IAEA-TECDOC-1558

Selection of Away-From-Reactor Facilities for Spent Fuel Storage

A Guidebook

IAEA
International Atomic Energy Agency

September 2007

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The originating Section of this publication in the IAEA was:

Nuclear Fuel Cycle and Materials Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

SELECTION OF AWAY-FROM-REACTOR FACILITIES FOR
SPENT FUEL STORAGE
IAEA, VIENNA, 2007
IAEA-TECDOC-1558
ISBN 978–92–0–104807–3
ISSN 1011–4289

Printed by the IAEA in Austria
September 2007

FOREWORD

This publication aims to provide information on the approaches and criteria that would have to be considered for the selection of away-from-reactor (AFR) type spent fuel storage facilities, needs for which have been growing in an increasing number of Member States producing nuclear power. The AFR facilities can be defined as a storage system functionally independent of the reactor operation providing the role of storage until a further destination (such as a disposal) becomes available. Initially developed to provide additional storage space for spent fuel, some AFR storage options are now providing additional spaces for extended storage of spent fuel with a prospect for long term storage, which is becoming a progressive reality in an increasing number of Member States due to the continuing debate on issues associated with the endpoints for spent fuel management and consequent delays in the implementation of final steps, such as disposal.

The importance of AFR facilities for storage of spent fuel has been recognized for several decades and addressed in various IAEA publications in the area of spent fuel management. The Guidebook on Spent Fuel Storage (Technical Reports Series No. 240 published in 1984 and revised in 1991) discusses factors to be considered in the evaluation of spent fuel storage options. A technical committee meeting (TCM) on Selection of Dry Spent Fuel Storage Technologies held in Tokyo in 1995 also deliberated on this issue. However, there has not been any stand-alone publication focusing on the topic of selection of AFR storage facilities.

The selection of AFR storage facilities is in fact a critical step for the successful implementation of spent fuel management programmes, due to the long operational periods required for storage and fuel handling involved with the additional implication of subsequent penalties in reversing decisions or changing the option mid-stream especially after the construction of the facility. In such a context, the long term issues involved in spent fuel storage, including long term caretaking/refurbishment of facilities or transition from one option to another in consideration of fuel technology evolution, changes in long term policies, market-based influences, as well as changes in regulatory criteria, deserve careful consideration.

Although it can be said that competitive services for AFR storage are currently available from the market, it is often not evident how to choose the suitable option or technology for storage because of the complex issues involved in the decision, including a range of future uncertainties. Furthermore, focal issues in selecting an AFR storage facility can shift with time as spent fuel management policies, strategies and technologies advance and can change from one country to another due to considerations particular to those countries. In addition, as some common issues such as the trend toward privatization of former public enterprises in this sector, together with the issue of public involvement, some profound impacts on the nuclear industry in general and spent fuel management in particular may be expected. This TECDOC attempts to provide information in the approach to select AFR facilities for spent fuel storage.

This TECDOC is an output of a series of meetings, which started with an Advisory Group Meeting in 2000, and was followed by three consultants meetings in 2001, 2002 and 2003. The contributions of the meeting participants and assistance from other experts are appreciated with a special acknowledgement to M. Rao who provided crucial services in elaborating the draft. The IAEA officer responsible for this publication was J.S. Lee of the Division of Nuclear Fuel Cycle and Waste Technology.

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1. INTRODUCTION

A window of opportunity currently exists for the nuclear power industry in meeting the world's climate change objectives, as the global community attempts to reduce atmospheric emissions (greenhouse gases) from energy production and use, as well as the rising prices of fossil fuels. Despite the decline of nuclear energy programmes in the western world in the past decades, the number of countries showing interest in nuclear power is growing globally, in the face of a rising demand for energy especially in the developing world and volatile prices of oil and gas, combined with the environmental effects from greenhouse gases [1].

Spent fuel management is perceived as one of the crucial issues to be resolved for sustainable utilization of nuclear power. In the last few decades, spent fuel management policies have shown diverging tendencies among the nuclear power production countries. While some Member States have adhered to reprocessing/recycle of spent fuel some others have turned to direct disposal. Many countries have not taken a decision yet, often with a "wait and see" position often reflecting a tendency not to rush prematurely toward any solution and wait and see if technology provides a better alternative in the future. Both the closed (reprocessing/recycle) and open fuel cycle (direct disposal) options for spent fuel management have been subject to a number of debates focusing on the pros and cons of various issues such as fuel cycle economics, proliferation risks, environmental impacts, etc. The current situation in the above three different groups of countries in terms of spent fuel management option is likely to persist in the foreseeable future. It is recognized however, that ultimate solutions such as disposal cannot be avoided indefinitely and should be implemented in a staged, stepwise, and cautious manner with freedom of choice for future generations [2].

In such a context, away-from-reactor (AFR) storage would continue to provide a safe interim solution until such final steps can evolve. AFR storage systems are expected to fill in the gap in spent fuel management programs across the Member States until ultimate steps are implemented.

The bulk of spent fuel inventories in the world are in storage, with the majority in water pools, but showing a tendency toward dry systems, which is considered more suitable for long term storage. Spent fuel storage can provide a flexible time span for further research and development in search of better solutions to the issues raised by the conventional fuel cycle options, such as the P&T (partitioning and transmutation) technology which offers the promise of reducing the quantity and radiotoxicity of radioactive materials to be disposed of. Such concerns and issues in spent fuel management and radioactive waste management, particularly from the prospective view for future nuclear reactor and fuel cycle systems, are being addressed in national and international initiatives such as the INPRO and the Gen IV initiatives [3].

It is therefore essential to consider technical innovations in future nuclear systems that can significantly enhance the efficiency of radioactive waste management systems, keeping in compliance with required criteria. These are indeed the objectives being pursued by the current initiatives for development of innovative nuclear systems such as the modern reactor concepts that deploy advances in fuel design such as the high burn up fuel.

Institutional control is an important component in the long term management of spent fuel. Globalization of market economy which has already brought profound impacts to the nuclear industry might bring a new shape to the organization of the spent fuel management business, based perhaps on 'cradle to grave' type of fuel cycle services, on regional/international level that could hopefully improve institutionalized control needed for long term management of spent fuel.

1.1. Global status in spent fuel management

Recent statistics in global spent fuel management forecast gradual shortage of spent fuel storage space at an increasing number of reactor sites in many countries. Progress with respect to ultimate solutions, such as direct disposal, has been slow, making it imperative on these countries to take suitable measures to accommodate the excess amount of spent fuel for a considerable period of time in the future. As of the end of the 2004, a total of 276 000 tonnes of heavy metal (tHM) of spent fuel had been discharged from nuclear power reactors in the world, of which 90 000 tHM have been reprocessed. The balance of this figure 186 000 tHM falls then in the category of storage inventory either in the temporary pools at the at-reactor (AR) sites or away-from-reactor (AFR) storage facilities. Among the spent fuel inventory in storage, the bulk amount is still in AR pools occupying 74% of spent fuel in storage, but the AFR storage has begun to multiply in an increasing number of sites around the world [4].

Looking to the future, projection of the total amount of spent fuel to be discharged from reactors would reach 339 000 tHM in 2010 and 445 000 tHM in 2020, with a proportional amount of reprocessing which has been contributing to about one-third of the reduction in spent fuel inventory in the past. Such a trend implies that roughly two-thirds of the projected total amount would have to remain in storage.

As the attention in many Member States continues to focus on sustainable development of nuclear power to meet future energy needs, spent fuel management will continue to remain a vital issue. While nuclear energy has recently begun to be viewed as viable option especially for growing economies and the international initiatives for development of innovative technologies might bring solutions that are more sustainable for the longer term, the current challenge facing spent fuel management, trends towards deferred decisions worldwide on the disposal alternative, and the tendency of many countries towards enhancing their programs in terms of alternatives and public acceptance, are likely to continue to put pressure on spent fuel storage in the years to come [5].

1.1.1. Need for AFR storage of spent fuel

In the past, the shortfall in pool storage capacity at a number of nuclear power plant (NPP) sites has been mitigated mostly by accommodating more spent fuel in the existing at-reactor pools by increasing storage densities with such methods as re-racking of fuel in the pools or trans-shipment of fuel among pools. These measures have substantially contributed to the efficiency improvement of storage and prolongation of the need for additional facilities. Since a couple of decades ago, however, these methods have begun to be used up requiring additional storage. The capacity building measures for AR or AFR storage have sometimes been achieved in response to the extension of the reactors' operation lifetime.

The successes in increasing the nuclear capacity factor and reactor life extension initiatives in several countries have further increased the need for storage, while the trend toward higher burn up have had an effect of reducing spent fuel arising for a given power generation. On the other hand, as more and more reactors are decommissioned, the spent fuel currently stored at these reactor sites would need to be removed from AR to AFR storage if other destinations were not available then. In countries that do not intend to remove the spent fuel from storage facilities until definitive plans are firmed up (so-called 'wait & see' countries), an adequate

AFR storage facility would be required to provide for storage until the future destination of the spent fuel in the backend of spent fuel management is available [6].

In the light of these global factors, it can be predicted that the extent and duration of spent fuel storage will likely increase in this century, in turn increasing the need for AFR storage. It is also recognized that current trends to privatization and globalization of the nuclear industry are likely to further spread with dynamic impacts on spent fuel management. In the meantime, political and socio-economic factors are likely to continue to exert their influence in the foreseeable future. Competitive business and market forces would further influence interest in AFR storage to be brought into service safely, economically and in a timely manner. As a result of these factors, there have been significant developments recently in the spent fuel storage business. Of importance among these developments are:

- Dry storage technologies have emerged to become a mature international industry offering a wide range of options, including leasing of equipment and services, with an increasing degree of innovation for the growing need of AFR storage in many countries. Maturing of technology and competitive markets combined with the increasing needs for long term storage is likely to accelerate the growth of dry storage technologies in the future.

- Trend towards bid competition due to globalization of the market economy now requires greater effort towards evaluation of alternatives and preparation and evaluation of bids in line with modern contract management methods. Project and contract management have therefore become a major task in the efforts for selection and implementation of cost-effective AFR storage for the majority of projects today.

- Public involvement as a criterion in the implementation process has been given higher priorities in many Member States. There has been increasing public engagement and input in many countries into responsive decision-making and particularly in areas such as legislative bases and policies, site selection, assessment of environmental impacts, and their relation to decision-making.

Although AFR storage is mostly the responsibility of the nuclear power plant operators or utilities, national policies or other arrangements could shift this responsibility to an implementing organization specifically charged with this task. An institutional principle that is being adopted by the majority of Member States is the so-called ‘polluters pay’ principle by which the utility sets aside a necessary fund for the down stream management of the spent fuel (or radioactive wastes) generated from electricity production. Assistance to Member States in establishing policies and national arrangements for spent fuel management is discussed elsewhere [7].

These factors among others have been taken into consideration in the preparation of this technical document in an attempt to provide some guidance to interested readers.

In many cases, the AFR storage has become a major undertaking and requires support from a number of stakeholders such as concerned ministries of the governments, authorities involved in licensing and environmental assessment, electricity ratepayers, affected communities and the general public. In such a multi-stakeholder environment, the successful undertaking of an AFR spent fuel storage facility could raise serious challenges to any organization charged with the task of acquiring AFR storage.

