP literature. The rate of degradation for the other issues may be not as large in research reactors as in NPPs, but the much higher frequency of shutdowns and power variations and the relative age of existing research reactors increases their importance. Research on aluminium alloys has been conducted and published elsewhere. Further information and references are presented in various case studies listed in Appendix IV.

In addition, guidelines for research reactors components life extension have been suggested and implemented in some Member States. Also, a decision making process to shutdown, refurbish, modify or decommission research reactor is currently taking place in several Member States [9, 10]. Various case studies involving reactor refurbishment because of ageing are listed in Appendix IV.

The IAEA has included in its budget and programme a Co-ordinated Research Programme (CRP) to address ageing problems. This CRP will be initiated in 1994 and will mainly cover issues related to non-destructive techniques and in-service inspection for research reactors.

3.5.2. Post-service surveillance and testing

After permanent shutdown of a facility and before decommissioning, a post-service surveillance and testing programme should be applied to detect and assess continuing ageing effects. This programme should continue as long as the old structures, systems and components of the facility still exist and the decommissioning process has not been completed.

During the decommissioning process, it may be possible to examine, perhaps destructively, components which were subjected to severe conditions. Such an example might be the core end of beam ports. This examination followed by publication of the results will contribute to the literature on ageing of research reactors.

4. DETECTION AND ASSESSMENT OF AGEING EFFECTS

4.1. AGEING DETECTION PROGRAMME

Since ageing may affect the overall safety of the research reactor facility, there is a need to detect and assess the effect of aged components on safety. Therefore, a programme for the detection of ageing effects should be timely established in the framework of the ageing management activities. This programme should be based on information from the design, maintenance and periodic testing of components and systems. Actual failures or incidents should be factored into this programme, which should also include an estimate of remaining service life for the components. In addition, this programme should include methods for the selection and categorization of equipment susceptible to ageing, the ageing surveillance activities, the methods for data collection and the methods for the further evaluation of the ageing effects. The assessment of ageing effects depends strongly on the provisions made for the collection, storage and evaluation of data. Therefore, appropriate attention should be given to these issues. The following sections describe the methods and activities which should be considered in the above programme.

4.2. SELECTION AND CATEGORIZATION OF EQUIPMENT SUSCEPTIBLE TO AGEING

The ageing detection programme should include a list of all systems and main components of the research reactor and an analysis of their susceptibility to ageing based on the ageing mechanisms discussed in Section 3.

The selection and categorization of equipment susceptible to potential ageing processes should be performed during the design process. Equipment and materials should be selected to minimize ageing effects.

The selection process should include:

- A recognition of the particular service conditions (e.g. pressure, temperature, radiation fluence, chemical environment);
- The importance to safety;
- Materials of construction (e.g. carbon steel, stainless steel);
- Required operation mode;
- Testing requirements;

- Maintenance requirements;
- Expected service life including an estimate of preservice use; and
- The ease of replacement.

The categorization of components, structures and systems susceptible to ageing should be based on factors such as importance to safety, repairability or replaceability. One example of such categorization of components is as follows:

Category I: Equipment of primary importance, not redundant, not easily repairable or replaceable (reactor tank, primary coolant system piping).

Category II: Equipment of primary importance, but redundant or can be easily inspected or repaired (e.g. electric power supply, control rods).

Category III: Equipment not primarily important but not easily inspectable or repairable (e.g. primary water purification system).

Category IV: Other equipment (e.g. auxiliary diesel generators).

Another example is categorizing by reactor systems indicating the importance to safety and replacement ease as parameters. Appendix I presents such a list of reactor systems and includes ageing mechanisms prepared for a pool type and heavy water type reactor.

Appendix II is a list of actual, reported ageing problems in research reactors. It is useful in identifying the main areas of concern. Additional guidance may be found in Ref. [7].

Information on equipment in-service specifications should be gathered during the selection to enable the follow-up of its current performance capability, maintenance and testing. Lacking such specifications, relevant information or from design from the manufacturer should be kept for the aforementioned purpose.

4.3. AGEING SURVEILLANCE ACTIVITIES

The ageing surveillance activities are part of the ageing detection programme, which is essentially a long term programme. These activities should be planned as early as possible and continue throughout the operating life of the reactor. Based on design, manufacturer specifications, operating experience and judgement, the ageing surveillance activities should be planned consistent with the equipment selection, categorization process and equipment qualification previously discussed. These activities should also take advantage of the existing preventive maintenance and periodic testing programmes. They may consist of the following:

4.3.1. Inspection and visual examination

Evidence of ageing problems can appear progressively or suddenly. A rigorous inspection and visual examination plan based on a periodic in-service inspection programme or on a schedule for all selected components and systems should be established. It may also be part of the preventive maintenance programme. Scheduled inspections and visual examinations should be established consistent with the component, system and structure category. Symptoms of ageing related problems are distortion of dimensions, surfaces or materials, leaks, cracks, and even discoloration. Operators and maintenance staff should be trained to report evidence of changes in the state or appearance of a component or material. These reports, along with those from the scheduled inspections are crucial for timely intervention to prevent or mitigate ageing effects. A culture of "everybody is always on duty to report on trouble" is the best way to cope with potential problems.

Inspection activities should also be planned for long maintenance and shutdown periods. They should include manufacturers recommendations for preventive maintenance tasks such as verification of tolerances, lubrications, etc.

4.3.2. Monitoring

Ageing effects may be detected by a change in measurable parameters. For example, increase in temperature or pressure may be an indication of the accumulation of corrosion products in the tube of a heat-exchanger and instrument drift may be an indication of electronic component degradation. Parameters should be measured periodically in a consistent manner and the readings should be compared and assessed. Physical parameters, such as temperature, pressure, flow rate, control rod drop times, radiation level (e.g. neutron and gamma), water quality, are indicators of the state of a system, structure or component.

4.3.3. Testing

Many ageing effects cannot be directly measured. Properly scheduled activities should be prepared to facilitate timely performance of comprehensive tests as needed. Testing may be used to look for signs of deterioration. Regularly scheduled tests should provide comprehensive information to assess ageing effects (e.g. resistance of cable insulation and leakage tests of confinement or containment structures, hardness change in a material due to irradiation). Non-destructive examination techniques may be useful to identify ageing-related degradation (e.g. ultrasonic thickness measurements to monitor erosion of pipe walls, measurement of physical distortion such as fuel element length or bow, dye penetrant measurements for welded joints in pool liner, vibration measurements for degradation of rotating equipment or interconnected structures, systems and components and radiographic measurements for internal component conditions). In some cases, a destructive test may be necessary (e.g. to measure the stored energy in a piece of graphite).

4.3.4. Performance tests

Ageing effects can be detected by checking the performance of a system, structure or component (e.g. drifting of set points or deterioration of electronic or mechanical components of valves and valve actuators or control rod drive mechanisms, may cause changes in the performance of a control system). For this reason, the results of the performance test programme, which is dependent on the specific design and operation of the facility, should be examined for evidence of trends which may indicate ageing problems.

4.4. DATA COLLECTION AND RECORD KEEPING

4.4.1. In-house experience

Data received through inspection, monitoring and tests should be collected at regular intervals, evaluated and retained. Operation and maintenance reports should be collected and analysed for signs of a deterioration problem. Often this data will be in the form of a technical report. The report should record the data on a daily, weekly, monthly, quarterly or yearly basis, according to the situation and condition of the component and its influence on safety.

Records of replacement, modifications and maintenance of reactor components are also an important source of information to understand the effects of ageing. The records should show the methods of problem identification, analysis and solution. Preparation of reports should be based on a written procedure.

These reports should be retained as long as the old or similar components, structures and systems of the facility still exist and the decommissioning process has not taken place. There may be special cases where information should be retained for a longer period, as required by the facility.

An example of an existing computerized data source for nuclear power plants is the Nuclear Plant Reliability Data System (NPRDS) of the Institute of Nuclear Power Operations [6]. Another example of power plant data collection and record keeping programme is given in Ref. [8].

The IAEA has completed a Co-ordinated Research Programme on Data Acquisition for Research Reactors PSA Studies with the objectives of developing a data collection system for research reactors and of generating research reactor specific reliability data for use in PSAs. Although the system is oriented to specific component failure data, the methodology can be useful for ageing related data collection [9].

4.4.2. Experience of other research reactor operators

While many methods are possible for data collection and experience on ageing from reactor facilities for analysis, one of the more useful methods is through the use of a questionnaire. An example of a data collection and analysis questionnaire used at a workshop on nuclear power plant ageing is as follows [2]:

For each system analysed, participants were requested to provide the following information:

- System name;
- Component;
- Actual or potential failure mode;
- Manner of discovery (actual or potential);
- Observed or suspected fundamental cause of failure;
- Observed or suspected ageing environment or ageing problems;
- Comments.

Table V was compiled by using the information provided.

An example of a questionnaire prepared for use with research reactors is given in Appendix III.

Mathematical models of ageing processes and probabilistic safety assessment techniques can be used to determined how ageing affects component and system unavailability. Reference [2] provides some details on the development of probabilistic safety assessment techniques applicable to ageing of power reactors that may be useful as an example. Reference [9] does the same for the case of data collection concerning the reliability of research reactor systems and components.

TABLE V. SAMPLE QUESTIONNAIRE (Source: IAEA-TECDOC-540)

System	Component	Actual or potential failure mode	Manner of discovery	Observed or suspected fundamental cause of failure	Observed or suspected ageing environment or ageing problems	Comments
HVAC	High pressure injection pump	Insufficient input	Failure during operation	Air flow blockage through cooler	Dirt/dust	-
Component cooling water	Piping	Pressure boundary	Routine walk through	Wall thinning	Liquid erosion	High flow rate
Component cooling water	Heat exchanger	Insufficient output	Operational parameter change	Poor heat transfer coefficient	Corrosive service water	Organic growth buildup
Emergency DC	MCCs for low pressure injection valves	Delayed response	Routine testing	Binding of switches	Corrosive vapours	Salt moisture in air
Service air	Air compressor foundation	Foundation failure	Special surveillance	Cracking of concrete	Vibration	--
Emergency AC	Cabling	Insufficient fire protection	Routine maintenance	Cracking of fire retardant coating	Insufficient moisture and high temperature	Coatings separated from cabling
HVAC	Fire damper	Insufficient fire protection	Special surveillance	Binding of damper	Dirt/dust	--

4.5. EVALUATION OF AGEING EFFECTS

4.5.1. In-house assessment

If an ageing detection programme is established shortly after a research reactor facility is placed into operation, no historical failure information will initially be available on actual facility components or systems. However, information from similar facilities or from research and test programmes will generally be available and should be utilized in setting management priorities in the programme. As operation of the facility progresses, data on ageing will become available. Periodic assessment of this data consistent with category and safety significance can yield information which can be used to evaluate the effectiveness of the programme. Modifications to the programme should be made based on recorded and compiled experience.

4.5.2. Use of experts

Experts may be utilized to supplement in-house capabilities especially in the applications of specialized inspection techniques, and in the areas of interpretation of inspection and test results. These may be engineers or scientists working in the nuclear industry, research and regulatory organizations which have knowledge and experience in nuclear research reactor performance and behaviour, or specialists from outside the nuclear industry.

4.5.3. Final assessment of an ageing related issue

Once the consequences of an ageing related problem affecting a structure, system or component have been identified, a final assessment of the situation regarding continuation of operation should be made. This may be done by answering the following questions:

1. Will the failure or degradation of the component, system or structure during reactor operation place the reactor operation outside the boundaries of the operational limits and conditions of the reactor licence?

2. Does the system or component fulfill its specified function? If not, what are the consequences?

3. May it fail soon or can there be a time estimate made or other indicating conditions assessed to determine the point of failure?

4. What are the consequences of a failure appropriately taking into account the single failure criterion?

5. Must it be assumed to be defective and out of operation?

6. Is it repairable or does it have to be replaced consistent with the maintenance programme?

7. Do repairs or replacement have to be discussed with relevant bodies?

8. When replacing components or systems, to what extent is it possible to use today's guides, standards and QA techniques?

9. What is the solution of the ageing problem?

5. PREVENTION AND MITIGATION OF AGEING EFFECTS

5.1. GENERAL

The prevention and mitigation of the effects of ageing may be accomplished by:

(a) Appropriate provisions made during the design of the reactor;
(b) Surveillance and testing activities to assess degradation of components and systems;
(c) A preventive maintenance programme;
(d) Periodic evaluation of operating experience;
(e) Optimization of operating conditions; and
(f) Repairing, replacing or refurbishing of components.