1.2. Scope

The AFR spent fuel storage facilities are, by definition, those facilities that are not built and operated as an integral part of the nuclear power plants, such as at-reactor cooling ponds, that exist at most nuclear power plants to provide for initial storage of spent fuel. They are functionally independent storage installations built at reactor sites or elsewhere[1]. The need for AFR storage facilities arises as space for spent fuel storage at the nuclear power plants is used up and means for augmenting storage at the plants are either exhausted or simply not available, while there is no further destination or long term solutions to the management of the spent fuel.

The purpose of this publication is to summarize and provide information on complex issues related to choosing an AFR option for extension of spent fuel storage capacities. The primary focus in this TECDOC is on selection of the AFR option.

When considering AFR storage as a solution to manage spent fuel, it must be recognized that this is not a final solution. Spent fuel would have to be eventually retrieved from AFR storage, to be sent to a final destination, either to direct disposal or to reprocessing (or perhaps to other emerging options like partitioning and transmutation in the future). In instances where these solutions have not yet been put in place, there will likely be requirements to foresee these needs at the time the AFR facility is being designed or licensed and have necessary adaptive management methods in place in order to cope with this future situation. Plans may also be required for extended management of the spent fuel when a decision is made to retire the AFR storage facility in circumstances where the ultimate solution (e.g. disposal) may entail a very long wait period (a number of decades or even beyond a century as being contemplated in several countries).

1.3. Structure of the report

As discussed earlier, this report attempts to provide information on the selection of AFR spent fuel storage facilities with identification of general stakeholders and criteria in such a process, and a review of potential associated issues.

Following this introduction, the report begins with a review of technological options available for AFR storage facilities, provided in Section 2. Broadly, these options include wet and dry storage options. The market and services available for providing AFR storage are briefly surveyed.

In Section 3, basic conditions are identified for spent fuel storage projects. Generic requirements common to any technological option are discussed and their role in developing specific project needs is reviewed.

In Section 4, criteria for the selection of an option for AFR storage facility are identified and their implications to decision-making are discussed. The needed information discussed in Section 4 and potential selection criteria are interconnected as shown simplistically in Table 1 and the selection process would have to effectively recognize the linkage and integrate these two areas into a comprehensive framework for AFR storage selection.

[1] For this reason, IAEA defined two different kinds of AFRs: reactor site AFR (RS) and off-site AFR (OS), distinct from at-reactor (AR) storage earlier discussed.

In Section 5, such a framework for the selection process is discussed in terms of generic steps involved in the services market and the methodology and techniques applied to the selection of an AFR storage facility are discussed from the formative stages of the project to the eventual selection of a supplier and the technology, including award of the contract.

In Section 6, the roles of stakeholder involvement including public engagement in the process is briefly discussed.

A list of references is provided at the end of the Sections. Some further information on the AFR storage systems in the world is provided in the Annexes.

2. STORAGE CONDITIONS, METHODS, AND SERVICES

Design of a spent fuel storage facility must demonstrate meeting performance criteria required for getting licensed before construction or operation. The requirements adhere to a condition of limited release of radioactivity from the storage by the facility design criteria. These design criteria typically ensure not only functional conditions for normal operation, but also basic safety features covering certain natural phenomena or accidents. The design criteria also include physical security measures put in place at the spent fuel storage site.

The storage technology is undergoing rapid change as new fuel and material design aspects are coming on stream and as advanced reactor concepts and high burnup fuels replace the older generation reactor designs and burnups. Together with the evolving need for storage longer than envisaged in the past, these changes may have significant impact on the design criteria.

2.1. Spent fuel conditions for storage

The key issue with respect to spent fuel behavior during storage (especially for long term storage) in normal operation of a storage facility is the safety concern, in particular with potential radioactivity release by failure of the cladding containing spent fuel. This is an issue that would also touch on a measure to contain the radioactive release in the concerned storage system, should there be a defect developed during the envisaged time span of storage. Therefore, it has been the focal point of licensing for a spent fuel storage system.

The potential failure of fuel cladding may be caused by the conditions of storage, i.e. temperature effects on cladding and fuel material in particular during the early period of spent fuel storage particularly in passively cooled systems such as dry storage containers [8].

Detailed characteristics of the fuel would be important information for the design of the storage facilities. Such information is specific to the fuel assemblies and encompasses a wide range of information, such as fuel cladding material, densities and grain sizes of fuel pellets, fuel rod configuration within the fuel assembly, thermal design characteristics of the fuel assembly, etc.

As the spent fuel storage capacity needs increase in the future, spent fuel in many Member States could be stored for much longer periods than currently envisaged (up to 300 years in some scenarios) before disposal or other endpoints. Many Member States have invested in research programs on generic issues of spent fuel storage performance providing an evolving and reliable database. The IAEA has initiated in 1997 a Coordinated Research Project (CRP) on Spent Fuel Performance and Research (SPAR) to collect and exchange spent fuel experience (a continuation of the earlier BEFAST I to III programs). This program focuses on fundamental questions related to advances in storage technology, such as in terms of new fuel designs, higher target burnups and material design changes [9].

2.1.1. Fuel types

The application of technical options in spent fuel management are dependent on the reactor and the fuel cycle, which in turn is dependent on the type and design of fuel being adopted. Although the preponderant fuel type in current use for the majority of commercial nuclear power today is the LWR fuel, there are several other fuel types in commercial use such as HWR, GCR, RBMK, etc. The main characteristics of these fuel types are summarized in Table 1.

Table 1. Fuel types in commercial use in the world

TYPE	DESIGN	PHYSICAL SPEC.	REMARK
LWR	PWR BWR WWER	Cubic/hexagonal cross-section, 4~5 m long, 200~500 kg weight/assembly	• Usually stored intact (can be consolidated) • Recyclable
PHWR	CANDU	10 cm dia × 50 cm long, 20 Kg /bundle	• Handled in tray/basket • No recycle
GCR	Magnox AGR	3 cm dia × 1.1 m long slug, 24 cm dia, 1m long assembly	• Need to reprocess • Dry storage possible
OTHER	RBMK	8 cm dia x 10 m long assembly (2 sections)	• Need to cut to size • No reprocessing
	PBMR	6 cm dia spherical form fuel element	• Canning • Possible to reprocess

Currently, the bulk amount of the global spent fuel inventory is represented by LWR type fuel part of which is reprocessed, together with Magnox and AGR types. Other types of spent fuel are stored [10].

2.1.2. Spent fuel cladding

The integrity of the fuel cladding would be an important factor since the cladding serves as a first barrier for the fission products during the storage period. Structural integrity of the cladding would also be important at the time of retrieval of the fuel assemblies following storage. There are some basic mechanisms that are considered to influence cladding integrity:

- Cladding rupture by stress/strain[2], due to the internal pressure of the fuel rod that could cause unacceptable levels of hoop stress in the cladding, dependent on storage temperature.

- Stress corrosion cracking (SCC) of the cladding which is a cladding failure induced by combined effects from fission gas constituents and stresses in the cladding.

- Oxidation and electrochemical corrosion of the cladding material: oxidative corrosion is caused by temperature dependence of the corrosion rate and is generally assessed by the Arrhenius Law whereas electrochemical corrosion is caused by galvanic interaction between non-similar structural materials in the fuel assemblies.

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[2] Also called ‘creep’.

- Hydriding that affects the mechanical properties of the cladding material by delayed hydride cracking, hydrogen diffusion and embrittlement.

- Other corrosive attacks due to uniform (aqueous) corrosion, crevice corrosion, pitting, and microbial induced corrosion.

Degradation of the cladding due to corrosion is generally not a time-limiting factor for zircaloy claddings for wet fuel storage. In the case of stainless steel cladding in wet storage conditions, corrosion is not time-limiting for up to at least 100 years. For dry storage however, cladding corrosion may need to be carefully considered due to the much higher operating temperature conditions in a storage facility. Thermal creep is generally considered the limiting degradation mechanism for dry storage limiting the operating temperature conditions for the fuel.

Detailed information on spent fuel storage experiences and on spent fuel integrity issues for various fuel types is available.

2.1.3. Fuel oxidation

The greatest concern on effects of stored fuel arises from progressive oxidation of uranium oxide to U_3O_8 in spent fuel that could cause volume expansion in the fuel leading to cladding failure.

In order to prevent the formation of U_3O_8 by oxidation during the period of spent fuel storage, the temperature should be kept well below a limiting value for that reaction. In addition inert gas coverage in spent fuel storage containers is typically used. As the oxidation reaction is critically dependent on the fuel temperature in the storage, technical options of using air as cover gas would have to take into consideration the ability to adequately cool the fuel in the storage regime.

2.1.4. Fuel burnup

Nuclear fuel designs have been changing over time in attempts to improve their characteristics. There has been a continuing trend toward higher burnup, which is now approaching levels that are twice the level achieved in early fuel development a couple of decades ago. Utilities have been increasing their use of higher burnup fuels for improved fuel efficiency, a trend that is likely to increase and advancing to different types of fuel such as PWR, CANDU and MOX fuels).

The higher burnup of fuel has a significant impact on the choice of the storage option and on the design of storage systems, due to the increased decay heat, inter-alia, which is roughly proportional to burnup, imposing a higher cooling load to the storage system[3].

2.1.5. Monitoring

The use of an inert gas to prevent fuel oxidation (thus allowing higher in-storage temperature) requires a high integrity containment system and also a means to monitor the presence of the inert environment. Air, helium, nitrogen, and carbon dioxide are currently being used in the countries were a part of Spent Fuel Performance Assessment and Research (SPAR). Loss of

[3] IAEA is currently carrying out an investigation on the influence of high burnup and MOX fuel and advanced reactor operations on spent fuel management.

inert gas could potentially lead to enhanced oxidation of the fuel material and the cladding. Such monitoring would need to be done periodically (even continuously in the case of relatively high temperature).

2.2. Technical options for storage

The technologies currently available for spent fuel storage fall into two categories, wet and dry, distinguished according to the cooling medium used [11], [12], [13]. Whereas wet storage option has been used for spent fuel storage and cooling at reactor sites and in some off-site storage facilities around the world, a variety of technical methods for dry storage have been developed since then and are available in the international market.

2.2.1. Intact fuel storage

Intact fuel storage, which is the most prevalent dry storage method, refers to storage of fuel assemblies with no attempts to pre-compact them or alter them by destructive methods prior to storage. A variety of storage systems have been developed to meet specific requirements of different reactor fuels and a number of designs based on these generic technologies are now available for dry storage for the spent fuel containers (also called casks) or vaults (horizontal, vertical etc). The technology continues to evolve keeping up with the design optimization and new materials. One of the driving forces of the trend towards dry storage options (especially those of casks) is the inherent technical flexibility linked to economics. Compared to the pool facilities, which need to be built at full capacity initially, the modular type dry facilities can be added as needed with the advantage of minimizing capital outlays [14].

A summary of the AFR storage concepts is as shown in Table 2.

Table 2. Storage options for AFR storage of spent fuel

TYPE	OPTION	HEAT TRANSFER	CONTAINMENT (MEDIUM)	SHIELDING	FEATURE	EXAMPLES
Wet	pool	water	Water/building	water	classic option	most ARs + many AFRs worldwide
Dry	metal cask	conduction through cask wall	double lid metal gasket (inert gas)	metallic wall	dual purpose	CASTOR, TN, NAC-ST/STC , BGN Solutions
	concrete cask/silo	air convection around canister	cavity lining / seal welding (inert gas)	concrete and steel overpack	vertical	CONSTOR, HI-STORM
	concrete module	air convection around canister	canister sealing (inert gas)	concrete wall	horizontal	NUHOMS NAC-MPC/UMS MAGNASTOR
	vault	air convection around thimble tube	thimble tube (inert gas)	concrete wall	several cases	MVDS MACSTOR
	drywell/ tunnel	heat conduction through earth	canister (inert gas)	earth	below ground	Not commercial

Several variations of these fuel storage concepts, often by combination of existing dry storage technologies, have been developed with prospective applications in the future.

Cask is currently the most popular option that can be purchased or leased from the competitive market for expedited installation, on the assumption that the necessary license can be obtainable and any other obstacles such as opposition from the affected local community have been or could be resolved. Inheriting the technology initially developed for large-scale transportation of spent fuel from storage to reprocessing operations, several large size casks are now being marketed for storage services. Concrete modules have also become popular as a competitive option, with more designs licensed and implemented over the years. Markets for concrete modules are merging with those for vaults as a compact storage system, in terms of advantages when land availability is an issue. Multi-purpose technologies (i.e. a single canister package for storage, transportation and disposal) have also been developed, for instance in the US, although its use for disposal package is subject to uncertainty [15].

2.2.2. Compact storage technologies in development (for cooled spent fuel)

Compact storage refers to storage where the fuel assemblies are stored with consideration to compaction by means of physical rearrangement of the fuel assemblies with a view to higher storage densities and generally considered in wet storage.

2.2.2.1. Non-destructive techniques

There are several technical methods for storage densification that have been developed so as to accommodate more spent fuel at limited space in existing storage facilities by rearrangement of storage racks into compact arrays (double density racks) or by placing of fuel rods into an aggregation of bundles, or even by destructive packaging.

- Reracking is a simple method that has been extensively used at many nuclear power stations requiring storage capacity extension, and thus has mostly been exhausted of its potential at existing plants, leaving little space for further compaction.

- Consolidation of spent fuel rods by their compaction has been developed as a method for, ideally, doubling the storage capacity for LWR assemblies, also making it possible to store the consolidated assemblies in a canister having about the same or even smaller cross-sectional dimensions than the original fuel assembly. First construed for AR storage capacity expansion, the techniques were used in fuel inspection, repair, and reconstitution and had also been applied to demonstration programs of spent fuel rod consolidation conducted in storage pools in the USA during the late eighties. Some programs for experimental purposes and demonstration in the dry environment were initiated later in the USA and in several other countries for some other applications, such as for instance, for conditioning of spent fuel in preparation for disposal [16].

2.2.2.2. Destructive treatment

The search for further technical options of spent fuel management has continued beyond rod consolidation technology of spent fuel assemblies. There were several research and developmental programs in pursuance of further compaction of spent fuel by destructive methods which can provide for not only volume reduction, but also better removal of heat and enhanced containment of radio-toxicity, with a view to optimize waste management in the fuel cycle backend.

Cutting of spent fuel assembly or rods is a technical option used in some cases that goes one step further into packaging for compact storage. A special case in point is the spent RBMK[4] fuel in which some 10 m long fuel assembly with two sections is halved in the middle (without damage to the fuel rods per se) and put into an ampoule for placement in a dry storage system (see section 2.2.5.2).

- *Segmentation of spent fuel rods*

This method was researched in the German program for packaging spent fuel in POLLUX disposal cask, which would be restrictive in its handling capacities with intact fuel assemblies. By cutting the fuel rods to suitable size, the POLLUX cask could be handled with less technical constraints for emplacement in the disposal repository. Further development of the technique has become inactive, however, due to political decision to review the disposal concept in Germany.

- *Compaction by dissolution and subsequent treatment*

The last available option is chemical dissolution of the fuel with subsequent treatment of the resulting liquid and solidification of the end products. This process can provide the additional advantage in the total waste management system of separating the short half-life or heat-producing materials from the long-half-life materials, which can significantly affect the packaging, transportation, and disposal parts of the waste management system [17].

2.2.3. Wet storage

Water pools are the most common option for storage of spent fuel immediately upon discharge from reactors, since they provide excellent heat transfer essential in the early phase of cooling. At the nuclear plants, these pools are generally integrated with the plant design and spent fuel management in these pools is part of the plant operation. This has come to be called generally as at-reactor or AR storage. This classic option will remain to be popular for AR storage by virtue of its cooling efficiency and biological shielding as higher enrichment, higher burnup and mixed oxide fuels become commonplace in the nuclear power industry requiring longer cooling in wet pools following discharge from these reactors.

For a long period, the wet storage of spent fuel using water pools was the predominant storage method. As an established practice since the early days of nuclear power, water filled pools have been used almost exclusively for initial shielding and cooling of spent fuel discharged from reactors not only for temporary storage at the reactor site but also for AFR storage at reprocessing plants. Extensions to existing water pools and construction of new pools are done wherever feasible and are continuing to be considered despite availability of dry storage options. As discussed earlier, the measures initially taken by a utility for alleviating capacity shortage encountered in spent fuel storage at a reactor site are usually some ‘easier methods’ for capacity expansion such as by packing more spent fuel in the existing space, rather than building an AFR facility which would require more money and time. The method most widely used was reracking which has therefore been mostly used up at most plants. Some storage racks were re-racked again to a higher density (up to ~3.5 times). When the capacity expansion methods are exhausted for technical or regulatory reasons, further additional storage capacity may be obtained by building of new facilities of AFR type [18].

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[4] Reaktor Bolshoy Moschnosti Kipyaschiy.

2.2.3.1. *Review of technical concepts in AFR pool design*

Most of the water pools share a number of common technical features and components, albeit some differences in the design concept due mainly to operational and regulatory requirements.

The notable differences are observable in the facility design for spent fuel handling and storage layouts among the design of AFR pools, which may be broadly grouped in several categories as following:

- ***Single pool***

This is the simplest layout for pools adopted mostly for small capacity pools including AR storage facilities. Crane with a fuel grappling system is usually used for access to any storage location in the pool. Circular pools with polar cranes provide an attractive layout alternative. As there is no other extension of the pool, spent fuel has to be removed by a cask to an external facility in case of necessity such as transfer of fuel to another pool facility[5].

- ***Serial pools***

This is a concept based on an initial single pool expanded later on with additional pool(s) in series which are inter connected by water gate(s) on the walls between the pools, or through underwater tunnels and spent fuel conveyors through which spent fuel movement can be performed as required. If the pool itself were used for transfer of spent fuel, isolation of a pool would be more difficult in case of such a need, such as major repairs.

- ***Parallel pools***

This is a concept in which a multiple number of pools are built in parallel, sharing a water canal (corridor) at one end for fuel transfer between the pools and elsewhere. The rationale for dividing AFR pool facilities into multiple storage areas includes better structural strength, enhancement of maintainability (repair), easier provision of a reserve for emergency situations (as may be required by some regulatory rules). Such a concept would provide more flexibility for long term storage because of the possibility of independent movement of spent fuel from one pool to another if required (such as for inspection of spent fuel or relining of the pool).

It is also to be noted that the AFR pools in several countries in eastern Europe and Russia are covered with metallic sheets allowing workers to walk around over the pool and at the same time reducing evaporative loss of pool water because of the cover.

The pools are housed in seismically qualified concrete buildings. Fuel assemblies are placed in storage racks or baskets located at the bottom of the pool and are resistant to movement by seismic events. For the majority of fuel types including that of the LWR, the racks hold the fuel assemblies in a vertical position and maintain the prescribed spacing between assemblies to maintain sub-criticality. The assemblies are normally inserted or removed vertically from the top of the racks, using mechanical handling systems.

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[5] Some designs therefore have an auxiliary storage space, connected to the main pool, to provide operational flexibility.

For AFR facilities, storage modules such as baskets are widely used for enhancing efficiency of spent fuel handling and storage, in which case operational features are similar to that of handling fuel assemblies. A few cases where spent fuel is stored horizontally include the CANDU fuel where bundles are laid horizontally on trays or modules stacked in layers and the Magnox fuel which is stacked in skips (mild steel boxes) stored under water for a short period of time before removal to reprocessing [19].

Pools are equipped with cooling systems (i.e. pumps and heat exchangers) and normally operate at 40°C or less. Cleanup systems are provided to maintain good water quality. Pools require optimum pool water chemistry and careful maintenance and monitoring of the pool structures for leakage. Current generation pools are usually lined with welded stainless steel plates and have leak detection and collection systems. In water-pool based AFR storage facilities, systems will be required for unloading (and loading) of spent fuel from (and to) transportation containers, generally provided in the form of specially reinforced loading and dispatch areas in the pool (often called impact pads). Facilities will also be required for vacuum drying and decontamination of containers and for auxiliary services such as inspection and maintenance.

The water pools can be located either above ground or underground depending on the local conditions and preferences. An example of the AFR water pool underground is the CLAB storage facility in Sweden.

Most of the smaller scale AFR storage facilities of water pool type have been built nearby at the reactor sites in consideration of various factors including sharing of infrastructure available from the reactor sites**.** The storage facility CLAB in Sweden is a unique case of a stand-alone water pool storage facility as a centralized AFR facility for handling and storing large amounts of spent fuel (5000 tHM which was later increased to 8000 tHM capacities) collected from various reactors. A special consideration for the CLAB is nonetheless its long term configuration for extended centralized storage pending direct disposal.

The option of constructing an independent wet pool for significant quantities of spent fuel has merit under certain circumstances and, in fact, has been adopted for storage or buffer storage for reprocessing of spent fuel, such as in Belgium (Thane), Finland (Okiluoto & Lovisa), Russia (Leningrad, Smolenskaya, Kuskaya, Novo-Voronezh), and several countries in Eastern Europe (Bohunice, Kozloduy, Greiswald), France (La Hague) Japan (Rokkasho-mura), Sweden (CLAB), Switzerland (Gösgen). See Annex II for global status of AFR pools in the Member States.

2.2.3.2. Safety issues of pool storage

As the classic option for spent fuel storage, extensive experience has been accumulated for spent fuel storage in pool facilities around the world. Water pool storage requires active process systems to ensure satisfactory performance and continuous attention to preserve water purity in order to exclude microbial (algae) growth and control the introduction of aggressive ions such as chlorides. Because of the large inventory of radionuclides under a relatively vulnerable protection against external hazards (such as earthquake, tornado, flooding, aircraft crash, etc.), wet storage has been subject to scrutiny in terms of a variety of safety issues in addition to other criteria such as economics, safeguards, etc.

The safety issues of major concern in spent fuel storage pool facilities can be summarized as:

- Loss of cooling;
- Radiation overexposure;
- Handling mishaps;
- Criticality.

Safety guidance on these issues has been discussed in other IAEA publications [20][21][22].

2.2.3.3 Advanced pool concepts

Some advanced pool concepts were reported for spent fuel storage incorporating in their design various enhanced features with a view to ameliorate the drawbacks of the wet storage system and for enhanced economics in operating costs by incorporating better features. Such advancements include for example cooling and purification systems modularized and located inside the pool itself by using submersible equipment (as in the case of the Nymphea system used in the storage pool at the La Hague reprocessing plant), protective concrete cover over the water pool, etc. Some further enhancement in terms of security has also been reported for the new pool facility design at the Gösgen nuclear station in Switzerland [23].