5.2. PREVENTION THROUGH DESIGN

The IAEA Code on the Safety of Nuclear Research Reactors: Design [3] has specific requirements related to ageing:

> "**Material selection**
>
> 543. In the design stage, an appropriate safety margin should be adopted to accommodate the anticipated properties of materials at the end of their useful life. Where material data are unavailable, a suitable material surveillance programme shall be adopted and results derived from this programme used to review the adequacy of the design at appropriate intervals. This may require design provisions to monitor materials whose mechanical properties may change in service owing to such factors as stress corrosion or radiation induced changes. Improved safety factors may be achieved by selection of high strength or high melting point materials."

Components and systems susceptible to ageing degradation should be so located as to facilitate free access for surveillance and testing.

5.3. PREVENTION THROUGH SURVEILLANCE AND TESTING

Surveillance and testing activities may be used to assess the degradation of components, systems and structures in order to adopt appropriate preventive or corrective measures. Ageing profiles may be developed from these activities allowing the replacement of an ageing component before its predicted degradation or failure. The frequency of the surveillance and testing should be optimized based on design, data, industry experience and manufacturers recommendations.

Material surveillance activities may include irradiation of material coupons in normal operation conditions (e.g. reactor tank materials such as aluminium or reflector materials such as graphite or beryllium). These coupons can then be removed for testing without disturbing the component material itself.

For those existing research reactors which require but lack such activities, irradiation in high neutron flux testing reactors may be appropriate. These surveillance and testing activities should be periodically reviewed following analysis of accumulated data.

5.4. PREVENTIVE MAINTENANCE

The IAEA Code of the Safety of Nuclear Research Reactors: Operation [4] states that:

> "908. Components important to safety may require special attention to prevent ageing effects from causing unexpected failures. In such cases a preventive maintenance philosophy is one of the approaches which should be adopted."

Preventive maintenance is utilized to detect and mitigate degradation and failure of components, structures and systems, and includes repair, replacement and refurbishment activities. Traditionally, the preventive maintenance programme is scheduled according to manufacturers' recommendations, warranty requirements and facility staff experience. This applies quite well for standard equipment and optimization of timing may be done as experience with this equipment grows.

For the research reactor components and systems exposed to environments which accelerate ageing effects, information from the literature and the experience from older facilities may be utilized to develop the preventive maintenance programme based on predicted failure rates. The maintenance programmes should be periodically reviewed following analysis of accumulated data.

5.5. PERIODIC EVALUATION OF OPERATIONAL EXPERIENCE

Periodic evaluation of operational experience should be performed, including periodic review and analysis of operations, surveillance, testing and maintenance records and reports. This is to ensure that all data which has been collected will be taken into account during analysis of the safety state of the facility. Also the operation and maintenance procedures should be modified to compensate for changes due to ageing.

The periodic evaluation of operating experience should be done systematically. It is advisable to have a permanent forum of experts (e.g. the safety committee) to do these evaluations on a prescribed schedule.

5.6. OPTIMIZATION OF OPERATING CONDITIONS

Operating conditions (or modes) have already been defined as part of service conditions which affect ageing processes. Periodic evaluation of operational experience may reveal the need to change operating conditions such as operation mode, core arrangements and chemical parameters of fluid.

The frequency of inspections is also a parameter which requires optimization. Too high a frequency of inspection and maintenance work or tests may also accelerate ageing and an assessment of this effect is required.

5.7. REPAIRING, REPLACING OR REFURBISHING OF COMPONENTS

Periodic evaluations of data should be conducted, and in some cases, a decision should be made to take an action to stop the deterioration process or replace a component. A summary report should be prepared of all the available data concerning the specific problem. This should include summaries of historical records (see Section 4.4), evaluation and assessment reports (see Section 4.5), and material regarding continued operation programme if existing (see Section 6). This summary report should be evaluated and answers should be given again to questions regarding operability and safety of the system (see Section 4.5.3).

Besides technical aspects, as described above, some other important factors should be taken into account [10]:

(1) Safety: What are the safety implication of continuing operation of the degraded system or of taking it out of service? (Some answers may be already given in the aforementioned assessment).

(2) Environment compliance: Is it possible to continue operation of the reactor without impairing environmental requirements?

(3) Programmatic need: What is the working programme of the reactor and what are the real organization or national needs?

(4) Costs: What are the costs involved in repairing, refurbishment or decommissioning of the facility?

All these factors should be considered in a systematic way, in order to reach a conclusion whether to repair, refurbish or replace the system. If the situation is not too safety significant, a decision may be taken to continue monitoring the ageing effects for a while and defer the intervention.

It is most important that before making any decision concerning a major repairing, replacing, refurbishment or modification project, consultations will be made with the safety committee, available experts and the regulatory body. A special 'task force' should be appointed to review the situation. This 'task force' should include the reactor manager and other members of the operating organization and experts on ageing effects from the operating organization or other organizations.

If a decision is made to correct the situation, a proposal has to be prepared and submitted to the proper authorities for approval. In many cases, this action will not be a simple one and may be a major maintenance task or modification. Guidance on modifications of research reactors is given in the IAEA Safety Series No. 35-G2, Safety in the Utilization and Modification of Research Reactors [5].

6. GUIDELINES FOR CONTINUED OPERATION

6.1. GENERAL

The high capital replacement costs for reactor facilities provides strong incentive to ensure continued operation of existing research reactors. However, the first and most important operation requirement is that a research reactor shall be able to meet its safety goals at any time, independent of age or other considerations. If these goals cannot be met for any reason, the reactor must be shut down, regardless of its age.

Experience has shown that, in most cases, it is possible to find some technically possible complementary provisions which maintain the reactor safety at an acceptable level. This is the general practice regarding research reactors. Most of the currently operating research reactors which were built in the 1950s and 1960s have undergone some kind of refurbishment in one or more of their systems. In some cases these modification projects covered almost all the main systems of the facility and they were considered reconstruction projects. The reason for such modification projects were various and ageing was not necessarily the unique reason. For example, the first type of 'common modification projects' was the replacement of the old instrumentation based on vacuum tubes with solid state instrumentation and later with more advanced electronics utilizing microprocessors. Modification projects, undertaken in the 1970s and 1980s, were mainly based on backfitting and ageing issues.