2.2.4. Dry storage

The spent fuel assemblies in general are amenable for naturally cooled dry storage after a few years of initial cooling in the water pool (of about 5 years for most fuel and about 10 years for high burnup fuel). The minimum required time of initial cooling in pools is mainly related to the burn up and the irradiation history. A review of spent fuel storage facilities implemented during the past several decades shows that the storage in a dry environment is becoming more common. Taking into consideration the extending period for decades or even longer that will required for spent fuel storage, it is obvious that the naturally cooled dry storage facilities are an attractive alternative to water pools, especially for long term storage, in terms of such aspects as economics and safety.

Dry storage methods rely on metal or concrete for shielding radiation from spent fuel assemblies, which continue to emit considerable decay heat that must be dissipated to the atmosphere. Discussion here is limited to only generic technologies, provided primarily to develop a context for the selection process described later. The four key types of dry storage options are:

- Metal cask;
- Concrete cask / module;
- Vault;
- Others.

The technologies are also distinguishable by their major technical characteristics, namely, the predominant heat transfer method, type of shielding, transportability, location with respect to the geological surface; degree of independence of the individual storage units; and the storage structure.

There are several generic types of these technologies available from vendors on the international market. An increasing number of storage facilities are coming into operation for each of these types. There are also a large number of facility designs based on these generic technologies that are now available. These technologies differ largely in terms of materials of construction, size, modularity, spent fuel configuration, layout of the storage containers (horizontal, vertical etc.) and methods for fuel handling.

A summary of AFR storage facilities in Member States is given in Annex II.

2.2.4.1. Metal cask

As metal casks have long been used for spent fuel transportation in the nuclear industry, there was a natural transition in its role to storage service. These casks can be designed solely for storage or as dual-purpose containers for both storage and transportation. Metal casks hold several spent fuel assemblies within a dry controlled environment. The casks are filled with inert gas and sealed after loading with the spent fuel.

The casks are sometimes stored in the open on a concrete pad or housed in storage buildings, depending on regulatory requirements. Primarily the cask structural material, which may be forged steel, modular cast iron or composite materials, provides shielding. Double-welded closures provide for radionuclide confinement. Heat removal is by conduction through the structural material.

There are a number of designs available from the international market. Metal casks are in general transportable. This is an advantage in the case of future need to move them to a further destination. On the other hand prices are higher due to the requirements for transportation.

Examples of these metal casks are Transnucléaire's TN-series, GNS's CASTOR series, and Westinghouse's MC-10 casks used in the USA, and Nuclear Assurance Corporation's NAC casks in USA and Spain (see Annex I).

2.2.4.2. Concrete cask / module

A common technical feature of this category of storage systems is its use of concrete shielding which was a development of significant technical and economic implications. Despite the common use of concrete shielding, there is a large variety of system designs offered in the market that can be grouped broadly into two categories, concrete casks and concrete modules.

- *Concrete casks*

A concrete cask is generally similar to the metal cask by shape. The concrete provides shielding, but a steel liner in the inner cavity of the concrete cask provides containment. The liner is sealed after loading the spent fuel. Concrete casks could be naturally cooled or ventilated. The designs are similar with the exception that the ventilated type is equipped with inlet and outlet airflow ducts. This permits greater dissipation of heat; hence a greater heat load can be accommodated in a cask of this type.

These concrete casks can be stored either horizontally or vertically. They can be stored in the open or inside a building to protect them against the weather. Since concrete casks are generally not transported loaded with the spent fuel, these casks will require facilities for loading (and unloading) of spent fuel from (and to) transportation containers. Concrete casks could also be built as dual-purpose containers for storage and transportation in which case the casks could require special armors or overpacks for meeting transportation regulations.

Examples of concrete casks are Sierra Nuclear's Ventilated Storage Cask (VSC) and the concrete silo[6] developed by AECL as a "storage-only" system. Another example of this category is the Dry Storage Container (DSC), developed by Ontario Power generation (OPG), which is a transportable system and the CONSTOR development by GNS.

- *Concrete modules*

Concrete modules are large monolithic structures, usually with a reinforced concrete wall, which are in general not portable in that they are anchored to the storage pad on the ground. The concrete module provides the shielding, while containment is provided by placing of spent fuel assemblies into canisters. The canister is sealed after loading the spent fuel. Some refer to these designs as canister-based systems.

The use of internal cooling allows significant amount of heat to be removed from the storage system by natural convection and prevents overheating and degradation of the concrete material in the shield. This is a significant feature, which is advantageous for loading hot fuel in large quantities. Similar to concrete casks, however, ancillary systems would be required for loading (and unloading) of spent fuel from (and to) transportation containers.

A representative example of concrete module is NUHOMS horizontal module of Transnucleaire. NAC adopted the multi-purpose system MPC and UMS that are canister-based systems. Holtec International in the US has also developed and commercialized Hi-Star/Storm system, which is also a canister-based system.

2.2.4.3. Vault

A vault is a reinforced and shielded concrete structure containing an array of storage cells built either above or below ground. Shielding is provided by the surrounding structure. Commercially available vault systems are located above the ground level and the heat is generally transferred to the atmosphere by natural convection of air over the exterior of the cells. Each storage cell or cavity[7] can contain one or more spent fuel assemblies stored in metal storage tubes or storage cylinders. Spent fuel is loaded into these tubes either on-site with fuel handling machines in a charge hall or off-site at the reactor pools. The vault itself can be a relatively simple design, but requires additional installation infrastructure for the reception and handling of the spent fuel assemblies.

The storage concept permits modular construction and incremental capacity extension. Examples of on-site loaded vaults are Magnox dry storage at Wylfa in the UK and the MVDS facility in PAKS in Hungary. Examples of vaults, which receive pre-loaded containers, are CANSTOR/MACSTOR at the Gentilly-2 NPP in Canada (and at Cernavoda site in Romania) *[24]*, CASCAD facility in France, and the Fort St. Vrain MVDS facility in the USA.

2.2.4.4. Subsurface store

There are several other storage concepts which have been in development, mostly based on subsurface application of heat conduction or convection. Even though they have not been used on commercial scale yet, changing circumstance in the spent fuel management area may make alternative concepts attractive provided they become competitive in the new criteria,

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[6] Also called concrete canister.
[7] This cavity is sometimes called 'pit'.

such as the security issues which have lately become a higher priority throughout the world [25].

The concept of placing nuclear facilities underground originates from the nuclear shelter concept of the cold war period. Not only military facilities, but also some civilian nuclear facilities were built underground, like the Swedish facilities for spent fuel storage (CLAB) and waste disposal (SFR).

- Underground vertical ventilated storage concept

Holtec International has recently applied for a license for an underground version of its current HI-STORM 100U. The design concept of HI-STORM 100U overpack is an underground vertical, ventilated modular dry spent fuel storage system engineered to be fully compatible with their HI-STORM 100 system. Each module stores a single canister/overpack unit and functions independent of any additional units.

The system provides for storage of fuel elements in a vertical configuration inside a subterranean cylindrical cavity entirely below the top-of-the-grade of the storage area. The enclosure container defines the MPC Storage Cavity, consisting of the container shell integrally welded to the Bottom Plate. The storage cavity is ventilated by outside air through the insulated ducts via natural convection [26].

- Drywell

A dry well is a stationary, below ground, lined, individual cavity. Shielding is provided by the surrounding earth and closure shield plug. Primary heat removal is by conduction into the earth[8].

Each storage cavity may be designed to contain several spent fuel assemblies, the actual number of fuel assemblies to be determined by the fuel characteristics and storage media. The storage medium can be air, nitrogen, carbon dioxide or any of the inert gases helium, argon or neon.

- Twin tunnel storage concept

This is a subsurface storage method which combines the drywell concept with borehole emplacement in a geological disposal facility, with a view to long term storage before disposal or retrieval for reuse.

In a design concept proposed by Colenco Power Engineering Ltd, the spent fuel transported from AR or AFR storage is placed into canisters with double wall sealing to be brought to a pair of horizontal tunnels interconnected with vertical boreholes for the canister emplacement. The cooling air ventilation flows from the lower drift to the lower tunnel and passes through the borehole to the upper tunnel and drift [27].

[8] Drywell had been one of the options considered for storage of spent fuel in the past, but has not yet been licensed anywhere in the world.

2.2.5. Storage of special types of spent fuel

Aside from major types of fuel such as LWR, CANDU, and GCR, there are some other 'exotic' types of fuel with technical characteristics that would require somewhat special systems for storage.

2.2.5.1. Pebble-bed reactor

A uniquely different method of spent fuel handling and storage is in the case of the pebble bed reactor THTR-300, which was developed as a demonstration reactor located in Hamm Uentrop in Germany. The pebble-like thorium fuel balls are drained down through an outlet to fill containers that are placed in dry pit storage. They are taken out from the buffer storage by a crane and brought subsequently to an adjacent loading station. One container loaded with 2 100 fuel pebbles is inserted in the metal cask CASTOR THTR/AVR. The loaded cask is provided with a primary lid that is bolted by a manipulator and moved to a working platform where the primary lid bolt is tightened for air-tightness and where the secondary lid is also bolted and air-tightness checked. After completion of cask loading, sets of 3 casks are put on a transport wagon by a heavy load crane and the casks are shipped to the Ahaus storage facility. Several hundreds of the casks were delivered to the Ahaus storage facility in the mid-nineties.

The pebble-bed reactor THTR-300 provided the technical basis for commercial scale PBMR reactor project being implemented in South Africa [28].

2.2.5.2. Special preparations for spent RBMK fuel storage

For some types of spent fuel, special processes are required in preparation for AFR storage, calling for extensive application of remote technology. A good example is the preparation of casks for AFR storage of spent fuel from RBMK reactors, as being done in Lithuania. The spent RBMK fuel assembly has a unique structure, which requires disassembly of the unusually long fuel element skeleton (~10 m) into two sections of fuel rods, including the associated structural materials, in order to fit into the commercially available casks for AFR storage [29].

The pioneering work for packaging of spent RBMK fuel for dry storage was initiated by Lithuania for the Ignalina Nuclear Power Plant (INPP) in 1997. The spent fuel pool bay at the INPP had been refurbished for the spent fuel operation and associated waste packaging. The long RBMK fuel in pool storage is segmented in vertical mode in a high hot cell enclosure. The bundles of fuel rods thus separated from the structural tube are loaded into 3.6 m long baskets, which can accommodate 102 fuel rods for subsequent storage back in the storage pool. Metallic structures arising from the operation are packed in the hot cell for subsequent disposal. After 5 years of storage in the pool, the baskets are taken out of the pool to the dry storage area for storage in the CONSTOR concrete and CASTOR metal casks licensed from GNS/GNB. Upon loading, the internal lid and cask cover are welded to provide leak-tightness.

2.2.5.3. Spent MOX fuel

In the case of MOX fuel containing reprocessed uranium, remote handling would have to be considered even for fresh fuel, depending on the radiation emitted from those fuels. Based on the characteristics of the spent fuel existing at the time of the selection of the AFR storage facility, some allowance may have to be made to make room for the future development of the fuel used in the reactors.

As physical specification of MOX fuel is similar to UOX (uranium oxide) fuel for LWRs, spent MOX fuel from LWRs would have a lot of similar technical features, even though the heat and radiological characteristics would be much more severe [30].

2.2.6. Storage market and services

There are a large number of facility designs based on these generic technologies that are now available[9]. A list of cask type products available in the current market is summarized in the Annex I.