Very few research reactors were designed based on a specific "design lifetime". Instead, very conservative design criteria were utilized. Engineering limits established for non nuclear applications were frequently set more conservatively for nuclear applications. Since a "lifetime" has not been established, the words "lifetime extension" have not been applied to research reactors. With proper operation, maintenance and replacement of components which have degraded through ageing, the "lifetime" of a research reactor is indefinite and usually determined by its continued usefulness and the costs of operation and maintenance.

In order to assess continued operation of a research reactor from the reactor safety standpoint, a methodical approach should be taken. Such an approach will utilize data from the ageing management programme and should incorporate the following considerations:

- A safety review of the reactor tailored to establish the actual status of the systems regarding degradation from ageing or other specific mechanisms;
- An overview of the potential refurbishment needs, by establishing a comprehensive list of systems and components, categorizing and prioritizing them;
- A selection of the critical items and identification of the relevant ageing mechanisms in order to perform a preliminary evaluation of the critical items;
- The establishment of the technical and economical feasibility of the refurbishment programme; and
- The identification of further studies and inspections to refine the preliminary assessment. Probabilistic risk assessment results may be of use for such refinements.

An example of such an approach is given in Ref. [11].

6.2. DEMONSTRATION OF AGEING STATUS THROUGH SAFETY REVIEWS

The IAEA has a long experience in the preparation and conduct of safety reviews with various objectives and scopes. The methodology used in these missions can be applied for ad hoc reviews of ageing dominant safety aspects or for examination of data for particular systems and components prior to a decision making process involving major repairs or replacements.

Guidance on the above topics is currently being compiled in a document on safety review of research reactors, covering managerial aspects such as preparing, conducting and reporting the review or technical notes related to specific areas to be reviewed. Amongst these areas are design, construction, maintenance and periodic testing, utilization and modification, where ageing of the safety related items or aspects of the facility may dominate the review.

Some Member States have required periodic reviews of the facility status regarding the safety requirements changes (backfitting), state of the art relative to equipment (technology changes) or to design. The above guidance may be straightforwardly adapted to this type of review.

6.3. APPRAISAL STAGES PRIOR TO A MODIFICATION PROJECT

For continued operation of a research reactor, modifications may be necessary. Guidance on the techniques which should be employed for the modification of a research reactor can be found in Ref. [5].

Appendix I

CATEGORIZATION OF REACTOR SYSTEMS CONCERNING THEIR IMPORTANCE TO SAFETY AND REPLACEMENT EASE

Table I.1 lists reactor systems indicating their importance to safety, their replacement ease and ageing mechanisms which may affect them. The abbreviations used in this table are explained in Table I.2.

TABLE I.1. TYPICAL REACTOR SYSTEMS AND THEIR SERVICE CONDITIONS OR AGEING MECHANISMS

Items	Safety related	Replacement ease	Mechanisms
POOL AND POOL INTERNALS (H_2O moderated reactors)			
- Pool structure/vessel	Y	A/B	1,2,4,5,6,12
- Core structure	Y	B	1,4,5,6,7
- Reflector	Y	B/C	1,4,5,12
- Control rods and mechanisms	Y	C	1,4,5,12
- Shielding	Y	C	1,5,12
- Beam tubes	Y	B/C	3,5,12
- Liner	M	B/C	1,3,5,12
- Fuel assemblies and storage	Y	C	1,5
REACTOR AND REACTOR INTERNALS (D_2O moderated reactors)			
- Reactor tank	Y	A/B	1,2,5,6,12
- Core structure	Y	B	1,2,5,12
- Control rods and	Y	C	1,4,5,12
mechanisms	Y	C	
- Fuel assemblies	Y	C	1,5
COOLING SYSTEMS			
- Primary	Y	B/C	1,3,4,5,6,7,12
- Pool	M	A/D	1,3,4,5,6,12
- Emergency	Y	B/C	3,4,5,6,12
- Make-up	N	C	5,12
- Purification	M	C	1,2,5,12
- Secondary	N	C	4,5,6,7,12
CONTAINMENT			
- Structure	Y	A	2,3,4,5,12
- Biological shield	Y	A/B	1,2,3,4,5
- Ventilation: - normal	M	C	2,5,6,12
- emergency	Y	B/C	5,6,12
- Penetrations	Y	C	1,2,4,5,12
- Isolation system	Y	C	4,5,12
- Stack	Y	B/C	6,12

TABLE I.1. (cont.)

Items	Safety related	Replacement ease	Mechanisms
CONTROLS AND INSTRUMENTATION			
- Shutdown systems	Y	C	4,5,12
- Protection systems	Y	B	4,5,12
- Control system	Y	C	2,4,6,12
- Control console	M	B/C	2,6,12
- Radiation monitoring	Y	C	5,12
- Process systems	M	B	4,5,6,12
- Annunciators	Y	C	2,4,6,12
- Instrumentation	M	C	1,2,4,6,12
- Cabling	M	B/C	1,2,5,12
- Remote SD/Monitoring	Y	C	5,12
- Pneumatic system	M	C	4,5,12
- Data acquisition	M	C	4,5,12
- Seismic protection	M	C	4,5,12
AUXILIARIES			
- Power system	M	B	6,12
- Emergency power system	Y	B/C	5.6.12
- Fire protection	Y	B	5,12
- Lightning protection	M	B/C	5,12
- Flood protection	M	C	5,12
- Communications	M	C/D	5,12
- Crane	Y	B/C	4,5,12
- Handling and storage	Y	D	5,12
- Transfer/fuel casks	Y	B/C	1,4,5,12
- Radwaste handling/ storage/disposal	Y	B/C	1,2,5,6,12
- Hot cells	M	B	1,5,6,8,12
- Compressed air	M	C	4,5,6,12
- Laboratories	M	C	5,6,8,12
EXPERIMENTAL FACILITIES			
- Cold/hot sources	M	B/C	1,2,3,4,5,6
- Shielding	M	C	1,5,12
- Rigs/loops	Y	B/C	1,2,3,4,5,6
- Beam lines	M	C	1,3,4,5,12
- Isotope production and irradiation facilities	M	C	1,2,3,4,5,6,12
- Rabbit systems	M	C	1,5,6,12
- Thermal columns	M	C	1,2,3,5
- Dry irradiation rooms	M	C	1,5,12
REACTOR BLOCK			
- Reflector	Y	A/B	1,4,5,12
- Thermal shield	Y	A/B	1,2,5
- Biological shield	Y	A/B	1,2,4,5
- Reactor block cooling system	Y	B	2,5,12

TABLE I.1. (cont.)

Items	Safety related	Replacement ease	Mechanisms
OTHERS			
- Organization	M	A	11
- Training	Y	C	11
- Documentation			
- Design	M	B/C	12
- SAR	Y	B/C	9,10
- Tech. specs.	Y	B/C	10
- Procedures	Y	B/C	10
- QA	M	B/C	9,10,12
- Reviews and assessment	M	C	9,10
- Physical protection	M	C	8,9,10
- Safeguards	M	C	8,10,12
- Conventional safety	M	B/C	8,9
- Licensing	Y	B/C	9
- Spare parts	M	B/C	8
- D_2O storage	Y	B/C	5,12
- D_2O leak collection	Y	B/C	5,12
- Cover gas circulation	Y	C	4,5,12
- Recombination	Y	C	5,6,12

TABLE I.2. ABBREVIATIONS USED

Safety related	Replacement ease	Mechanisms
Y - Yes N - No M - Maybe	A - No B - Difficult (tech. or costly) C - Normal D - Readily	1 - Radiation 2 - Temperature 3 - Pressure 4 - Cycling 5 - Corrosion 6 - Chemical 7 - Erosion 8 - Technology changes 9 - Safety requirements 10- Documentation 11- Human factors 12-Design/operation/maintenance

Appendix II

AGEING PROBLEMS REPORTED IN RESEARCH REACTORS

The present compilation has been made using the presentations reporting ageing problems at the following international meetings: (1) International Symposium on Research Reactor Safety, Operations and Modifications, held in Chalk River, Canada, 23–27 October 1989; and (2) Seminar for Asia and the Pacific on Ageing, Decommissioning and/or Major Refurbishments of Research Reactors, held in Bangkok, Thailand, 18–22 May 1992.

The list is by no means complete. However, this information illustrates the current concerns of operators of research reactors and the dominant mechanisms of ageing which threaten the integrity of the reactor systems.

Table II.1 refers to the name and place of the reactor, reference numbers, page or paper numbers, type of the reactor, component or system code of the particular service condition or ageing mechanisms as adopted in Appendix I and notes. In addition, this information has been summarized in Table II.2 showing statistically the distribution of reported ageing mechanisms.

TABLE II.1. TYPICAL AGEING PROBLEMS REPORTED IN RESEARCH REACTORS

Reactor name	Member States	Ref.	Reactor type	Item	Mechanism	Notes
Ref: Chalk River Symposium						
NRU	Canada	12 p.100	Heavy water	Reflector tank	12	Aluminium: porous welds
ATR	USA	13 p.421	Tank	Reflector	1	Beryllium: non-uniform growth
				In-pile tubes	1	Stainless steel: embrittlement
				Neck-shim housing	1	Aluminium: non-uniform growth
				Flux trap buffle	1	Aluminium: non-uniform
				Safety rod assembly	1	Hafnium: embrittlement
				Control shims	1	Hafnium: loss of ductility
FRG	Germany	14 p.447	Pool	Cooling towers	12	Wood: deterioration
				Pool liner	6	Ceramic: leakage
				Pool pipe penetration	6	Concrete: leakage
				Pool floor	6	Concrete: carbonization-cracks
BR2	Belgium	15 p.737	Tank	Moderator-reflector	1	Beryllium: swelling, cracks
TRICO II	Zaire	16 p.757	TRIGA MARK II	Reactor tank	5	Aluminium: pitting
HWRR	China	17 p. 767	Heavy water	Reflector	1	Graphite: growth, energy storage oxidation, strength
				Reactor tank	5	Aluminium: water/gas boundary
					1	loss of ductility
					5	radioactivity

TABLE II.1. (cont.)

Reactor name	Member States	Ref.	Reactor type	Item	Mechanism	Notes
HFR	Euro. Comm.	18 p.828	Tank	Reactor tank	1	Aluminium: embrittlement
		19 p.924		Primary HXs[a]	4	Tube vibrations, loose baffles
				Reflector	12	Beryllium: mech. damage, wear,
					1	deformation, embrittlement
				Outlet cooling line	5,7	Wind & corrosive environment
ETRR-1	Egypt	20 p.839	Tank WWR	Instrumentation	9	
KUR	Japan	21 p.1067	Tank	Thermal column	1	Graphite: stored energy
				HXs	5	Steel: leakage
				Ins. tube	12	Stainless steel: leakage
Ref: Bangkok Seminar						
HIFAR	Australia	22 2C	Heavy water	Reactor tank	1	Aluminium: strengthening, corrosion
HWRR	China	23 5C	Heavy water	Reactor tank	5	see Chalk River Symposium, p.767
				Primary HXs	5	
CIRUS	India	24 6C	Heavy water	Reactor tank	1	Aluminium: embrittlement
		25 18I			5	Corrosion patches
				Calandria tubes	5	Aluminium: (pin hole leak)
				Reflector	1	Graphite: Stored energy
				Biological shield	1	Concrete: cracks
				Rad. shield window	1	High dense glass: fogging
					6	patches
				Main HXs' tubes	5,7	70/30 Cn-Ni: leakage, thinning
				D_2O HXs' shells	5	Stainless steel: IGSC cracking
				D_2O storage tank	5	Stainless steel: Haze
				Pump foundations	4	Concrete: cracks
				Pump impellers	7	Erosion caused vibrations
				Pump casing		
				M/pump gear ass.	4	Vibrations
				Heavy water piping	5	Stainless steel: rad. corr. prod
				Primary cooling piping	5,12	Chlorideom; Stainless steel: rad. corr. prod. deposition
				Strainers	12	Changed
				Power control	8	Obsolete vacuum tube
				Dome supp. girders	5	Low carbon steel: Galvanic cell
				Water reservoir	5	Leakage
				Electrical cables	5	Saline atmosphere
				Transformers	5	Saline atmosphere
				Jetty supports	6	Concrete: "signal of distress"
				Jetty supp. rollers	5	Steel: jammed
				Underground vent. duct.	6	Concrete: leakage
PARR	Pakistan	26 10C	Pool	Instrument & control	8	

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[a] HXs: heat exchangers.