Based on the above technologies, the spent fuel storage industry provides a variety of storage facility designs. By virtue of market globalization, the industry has now become international with a strong presence in many Member States with a mature nuclear power sector. In most cases, the storage designs are modular and allow capacity extension matching the spent fuel arising at the NPP. Facility modules are generally built contiguously to facilitate efficient use of space, and sharing of services. Industrial experience has been steadily accumulating for a number of years with dry storage as well as wet storage.

Current AFR technologies are mostly based on R&D of the past few decades, which focused on 20-50 year storage. Extension of these technologies to a 50-100 year timeframe is generally considered practical. For much longer terms such as a century or more, there may be a number of questions that may need further attention. The countries involved in Spent Fuel Performance Assessment and Research (SPAR) are currently focusing on the R&D aspects of such longer term storage and the R&D findings of these Member States would be beneficial as the spent fuel storage technologies further mature to meet the needs of the future.

The AFR storage facility includes, by necessity, various infrastructures and services, such as an off-site transportation system, fuel loading stations at the NPPs, vacuum drying systems for drying the fuel following removal from wet pools, systems for container or cask reception at the AFR storage, automatic welding systems for sealing containers, and project infrastructure, which may include administrative/technical buildings, security and safeguards systems, and systems for radiological monitoring and radioactive waste management. The international storage industry caters to most of these infrastructure needs and services. Services can be acquired or leased in certain cases (such as transportation containers). These services would complement the services and infrastructure that may already be available to start with, such as at the NPPs. The existing infrastructure has an important implication to the operating costs, among others, because the bulk of the resources available from the infrastructure (such as the NPP) can be shared for the operation of the storage facility. This is an important point to remember especially in the case when the infrastructure is to be removed such as for nuclear plant decommissioning at which time, new services and infrastructure would require to be substituted.

The technology of AFR storage has now grown with an ability to provide support with respect to not only storage products, but also in all the various infrastructure needs. The prospects are that the need for AFR storage will continue to grow in the decades to come and a highly

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[9] A detailed review of the entire range of technologies available from vendors is beyond the scope of this document (see Appendix).

mature industry would be globally available to serve the Member States generating nuclear power.

2.2.7. Long term issues

An issue for long term storage of spent fuel at AFR facilities is the storage extension beyond the licensed period. Several possibilities could be considered:

- The storage period is extended for additional span of time, with or without refurbishment of the facility, as would be acceptable to the regulatory authority.
- The spent fuel in storage is moved to another facility ("rolling storage") as required by technical or regulatory considerations.
- The facility converted into another type (such as from wet to dry), with or without additional operational constraints or requirements on the spent fuel in storage.

Most considerations given to the long term storage of spent fuel have focused on the first or second categories. An IAEA technical document was drafted on the first case, while the second case was considered by the studies conducted in several Member States. The third case does not seem to have been examined yet [31].

3. AFR PROJECT CONSIDERATIONS

3.1. Introduction

The task of identifying storage requirements would be the foremost challenge to utilities seeking AFR storage irrespective of whether they intend to self-manage such projects or outsource them to take advantage of the available storage service sector.

In this section, a review is made to identify the requirements for a project for selection of an option for spent fuel storage. Most of these requirements are of a generic nature common to any project to implement a plan for spent fuel storage in an AFR facility.

3.2. Generic considerations for spent fuel storage projects

Customer needs may differ from country to country and from site to site in terms of specific requirements, conditions or constraints. Where a need for an AFR storage facility is recognized, an initial action to identify options available would be required. This requires the customer (or the project representative) to define, understand and then specify all the requirements including the boundary conditions and various project constraints. Notwithstanding the variety of specific requirements that exist in different countries and situations, there are some generic issues required for any project to be implemented for spent fuel storage. Whatever types of AFR storage facility may be envisaged, the topics addressed in this section are likely those which will have to be given consideration in defining requirements for a project [32], [27].

The project procurement cycle could be broadly divided into two phases: (i) technology selection phase and (ii) tendering and contract phase. The technology selection phase will carry the project through initial feasibility studies and other evaluations needed for selection of the most suitable option. Following the completion of the technology selection phase, the project is taken to the tendering phase. A functional specification[10] document, based on the functional requirements, and the technological selection process, among other data, would provide a contractual basis for the potential bidders. The requirements therefore provide overarching information not only for technology selection, but also for use in the entire procurement cycle.

Although each AFR storage project is unique, an essential characteristic of the process by which it is selected is the common need for the progressive elaboration of its requirements, which must be carefully coordinated in the project scope. Starting with the formulation of the need, the requirements are specified with continuing attention well into the development of the functional specification for the tendering process.

The aim of identifying these requirements is to develop a common understanding on the project needs and planning parameters regardless of the technological option to be chosen. A project charter, plan or strategy is the end product of this exercise. Such a document will provide an approach in terms of the work that must be done to acquire an AFR storage system identifying all the generic requirements and boundaries. This may also include delivery dates, organizational needs and various management plans such as for the project scope, schedule, cost, procurement, quality and human resources. Necessary approvals such as regulatory licenses and environmental permits would need to be obtained. AFR storage project requirements often have to evolve step-by-step building on earlier versions until they get sufficiently defined to be of use in actual project implementation.

It is important to develop the practice of documenting all the assumptions made in the formulation of requirements such that there is a clear understanding shared between stakeholders in the project on how the requirements were arrived at during the early stages of the project. The listing of assumptions allows the project staff to review the requirements during the project if necessary and also helps the bidders at a later stage to understand the requirements and propose changes if they find themselves unable to meet them.

3.2.1. Information on the spent fuel to be stored

Technical information on the spent fuel to be stored is the very basis for the design of the facility and associated systems. It would include, among others, inventory, locations, types of fuel, technical characteristics, etc. There is a vast and increasing array of fuel designs which are still evolving as advanced reactor systems are coming into service and high burnup fuels, mixed oxide (MOX) and other new fuel designs are becoming common place.

The need for spent fuel data depends on the use of the required data. There are several levels of users of the spent fuel as following.

- Utility (generator) and organizations assigned with spent fuel management,
- National level regulator and stakeholders, and
- International organizations.

Because of the current status of institutional arrangement based on the “polluters pay” principle adopted by the majority of countries, the primary users of spent fuel inventory data are the utilities which supply relevant data to the national regulator as required. There have

[10] Also known as Bids Invitations Specifications (BIS).

also been several international cooperation initiatives on spent fuel management on regional level, but so far without any tangible results.

In general practice, the information on nuclear fuel is passed over from one operator to another in the fuel cycle (sometimes attached with the fuel shipment as a manifest) together with the physical and legal transfer of management responsibility and in many instances, ownership of the spent fuel.

The information on spent fuel may be broken down into the following categories:

3.2.1.1. Spent fuel arising and storage projection

The key information required for the determination of the throughput of the AFR facility and the establishment of its operating scheme includes the annual production rate and the cumulative amount of spent fuel taking into consideration the factors mentioned in previous section. Based on this information, a projection of needs for the spent fuel storage is made and the total capacity required is estimated including later potential expansion of the facilities.

It may not be possible or necessary to foresee fully the envisaged AFR spent fuel storage capacity since nuclear programs in most Member States are continuously changing. Decisions will have to be made according to available projections of spent fuel arising and remaining pool capacity at the nuclear plants. Allowance would be required at the AR pools for contingencies such as removal of reactor fuel load in emergencies (referred to as core discharge) and pool operational contingencies. Allowances would also be required to deal with potential project delays in planning AFR storage. A staged, modular approach may well be more appropriate to satisfy immediate needs (i.e. several years of storage) of capacity building and for planning provisions for future extensions. Future requirements could be included at the initial design stage at a preliminary conceptual level and refined at the time of modular expansion of the AFR storage systems.

3.2.1.2. Spent fuel types

There are several types of spent fuel including pressurized water reactor (PWR) fuel, boiling water reactor (BWR) fuel, mixed oxide (MOX) fuel, Canada Deuterium Uranium (CANDU) fuel, other pressurized heavy water reactor fuels and advanced gas cooled reactor (AGR) fuel. Fuel types differ not only among reactor types, but also among various vendors who manufacture different fuel for different reactor types (such as Babcox and Wilcox, Combustion Engineering, Westinghouse, Framatome and Russian reactors) who use customized fuel designs of differing enrichment and burnups[11].

It would be necessary to recognize the impact of individual fuel types on the AFR storage in cases where an AFR storage system is to be designed for multiple use of spent fuel from many reactor types.

[11] There are various types of research reactor fuels, experimental assemblies, reactivity booster assemblies, spent fuels from the earlier reactor types, and fast breeder reactors (FBRs), which may not fall into the above categories but may require to be considered for AFR storage.

3.2.1.3. *Spent fuel characteristics*

Spent fuel is characterized by the changes that occur during the in-service operation of the nuclear fuel in a reactor. These include depletion of the fissionable isotope, such as ^{235}U and concentration of several hundred fission product nuclei in the fuel. The degree to which such changes occur depends on the burnup of the fuel, i.e. amount of energy produced by the fuel per unit mass of the fuel (expressed usually in MWd/kgU). All of the nuclei are subject to radioactive decay, some of which take hundreds of thousands of years or longer. These fission products are normally contained within the ceramic fuel matrix in the containment envelope provided by the fuel cladding. With suitable shielding of the external radiation in the spent fuel, adequate protection can be provided during handling and storage. In the case of defective fuel, however, leakage of radionuclides from the fuel would be an additional consideration [33], [34]. Heat production in the spent fuel is a direct consequence of the radioactive decay and is a significant factor to be considered in the design of storage systems.

All spent fuel related factors affecting the storage system should be determined. Key safety objectives that require accurate spent fuel data are sub criticality assessments, heat removal assessments and radiation shielding calculations. Characteristics of the spent fuel assemblies to be stored should include at least the following parameters:

- Assembly/bundle identity (serial number of assembly/bundle),
- Physical description (fuel and clad type and geometry, post-irradiation form, mass),
- Initial enrichment and discharge burnup (composition, materials, isotopes, etc.),
- Irradiation history (residence times in the core, linear power rating, reshuffling schemes etc.),
- Age of spent fuel after removal from the reactor,
- Information on defective or leaking fuel, with possible logging of water (important for long term safety requirement), and
- Any unusual features of particular fuel assemblies (experimental assemblies, boosters etc.).

Spent fuel characteristics are generally tracked by highly developed and complex codes during in-service operation and information is generally available to a high degree of sophistication. Further evolution of spent fuel characteristics during the storage period (decay heat, radioactivity reduction, radiation-induced effects etc) as well as monitoring technologies for spent fuel integrity/degradation during storage is also reaching a mature level of understanding. The above information is generally compiled on an individual assembly basis, since some of these factors could widely vary from fuel to fuel depending on its power history. For this purpose, a readable number embossed on it by the manufacturer is generally used to identify the fuel assemblies and to correlate their data. Based on this information, and using appropriate computer codes, various other information needed for the storage system design and for various assessments can be further developed for the fuel assembly, such as decay heat output in the fuel, fission and actinide product inventories, external radiation data, and detailed database required for meeting safeguards requirements.

It is important to recognize that spent fuel is made of reactive materials and will be subject to physical and chemical changes over time. These changes may affect the overall safety and integrity of the spent fuel in storage and therefore the overall safety of the storage system. Adequate provisions must be made to take account of these changes that may arise both during irradiation and following discharge from a reactor.