TABLE II.1. (cont.)

Reactor name	Member States	Ref.	Reactor type	Item	Mechanism	Notes
PRR	Philippines	27 11C	TRIGA conv.	Pool liner	12	Aluminium: leakage (weld defects)
TRR-1	Thailand	28 13C	TRIGA MK III	Pool coat	6	Epoxy resin: blistering
				Beam tubes	5	
				Instrument & control	8	
Dalat NRR	Vietnam	29 14C 15C	(Tank in) Pool	Reactor tank/ components	5	Aluminium: spots & pittings
				Fuel cladding	5,12	Aluminium
				Control system	8	
SILOE	France	30 16I	Pool	Pool liner	9	To meet design requirements
				HXs tubes	5	Tube leakage
TRIGA PUSPATI	Malaysia	31 24C	TRIGA MK II	Cooling tower	12	
TRIGA MARK II	Bangladesh	32 25C	TRIGA MK II	ECCS pipe	12	Aluminium

TABLE II.2. STATISTICAL DISTRIBUTION OF REPORTED AGEING MECHANISMS TAKEN FROM DATA IN TABLE II.1

Radiation	1	XXXXXXXXXX●●●●●●●
Temperature	2	
Pressure	3	
Cycling	4	XXX
Corrosion	5	XXXXXXXXXXXXXXXX●●●●●●
Chemical	6	XXXXXXX
Erosion	7	XXX
Technology changes	8	XXXXX
Safety requirements	9	
Documentation	10	
Human factors	11	
Design/operation/maintenance	12	XXXXXXXXX●

Keys:

X Actual problem.

● Concern, problem not confirmed.

Appendix III

QUESTIONNAIRE ON AGEING RELATED DATA COLLECTION

1. Operation days/month ... days
2. Operation hours/day ... hours
3. Total kW.h/month ... kW.h
4. Average power (during month) ... kW
5. Reactor core condition

   (a) Number of fuel elements ... fuel elements
   (b) Number of dummy elements ... dummy
   (c) Number of control rods ... rods
   (d) Core reactivity excess ... % Δd/k

6. Pool internals condition

   During the last five years have you observed any defect (D), discolouring (C) or corrosion (R); or carried out any modification (F) or major maintenance (T) in the following items?

- Fuel ... D / C / R
- Core ... D / C / R / F / T
- Pool liner ... D / C / R / F / T
- Reflector ... D / C / R / F / T
- Control rods/mechanisms ... D / C / R / F / T
- Shielding ... D / C / R / F / T
- Beam tubes ... D / C / R / F / T
- Fuel assemblies/storage ... D / C / R / F / T

7. Control and instrumentation

   Have you renewed (N), performed major maintenance (T) or discovered any malfunctions (M) in the following systems or components?

- Shutdown system ... N / T / M
- Protection system ... N / T / M
- Regulating control system ... N / T / M
- Control console ... N / T / M
- Radiation monitoring system ... N / T / M
- Variables process system ... N / T / M
- Annunciators system ... N / T / M
- Instrumentation and control system ... N / T / M
- Cabling ... N / T / M
- Remote shutdown/monitoring ... N / T / M
- Pneumatic system ... N / T / M
- Data acquisition system ... N / T / M

8. Cooling systems

   Have you renewed (N); carried out major maintenance (T) on, or detected any corrosion (R), malfunction (M), or leakage (L) in the following systems?

- Primary ... N / T / R / M / L
- Pool ... N / T / R / M / L

- Emergency ... N / T / R / M / L
- Make-up ... N / T / R / M / L
- Purification ... N / T / R / M / L
- Secondary ... N / T / R / M / L

9. Confinement or containment system

   Have you renewed (N); carried out any replacement/ modifications (F), or major maintenance (T) on; or detected any defect/crack (D), or malfunction (M) in the following items?

- Structures ... M / F / T / D
- Biological shielding ... N / F / T / D
- Ventilation system ... N / F / T/ M
- Penetrations system ... N / F / T / M
- Isolation system ... N / F / T / M
- Stack ... N / F / T / D / M

10. Auxiliary systems

    Have you renewed (N); carried out any major maintenance (T) on; or detected any malfunctions (M) in; or do you not have (H), the following items?

- Power system ... N / F / T
- Emergency power system ... N / F / T / H
- Fire protection ... N / F / T / H
- Lightning protection ... N / F / T / H
- Flood protection ... N / F / T / H
- Communication ... N / F / T / H
- Crane ... N / F / T / H
- Handling/storage ... N / F / T / H
- Transfer/fuel casks ... N / F / T / H
- Rod waste/storage/disposal ... N / F / T / H
- Hot cell ... N / F / T / H
- Compressed air ... N / F / T / H
- Laboratories ... N / F / T / H

11. Experimental facilities

    Have you renewed (N); carried out any modification (F) on, or detected any defect/crack (D), or corrosion (R) in the following items?

- Cold/hot source ... N / F / R
- Shielding ... N / F / D
- Rigs/loops ... N / F / D
- Beam tubes ... N / F / D / R
- Isotopes production/irradiation ... N / F / D / R
- Rabbit system ... N / F / D / R
- Thermal column ... N / F / D / R
- Dry room ... N / F / D / R

Appendix IV

CASE STUDIES ON MANAGEMENT OF AGEING IN RESEARCH REACTORS

The following list includes various contributions to the Technical Committee Meeting on Management of Research Reactor Ageing held in Vienna from 16 to 20 November 1992. This material is available on request from the Engineering Safety Section, Division of Nuclear Safety, International Atomic Energy Agency, Wagramerstrasse 5, P.O. Box 100, A-1400, Vienna, Austria.

Most of the contributions (Cases A-H) describe activities accomplished in various types of research reactors in the framework of reviews of the reactor facility status or modification projects, which were mainly originated by ageing concern. The following types of research reactors are covered:

- Pool type reactors (Cases A, B, C).
- TRIGA reactors (Case D).
- Heavy water and tank reactors (Cases E and F).
- Other types (Cases G, H and I).

Case J describes the present status of research reactor ageing in Japan, Case K presents the experience with aluminium alloys in Russian design type research reactors and Case L describes accumulated experience in visual experience with an underwater telescope.

CASE A: EGYPT

In-service inspection of ET-RR-1 reactor vessels and spent fuel storage tank

M. Khattab, Shafy
Atomic Energy Authority

K. Konoloplev, Yu. Samodurve, S. Orlov, V. Didenko, O. Jackorev
Petersburg Nuclear Physics Institute

CASE B: PORTUGAL

Modification and modernization of the Portuguese Research Reactor (RPI)

J.B. Menezes, F.M. Cardeira
Laboratorio Nacional de Engenharia e Tecnologia Industrial

CASE C: GREECE

Compilation of improvements and backfitting measures for the GRR-1 research reactor at "Demokritos", Athens

J. Anoussis, J. Armyriotis, C. Papastergiou, E. Stakakis, C. Zikides
Institute of Nuclear Technology - Radiation Protection

CASE D: AUSTRIA

Reinspection plan for the TRIGA Mark-II reactor Vienna

H. Böck, J. Hammer, G. Zugarek
Atominsitut der Österreichischen Universitäten

CASE E: DENMARK

Ageing of the DR 3 Reactor

H. Floto
Risø National Laboratory

CASE F: NORWAY

"Improvement Programme" - JEEP II
Preventive and corrective action to mitigate the effects of ageing

K. Caspersen
Institutt for Energiteknikk

CASE G: BELGIUM

Refurbishment project for the BR-2 reactor and summary of the major ageing issues

E. Koonen
CEN/SCK

CASE H: RUSSIAN FEDERATION

Redesign of the SM-2 reactor facility

V.A. Gremyachkin, A.V. Klinov, V.A. Kuprienko, M.N. Svyatkin, V.A. Tsykanov
RIAR, Dimitrovgrad

CASE I: NORWAY

The OECD Halden project and the HBWR

T. Hernes
Institutt for Energiteknikk

CASE J: JAPAN

Present status of research reactor ageing in Japan

T. Kodaira
Department of Research Reactor
Tokai Research Establishment, JAERI

CASE K: HUNGARY

Ageing of aluminium alloy structures of research reactors

F. Gillemot, Z. Honti
Atomic Energy Research Institute, Budapest

L. Gillemot
Institute of Non-ferrous Metals, Budapest

A. Amajev
Kurchatov Institute, Moscow

A. Csizmazia
I. Szechenyi University, Gyor

CASE L: HUNGARY

Some observation of nuclear research reactor ageing

C. Varga, A. Csoke
Nuclear Services, Ltd

SAFETY SERIES PUBLICATIONS ON RESEARCH REACTOR SAFETY

SAFETY STANDARDS

Code on the Safety of Nuclear Research Reactors: Design, No. 35-S1	1992
Code on the Safety of Nuclear Research Reactors: Operation, No. 35-S2	1992

SAFETY GUIDES

Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report,No. 35-G1	1994
Safety in the Utilization and Modification of Research Reactors, No. 35-G2	1994
Emergency Planning and Preparedness for Research Reactors, No. 35-G3*	
Safety in the Commissioning of Research Reactors, No. 35-G4*	
Safety in Decommissioning of Research Reactors, No. 35-G5 (Safety Series No. 74)	1986

SAFETY PRACTICES

Operational Limits and Conditions for Research Reactors, No. 35-P1*

Safety Instrumentation for Research Reactors, No. 35-P2*

Radiation Protection Service for Research Reactors, No. 35-P3*

Maintenance and Periodic Testing for Research Reactors: A Safety Practice, No. 35-P4*

Operating Procedures for Research Reactors: A Safety Practice, No. 35-P5*

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*Planned for publication.

SELECTION OF IAEA PUBLICATIONS RELATED TO THE SAFETY OF RESEARCH REACTORS

SAFETY SERIES

9	Basic Safety Standards for Radiation Protection: 1982 Edition	1982
35	Safe Operation of Research Reactors and Critical Assemblies: 1984 Edition	1984
49	Radiological Surveillance of Airborne Contaminants in the Working Environment	1979
55	Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities	1981
57	Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases: Exposures of Critical Groups	1982
67	Assessing a Value to Transboundary Radiation Exposure	1985
72	Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency *(being revised)*	1985
73	Emergency Preparedness Exercises for Nuclear Facilities: Preparation, Conduct and Evaluation	1985
74	Safety in Decommissioning of Research Reactors	1986
75-INSAG-3	Basic Safety Principles for Nuclear Power Plants	1988
77	Principles for Limiting Releases of Radioactive Effluents into the Environment	1986
81	Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency: Principles, Procedures and Data	1986
84	Basic Principles for Occupational Radiation Monitoring	1987
86	Techniques and Decision Making in the Assessment of Off-Site Consequences of an Accident in a Nuclear Facility	1987

TECHNICAL REPORTS SERIES

230	Decommissioning of Nuclear Facilities: Decontamination, Disassembly and Waste Management	1983
237	Manual on Quality Assurance Programme Auditing	1984

249	Decontamination of Nuclear Facilities to Permit Operation, Inspection, Maintenance, Modification or Plant Decommissioning	1985
262	Manual on Training, Qualification and Certification of Quality Assurance Personnel	1986
267	Methodology and Technology of Decommissioning Nuclear Facilities	1986
268	Manual on Maintenance of Systems and Components Important to Safety	1986
351	Planning and Management for the Decommissioning of Research Reactors and Other Small Nuclear Facilities	1993

TECDOC SERIES

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233	Research Reactor Core Conversion from the Use of Highly Enriched Uranium to the Use of Low Enriched Uranium Fuels: Guidebook	1980
348	Earthquake Resistant Design of Nuclear Facilities with Limited Radioactive Inventory	1985
400	Probabilistic Safety Assessment for Research Reactors	1986
403	Siting of Research Reactors	1987
448	Analysis and Upgrade of Instrumentation and Control System for the Modernization of Research Reactors	1988
517	Application of Probabilistic Safety Assessment to Research Reactors	1989
636	Manual on Reliability Data Collection for Research Reactor PSAs	1992
643	Research Reactor Core Conversion Guidebook (Volumes 1–5)	1992