Overall, some effort may be required to define acceptance conditions for spent fuel in the AFR storage facilities such that AFR storage design specifications can be developed compatible with the received spent fuel. This will require cooperation between the NPPs and the project staff such that any extraordinary technical difficulties can be identified in advance and resolved in the best possible manner. NPPs will also be the keepers of operational information on stored fuel at the reactor sites, particularly information on fuel failures or damages during in-service and later on during handling and storage at the reactors, which would be necessary in customizing the AFR design to spent fuel condition.

It should be noted that fuel characteristics change as nuclear fuel and reactor technology advances in various countries, such as from increased burnup of fuels, use of recycled plutonium in fuels (MOX and mixed carbide fuels), achievement of higher densities and other improvements, leading to trends in spent fuel characteristics different than those for current reactor fuels. Based on the characteristics of the spent fuel existing at the time of the selection of the AFR storage facility, some allowance may have to be made to make room for the future development of the fuel used in the reactors. The modular approach for AFR storage will allow the required flexibility to take into consideration any unforeseen changes that could take place in the future including changes to fuel characteristics, containers, regulatory requirements, and the knowledge base of storage systems. A modular approach as well as adaptive measures incorporated during design will also allow future improvements in the storage systems themselves to be accommodated based on the lessons learned in the initial stages and from feedback from the storage operations.

3.2.1.4. Defective fuel

Defective fuel may require special attention in terms of canning them prior to storage in an AFR (if it is not done already at the reactor pools). Operational objectives and safety approaches for defective fuel may differ for NPPs and for AFR storage facilities. What may be considered generally acceptable for at-reactor storage may not be suitable for AFR storage due to potential for contamination during transportation and long term storage. This may require special size containers for storage as well as transportation if they do not fit into standard containers. An agreed upon criteria (usually based on sipping procedures) would be established to identify defective fuel that need placement in a sealed can.

Adequate provision of information on the defectiveness (with possible logging of information) is particularly important for design of dry storage systems, as evidenced by the spent RBMK fuel storage project in Nuhoms system at Chernobyl [31].

At the AFR storage specific detection systems would be considered to confirm NPPs' data as spent fuel is received, confirm fuel integrity during further storage, and ultimately confirm fuel integrity at the time of fuel retrieval.

3.2.2. Location and infrastructure

The selection of a site for an AFR facility shares a lot of features common to many other types of nuclear facilities. Any potential site will require an adequately controlled single-use land area to accommodate storage facilities and various infrastructures and to ensure that radiation doses due to resulting activities from all pathways are within acceptable limits as defined by the regulatory bodies in the Member States.

The site should be compatible with the construction and operation of the AFR storage facility. Sites that are at geologic fault areas, flood plains, wetlands and habitats for endangered and threatened species are obviously less suitable. The AFR implementing organization would also be advised to avoid land with exploitable mineral and energy resources, land adjacent to airports, toxic chemical facilities, facilities manufacturing or using explosives, and refineries.

3.2.2.1. Siting options

Any design and construction of AFR storage facilities is closely tied to the site where the facility is to be located. Consideration to siting options is therefore an important part of any AFR storage selection. Site conditions must fit the initial intent for the AFR storage facility that may consist of policy alternatives such as a single national facility, several facilities at various local sites or even regional locations shared between two or more countries.

Preference may be given to on-site storage at sites already involved in nuclear activities (such as NPPs) for the reason of sharing existing infrastructure. Local communities at such sites may already be familiar with nuclear undertakings and may be more favorable to hosting an AFR storage facility than the communities at the non-nuclear sites. Some countries may have other preferences, such as collocation with an eventual disposal site or reprocessing sites. Collocation would bring more constraints in terms of site conditions compared to an independent site only for storage.

One of the possibilities is the conversion of a storage facility to a disposal facility in a phased approach. Essentially in this option, AFR storage is conceptualized as an underground vault system, where the fuel is stored for several decades or centuries, and then converted to disposal facility, after all the uncertainties with regard to future spent fuel strategy are resolved.

In the case of regional locations, it is important to recognize and give proper attention to the international obligations that may apply to such locations (See Section 3.5).

3.2.2.2. Site characteristics

Site characteristics are essential features that may take considerable attention in making a proper decision on an AFR storage selection especially in case of a site in a recognized green area. These are not only important for engineering design of an AFR storage facility, but also for safety assessments and environmental impact assessments. Detailed baseline characterization of the site would be essential to not only identify site characteristics but also provide a baseline for establishing project impacts on the site generally required by the national regulator. Of importance are site data that are required for constructing a facility, site-related natural phenomena pertaining to storage safety (such as earthquakes, floodplains), and environmental and social factors.

The extent to which site characterization is required would depend on the type of AFR facility being considered. An underground facility would obviously require more detailed characterization of the subsurface (i.e. groundwater flow and quality, geosphere/biosphere interface, geomorphology etc) as well as the surface characteristics to properly model safety and environmental assessments.

Typical information that needs to be developed with respect to a potential site includes:

- Geographical location and site description;
- Probable weather conditions;
- Availability of infrastructure (water, electricity, telephone and other services);
- Availability of labor, subcontractors, construction materials and equipment;
- Access conditions to the site;
- Local regulations and ordnances;
- Topography and drainage;
- Subsurface soil, rock and water conditions;
- Transportation and freight facilities to the site;
- Environmental data (about land, water, wildlife); and
- Socio-economic data (demography, local economy, social factors).

Site selection and decisions could involve in most cases a range of stakeholders, particularly local governments (municipalities) and affected communities (see Section 6).

Site selection should also give some consideration to long term institutional measures that may have to be implemented at the site for reasons such as: sustaining the initial site conditions over the storage period or alternatively ensuring that changes to the site from normal evolution are acceptable; achieving social acceptance in that the site is being monitored over the storage period; and implementing institutional controls necessary as a safety measure for the licensing.

3.2.3. Functional considerations

By definition, an AFR storage system implies that the spent fuel will have to be unloaded from a storage facility at the nuclear power plant and transported to its away-from-reactor site. Facilities and infrastructures are required for the handling and transportation, as well as storage, of spent fuel.

3.2.3.1. Facility planning

The facility planning is not limited only to considering conditions and constraints of the relevant facilities at the nuclear power plant site and at the proposed storage location, but also has to consider the transportation system and route.

- At the nuclear power plant site, conditions will have to be identified for loading and handling equipment, modifications that may be needed at the NPP and its pool to handle transportation containers or storage containers, and other possible changes that may be needed to existing infrastructure (such as transportation corridors) to support spent fuel handling and movement.

- An appropriate transportation system includes information on selected transportation containers and vehicles, modes (i.e. road, rail or water) and routes for transportation. It is important to plan necessary emergency response systems, arrangements and infrastructure for off-site transportation.

- At the AFR storage location, a facility (system) would be needed for either receiving transportation containers or for receiving loaded storage containers, and for handling and movement of spent fuel within the storage facility itself.

- Transportation of nuclear material always raises considerable public concern (and has the potential to emerge as a formidable problem in many countries). In is important that public concerns be addressed through appropriate consultation and communication programmes.

3.2.3.2. Transportation considerations

Transportation is a vital link in any AFR storage system. At the outset, spent fuel would be transported either in dedicated licensed transportation containers (transport-only casks) or in storage containers, with over-packs if needed, if such arrangements meet the licensing requirements [35].

If transport-only containers are used, spent fuel will be loaded into these containers at the at-reactor pools and transported to storage at the AFR storage facility [36]. If the intent is to load the spent fuel at the at-reactor pools into storage containers, systems would be required at the NPP for loading the spent fuel and for sealing the containers with welded or bolted enclosures prior to transportation. Loading of the fuel at the pools can be done either directly inside the pool (wet loading) or alternatively, in a dry loading cell adjacent to the pool. Some NPPs may not have adequate features for off-site transportation of spent fuel and thus may require significant refurbishment or modifications of AR pool facilities.

Planning of spent nuclear fuel transportation may require considerable attention for some AFR storage facilities that may be far away from the nuclear plant site. This may involve discussions with the shipping companies to ensure that the transportation plans are practical and that the logistics could be implemented. On-site operations for the preparation of transportation containers, loading and unloading, contamination control and inspection would require significant effort both at the AFR storage site and the AR facility at the NPPs. The degree of attention required may differ from country to country depending on country's specific factors and circumstances. Transportation regulations may be different from one country to another, although with respect to transportation containers, Member States have generally adopted IAEA guidelines and regulations[12].

The functional requirements of transportation and handling should be identified at the beginning of the selection process including the accessibility for rail/road/water transport from the NPP to the AFR storage site. If there is any preference related to the fuel handling and preparation before storing the fuel in the AFR facility (such as spent fuel drying, inert gas filling and sealing of containers before placing it in dry storage), it should be defined. Such preferences may also relate to the location where such activities are carried out, i.e. the AR site (NPPs) versus AFR storage site.

3.2.3.3. Storage/transportation interface

The storage/transportation interface needs to be carefully studied since many of the factors generally considered for storage may not be ideal for transportation. Factors that impact the transportation interface could include:

- Size and capacity of the transportation container;

[12] Details of transportation regulations are beyond the scope of this publication. The reader may take advantage and search existing IAEA literature in this regard.

- Bare, encapsulated or containerized;
- Condition and integrity of the fuel;
- Degree and nature of surface contamination on the fuel (crud);
- Age of fuel (heat and shielding requirements);
- Burnup and radionuclide content; and
- Shock and vibration characteristics.

Other factors relating to the transportation system interface could include specific regulatory considerations for the transportation container, special loading and unloading procedures, crane capacity and dimensional limitations, special shielding constraints, and protection against transportation accidents.

An interesting question in this context is the technical option for developing dual purpose, storage and transportation container, or multiple purpose cask or container for storage, transportation and disposal. The USDOE initiative in the mid-nineties for multi-purpose canister (MPC) resulted in development of several industrial products in commercial use [37]. A similar initiative is being launched in Europe [38].

3.2.3.4. Transportation containers

Licensed transportation containers are usually readily available from a variety of suppliers or can be readily developed to meet specific needs as necessary. However, docking arrangements and systems for handling of fuel from transportation containers need also to be considered.

3.2.3.5. Customized containers

Depending on the type of fuel involved, containers may have to be customized in some cases. Leasing of these containers and subcontracting of transportation services are also available options for consideration.

3.2.3.6. Retrieval requirements

Since the AFR storage is not the final stage in the disposition of spent fuel, retrievability considerations are important at any time during the storage period and in particular at the end of the lifetime of the storage facility. To this effect, fuel handling and loading systems and equipment are typically an integral part of the storage system. Need for spent fuel handling during long term storage may arise from transfer to another storage system for whatever reasons. For cases of dry transfer, a major concern may be the spallation of crud, characteristics of which are not well known.

The uncertainties inherent in long term endeavor such as spent fuel disposal have provoked a lot of debate in the approach to design provisions , including retrievability (or reversibility) of spent fuel disposed should such need arise[13] [39].

Generally when AFR storage is considered, spent fuel is not packaged to meet disposal requirements, since these requirements would depend on disposal facility design specific considerations such as host rock type, groundwater quality, container corrosion allowances, and long term durability of containers extending from several hundred to thousands of years.

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[13] The issue of retrievability of spent fuel in the context of pre- or post- disposal is another issue.