PROCEEDINGS SERIES

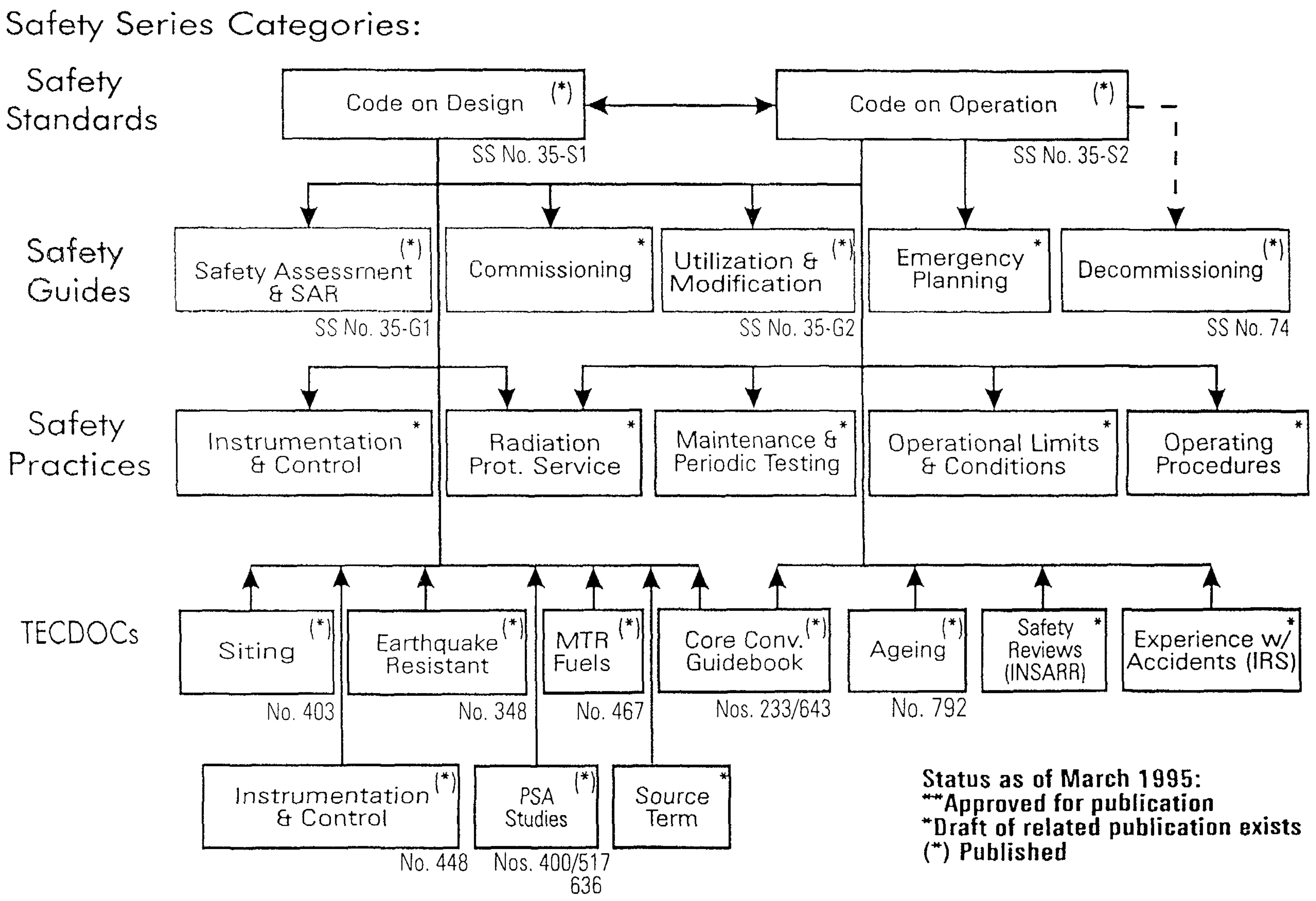
STI/PUB/700	Source Term Evaluation for Accident Conditions	1986
STI/PUB/701	Emergency Planning and Preparedness for Nuclear Facilities	1986
STI/PUB/716	Optimization of Radiation Protection	1986

PROPOSED PUBLICATIONS ON RESEARCH REACTOR SAFETY

This chart shows the set of publications produced within the Research Reactor Safety Programme (RRSP), indicating those that have already been published. The chart also shows the hierarchy of the different publications in the IAEA Safety Series, namely, Safety Standards, Safety Guides and Safety Practices. These publications are prepared following strict procedures which include their submission for review and consensus of the technical content to an IAEA Technical Committee Meeting or Advisory Group Meeting; for review and comments to all IAEA Member States and for a final technical review and approval to the IAEA Safety Series Review Committee (SSRC).

The TECDOCs on ageing and safety reviews, because of their objective and scope, are also subjected to a strict process for review and approval for publication. However, they are not submitted to the SSRC.

IAEA RESEARCH REACTOR SAFETY PUBLICATIONS (Schematic)



Status as of March 1995:
****Approved for publication**
***Draft of related publication exists**
(*) Published

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CONTRIBUTORS TO DRAFTING AND REVIEW

IAEA Internal Working Group on Research Reactor Ageing

November 1988

Alcalá-Ruiz, F., Byszewski, W., Muranaka, R., Zyszkowski, W.

Consultants Meeting

13–16 November 1989

Abu Razak	Research Centre for Nuclear Techniques, Bandung, Indonesia
Abou Yehia, H.	Centre d'études nucléaires de Fontenay-aux-Roses, France
Alcalá-Ruiz, F.	IAEA
Carter, R.	Consultant, Bethesda, Maryland, United States of America
Egorenkov, P.	I.V. Kurchatov Institute, Moscow, Russian Federation
Ernst, P.	Nuclear Center, McMaster Univ., Hamilton, Canada
Krull, W.	CKSS Forschungszentrum, Geesthacht, Germany
Merchie, F.	Centre d'études nucléaires de Grenoble, France
Ross, I.D.	Atomic Energy of Canada Ltd, Chalk River, Canada

Technical Committee Meeting

16–20 November 1992

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