To meet these potential requirements for transfer to disposal, spent fuel stored in the AFR storage would need to be conditioned and packaged in suitable long-lasting containers. These considerations would ensure *a priori* that any effects on spent fuel during AFR storage do not compromise retrieval of the spent fuel in all respects. The importance of preserving spent fuel integrity and retrievability during AFR storage is highlighted by this example. It is plausible that development of multi-use containers for storage, transportation and disposal may overcome this constraint to some extent in the future.

3.2.4. Long term issues

With the tendency of extending the periods of spent fuel storage, the duration of spent fuel storage at AFR facilities has become a critical question as for any other storage facility and is also a factor in selection of the AFR approach.

3.2.4.1. Resources and institutional control considerations

A need for resources, financial as well as human, relate to not only the short-term, but also the long term operation of the facility. Several considerations must be taken to ensure resources over the required timeframe. While resource assessments in the short term are generally straightforward, long term assessments are complex due to a number of issues discussed in this section.

Related to the need for resources to be available for long term, the institutional stability to cover the storage time span is another issue to be considered for the required services.

3.2.4.2. National policy

The compatibility of the AFR storage facility with the back-end of the fuel cycle strategy of the nuclear program in a Member State is essential. This means proper interface with other facilities and if disposal of the spent fuel is planned, compatibility with disposal, to the extent that such information is available during the selection process. Necessary resources should meet not only current needs, but also assure long term management and stewardship responsibilities depending on the back-end strategy.

An AFR storage facility is not meant a “disposal” option. Therefore attention should be given to the future management of the stored spent fuel after the design life of the AFR storage. This consideration might influence the development of the AFR storage facility so as to make the future management easier and less costly. It is generally assumed that spent fuel from the AFR storage will be retrieved for transportation to an ultimate destination depending on the timeline provided by the national programs. However future management needs could also involve retrieval of the spent fuel from the AFR storage, and re-storage in an alternate facility if the ultimate destination for the spent fuel is not available or delayed. In either case, the timelines and retrieval activities required would drive the resource requirements both in terms of financial and human terms. Uncertainties with respect to future management needs often make this issue difficult to resolve.

A modular approach to building the AFR storage facility may help alleviate that concern. It facilitates taking into account future needs, technology, knowledge base etc. in a gradual manner in the AFR storage such that risks with respect to future management are minimized. In any event it is normal practice to initially build several years of capacity, and expand the facility as required over time.

3.2.4.3. Facility life and possible modifications

The lifetime of the AFR storage facility should be determined based on the necessary storage period prior to any future destination, be it reprocessing or disposal. In cases where such period is very long, one may be constrained by the achievable design life of the facility, in which case the spent fuel may have to be transferred from one facility to another. Transferring the stored spent fuel from one facility to another may take several years, even decades, depending on the amount of fuel and loading and handling constraints at the facility. Such limitations would have to be given consideration in developing AFR storage, particularly in terms of facility durability, licensing conditions with regard to facility design life, and any licensing agreements with respect to extended use of the storage facility beyond the licensed period.

Need for spent fuel movement from one facility to another or from one location to another may arise for various reasons including safety and/or regulatory issues, or economic and strategic reasons. It may require minor or major refurbishment of the storage facility in use or construction of a new facility, depending on the functional requirements for the need arising from circumstantial change. This is an issue of contingency which could become an important consideration for long term storage of spent fuel in the future.

These issues are not new to the spent fuel management industry and many countries participating in SPAR[14] have R&D programs aimed at extendibility of storage systems. These include programs such as: monitoring storage parameters (such as fuel integrity, structural integrity etc) in wet and dry storage systems in several countries, life extension studies (such as from 50 to 100 years in Hungary), and procedures for extended monitoring of spent fuel, and investigation of very long storage periods (for example 300 years of dry storage in France).

3.2.4.4. Long term integrity

In preparation for storage of spent fuel for a long term time span, the ageing mechanisms of the facility and its equipment, in addition to the integrity of spent fuel itself are important.

It may be necessary to implement storage and spent fuel monitoring plans to provide ongoing information on the structures and the fuel. Although it is a usual practice to consider a lifetime of few decades for spent fuel storage facilities (and perhaps 50 to 100 years), longer periods might require caution because of uncertainties involved. Extended storage periods may also augment the need for a carefully designed monitoring plan and proper provisions to handle possible contingencies. Although spent fuel behavior during storage has been studied to some extent, experience with long term integrity of storage structures is generally not yet available [40].

3.2.5. Safeguards

Due to the sheer amount of spent fuel inventory in storage facilities around the world, and the significant amount of nuclear materials they contain spent fuel storage facilities represent an important part of IAEA safeguards requiring significant resources.

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[14] Spent Fuel Performance and Research (SPAR) programme of IAEA (see [9])

The objective of the safeguards is the timely detection of diversion of nuclear material for non-declared purposes and deterrence of such diversion by early detection. The IAEA safeguards system is based primarily on the use of materials accountancy as a safeguards measure, with containment and surveillance as major complementary measures. General information on the IAEA safeguards program and related functional requirements are contained in other IAEA publications [41].

In the context of AFR storage operations, the facility operator should be aware at all times of the location and quantities of nuclear materials in storage and to provide the necessary reports defined within the particular Safeguards Agreement between the Member State and the IAEA.

Specific nuclear material accountancy and control procedures necessary to facilitate routine safeguards inspection activities include:

- Design information provision and verification;
- Arrangements and procedures for material transfer;
- Material balance reporting; and
- Maintenance of records and reports.

In addition the facility design must include provision of equipment and systems for surveillance of the inventory subject to safeguards. Operational considerations should be given to the requirements for any services necessary to support this equipment.

Safeguards seals are extensively used for dry storage types of metal or concrete casks. In the case of dry storage systems for spent CANDU fuel, intubations (a tube which passes through the shielding body) is provided in such a way that a detector device can be inserted for verification of fissile material content by safeguards inspectors.

3.2.6. Physical protection

Provisions for physical security of the storage system with the associated spent fuel are also necessary. Physical protection is an important part of national legal and regulatory framework for nuclear facilities, which is also related to international convention [42].

Potential consequences from unauthorized movement and misuse of spent fuel and sabotage against the facility make physical security an important system in the AFR storage. Physical protection measures not only include a mixture of hardware and designed features to minimize such possibilities but also various administrative controls in the facility such as on-site security staff and procedures. Such controls may outreach comprehensive measures by the Member State to locate and recover missing material in case of unauthorized removal of spent fuel from the facility.

Physical protection of spent fuel storage facilities has recently become an issue of mounting concern due to the possibility of facilities becoming a target of terrorism. Given the large amount of radioactive material and potential for major accidents (particularly with pools), some Member States may prefer to go for more secure designs i.e. underground storage or additional protective systems (see section 2.2.4.4).

3.2.7. Emergency response capability (on- and off-site)

In the case of AFR storage, the emergency provisions usually considered in nuclear emergency planning such as rescue plans should take into account large quantities of spent fuel involved and off-site transportation of spent fuel.

For instance, consideration should be given to having readily usable extra capacity for spent fuel should an emergency occur within the facility that may require the removal of some spent fuel [15]. With regard to transportation, considering public protection and safety, readily available measures must be in place to take into account any off-site transportation emergencies that may arise. These could include off-site emergency organizations and staff, such as police, fire, environment and public health emergency personnel [43].

In either case, it would be necessary to identify the type of emergency that can occur, methods to identify and mitigate their consequences, and appropriately trained personnel and organizational systems to deal with such emergencies.

3.3. Regulatory requirements

Some countries, having been engaged in spent fuel management for many years, have set up comprehensive national standards, safety regulations, emergency response and licensing procedures, etc. for activities involving spent fuel. These systems can serve as a model in countries where the relevant national regulations are not yet fully developed. However, a careful analysis has to be made in order to identify the limitations of such practice in meeting particular national expediency for putting regulations in place.

3.3.1. Nuclear licensing and environmental impact assessment

The key objective of the licensing is identifying and evaluating effects of AFR storage on human health and safety considering both the public and the workers at the AFR storage, and the environment. National regulations generally specify allowable radiological exposure limits (for both the public and the workers) and limits that may be applicable to environmental protection based on internationally recognized data and guidance such as from the ICRP, the UNSCEAR and the IAEA. Such protection is provided through containment and isolation of radioactivity in the spent fuel. While radionuclide containment is provided by engineered systems, isolation is also achieved by proper site selection, exclusion distances between the facility and the permanent settlements or protective zones and institutional control to limit the access to the site. It is recognized that impacts on the environment and future generations from AFR storage should be no greater than those that are currently considered acceptable[16]. Bounding assessments are generally made that take into account not only normal activities at the facility but also extreme situations such as system failures and disruptive events.

Licensing requirements should be identified in the beginning of any project to ensure timely compliance and to take this factor into account in selecting technologies. Licensing could involve several regulatory authorities, and the extent of licensing, agencies involved and the coordination effort required will have to be clearly established.

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[15] This is in effect a point of consideration taken into the design of the AFR pool by VNIPIET.
[16] It is also argued that sufficient conservatism should be built into the design to cover any changes to regulations that can be reasonably expected in the foreseeable future.

Licensing of an AFR spent fuel storage facility encompasses some related activities to be affected by the AFR storage, in addition to the AFR storage facility itself, including siting, design, construction, commissioning, and operation:

- The nuclear power plant site where necessary modifications in AR pool may be required to support the AFR storage (such as changes to reactor pools and transportation access). Changes required are often complex due to the reason that these involve an operating facility and require additional licensing effort that involves the operating nuclear power plant.

- The spent fuel transport system, including interfacing systems at the nuclear plant and the AFR storage site, and along the transportation route, which may need to take into account appropriate risk assessments and the involvement of all affected stakeholders (transportation workers, communities along the transportation route, etc.).

License conditions may differ from country to country, but may usually include a few traditional stages, such as:

- Site approval
- Construction permit
- Operational permit
- Decommissioning license.

It has also become normal practice for most nuclear facilities to address in the licensing process the decommissioning and site remediation stages at the end of the facility life.

Each of the licensing stages requires preparation of an appropriate Safety Analysis Report (SAR) to support the application for the relevant stage. The content will reflect the particular stage of licensing, gradually increasing in scope to support an application to operate a constructed facility.

Licensing is often a time-consuming activity due to the extensive analysis required for supporting safety design of the facility. Some planning may be required to assess the timelines and ensure that licensing activities are taken up sufficiently in advance and in parallel with other project activities, where feasible, such that any negative impact on project schedule is minimized.

Usually for a new installation it is necessary to provide an environmental impact study as part of the documentation supporting the request for a license. The purpose of such a study is to ensure that adequate attention is given to the short-term and long term effects on the environment. In most countries, however, the environmental impacts are regulated through a dedicated environmental assessment process that is often coordinated and harmonized with the nuclear licensing process.

In many Member States, a decision to build AFR storage would trigger an environmental assessment process legislated by the government. Environmental assessment is a focused response to the protection of the human and natural environment. The objective in general terms is to inform the regulators if there are significant adverse effects from the project. It is a process that may differ among Member States in its details if not in intent. Due to the long term nature of the AFR storage system, environmental stewardship requirements over the storage period would be a key consideration.

An environmental assessment process would generally include assessments of environmental impacts of the facility over its life cycle from the range of activities involved, primarily construction, operation and decommissioning. Environmental assessment methodologies may adopt an "ecosystem" approach with a focus not only on human terms, but also all valued ecosystem components that form the complex web of the natural environment consisting of terrestrial and aquatic components. Effects of the project on the biophysical environment in terms of land, water, air and noise would be assessed. Methodologies are available to identify areas of potential environmental effects, which may include simple checklists to matrix evaluations, network analysis, and detailed ecological modeling.

The process would be designed to provide opportunities for the public and affected communities to participate in the decision-making processes through consultation, which may include public hearings. It could include elements of other assessments such as feasibility and licensing assessments, but would be in response to different legislative requirements stipulated by the Member States. The environmental decisions to proceed with the project are given by the regulatory bodies in charge of the environmental assessment process.

As discussed earlier, environmental assessment and approvals are country specific. Generally however, the key steps involved are:

- Project notification to the government and the public;
- Preparation of guidelines by the involved ministries (if not already available);
- Preparation of environmental impact statement according to the guidelines;
- Public notification and hearing if required by the regulations;
- Public and government reviews;
- Formal submission of the final statement for approval;
- Government decision.

Preparation of the environmental impact statement is a complex multi-disciplinary activity that may involve diverse activities, such as evaluation of conformity with regulations at all levels of government, involving land use, environmental quality, community socio-economic impacts, and various other legal mandates. The process may include a formal set of evaluations and activities such as defining the proposed project, identifying alternatives and evaluating them, quantifying environmental effects from the project, and public and government consultation. The lead time and strategies for such activities have to be carefully judged and built into the project schedule to avoid unexpected delays and hurdles.

3.3.2. Other regulatory studies and approvals

There may be several studies required both for the selection of technological options and for final approvals for the selected option to proceed with acquisition of the assets. Such approvals may be required from a number of regulatory agencies for different components of the project such as approvals for the site, nuclear approvals, and approvals for transportation. This may vary from country to country [44].

Although ideally necessary staff for regulatory studies could be appointed within the project organization, there may be situations where necessary expertise would have to be sought outside the organization due to the specialized nature of such expertise. Examples of such expertise are thermal analysis of storage systems, site hydro geological studies, fuel behavior in storage, and radionuclide pathway analysis for storage and transportation. A thoroughly reviews of regulatory studies needs to be organized most likely by legislator (but could in preliminary phase be also organized by the applicant). This would also help establishing necessary resources to participate in the selection and approval processes.

Although regulatory approval processes could differ from country to country, generally consist of the following steps:

- Applicant makes a license application to the regulatory body providing necessary analysis (safety assessment reports);
- Regulatory body reviews the application and if acceptable;
- Regulatory body authorizes the applicant to proceed with the activity for which license has been requested.

The license in the case of the storage application could be provided in stages, such as a site license, license to construct, and license to operate. Licenses for transportation of spent fuel normally require license for transportation packages and license for the transportation of spent fuel.

The content of the safety assessment reports and the license application include among other things:

- Description of safety assessment for the proposed facility and site;
- Description of the storage systems and the various safety-related infrastructure with special attention to their design features including design criteria, design bases (including external events), and design and safety analyses under normal and accident conditions (i.e. in terms of committed dose equivalent to an individual outside the site boundary);
- Description of the transportation system and safety analysis of transportation;
- Description of the interfaces at the NPP and their safety analysis;
- Applicable codes and standards;
- Operational plans and plans for controlling occupational radiation exposures;
- Plans for coping with emergencies;
- Plans for radioactive waste management;
- Quality assurance plans;
- Plans for physical security and safeguards;
- Decommissioning plans;
- Financial assurances for the long term management of the spent fuel over the life of the storage system and;
- Plans for defueling of the storage system at the time of disposal or at the end of the storage facility life.

3.4. Project management, quality and risk

A project to provide an AFR facility for spent fuel storage would require proper management service for the implementation of the project. Since the key responsibilities of the nuclear power plant organizations are the operation and the maintenance of the nuclear power plants to generate electricity, project management capability may not already exist within such organizations to handle such projects. This situation may also be true in the case of implementing organizations charged with the task of providing AFR storage. These organizations may acquire such expertise by outsourcing, i.e. through the hiring of project management personnel, depending on the availability of relevant resources. Such staff could include:

- A project manager accountable for the AFR storage project possibly from within the organization to help define a process by which AFR storage need could be resolved;
- External (or internal) expert project management staff to support and manage the project on behalf of the organization; and
- Advisory bodies consisting of experts in different areas to provide ongoing support to the project.

The project management organization, so appointed, will be generally responsible to carry out the initial feasibility studies, technology selection, and selection of suppliers/contractors to design, procure, construct, commission, and train staff for the AFR storage. This organization may include on its staff experienced consultants and architect/engineers (A/Es) integrated in its structure so as to provide appropriate support to the overall project contract strategy.

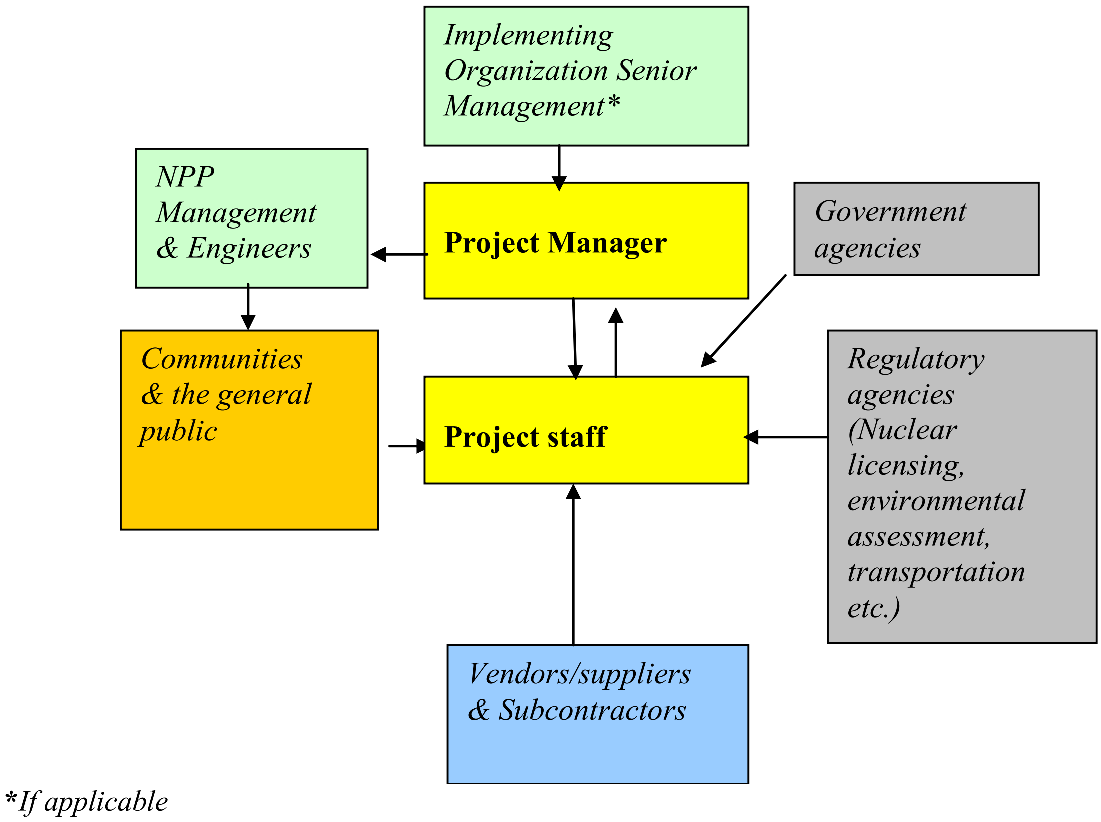

Fig. 1. Partners in the AFR storage project.

3.4.1. Contractual terms and conditions

A contract to perform a project is likely to include the following contents [45]:

- Contractual frame;
- Terms and conditions;
- Financial clause;
- Schedule of delivery;
- Performance;
- Warranty and resolution of conflicts;
- Reporting.

3.4.2. Quality assurance

All activities related to an AFR storage facility shall be subject to a quality assurance program encompassing the entire procurement cycle including the selection process and the various stages such as the detailed design, construction and the operation.

The objective of the quality assurance is to ensure with confidence that the storage system will perform satisfactorily during service. To that end, quality assurance will include all planned and systematic actions necessary to assure that all aspects of the project, covering activities, systems, components and materials meet the quality requirement. The quality assurance requirement shall always be commensurate with the safety and licensing requirements. There are relevant IAEA publications elaborating quality assurance needs in nuclear projects that may be taken into account in developing a quality assurance programme [46].

3.4.3. Stakeholders involvement

Successful AFR storage projects include also successful partnerships between the project and its various stakeholders. The stakeholders include the project staff, NPP management and plant engineers, senior management of the project, regulatory authorities for licensing and environmental assessment, various government agencies that may have a stake in the project, site communities and the general public, vendors and suppliers and their subcontractors (see Fig. 1). Nurturing these partnerships would be an important consideration in many countries for a project and a strong determinant for success. It might be a daunting task to obtain public participation where needed if proper attention is not given to public involvement. Lack of public support could delay or even prevent the implementation of any AFR storage solution.

Decision to construct an AFR spent fuel storage facility cannot be made without the full participation of all relevant stakeholders. Depending on the intent, this could include the need to alleviate local community concerns, concerns of the general public, or concerns expressed at national or even regional levels (if neighboring countries could be affected or international facilities are considered).

Implication of stakeholder involvement must be envisaged at a very early stage as it could deeply influence storage plans, degree of regulatory and political support to storage plans, public and community support, etc. Therefore it is important to identify early who might be the stakeholders involved, and design a process to involve all stakeholders in order to reduce risks related to stakeholder acceptance in various stages of the project life cycle [47].

There may be specific requirements in Member States to involving the public in consultation activities and decision-making. This area is currently subject to many discussions at various local, national and international levels that could result in evolving future requirements [48].

3.4.4. Project risk management

3.4.4.1. Nature of project risks

Exposure to project risk is expected in a project like AFR storage as in the case of any other industrial projects. The project sponsor and project management organizations are accountable to their stakeholders, and have a range of obligations to be met, such as in terms of cost, quality, legislative compliance, safety and environmental protection, financial liability [17] and political support. A mature organization would have a risk management strategy fully integrated into its procurement cycle. Figure 2 illustrates the essentials of the risk management process.

Risks could arise both due to external factors (legal challenges, environmental causes) and internal factors (cost, schedule, safety, quality). A good strategy will have a continuous process to identify, assess and respond to risks during the entire project. Risks are generally the greatest in the early stages of the project and should diminish as the project evolves towards completion. Early risk assessments provide opportunities to take mid-course corrections and allow the project staff to change risk-causing uncertainties into opportunities. Risk assessment carried out prior to award of contract permits the project manager to recognize business and financial risks, and put in place measures to avoid, reduce or absorb such risks [49].

In an AFR storage project, unmitigated risks could lead, in the extreme, to unacceptable situations such as: inability to store the fuel making continued operation of the NPP difficult; serious challenges from the public or other stakeholder groups; inability to finance the project due to cost over-runs; unmanageable safety and environmental issues, or similar contingencies. Without consideration to avoidance strategies, alternatives and fallback positions, risks could have disastrous consequences on the project as well as the NPP.

3.4.4.2. Project risk assessment and management

At the simplest level, project risk assessment is carried out by the project staff through structured discussions about potential pitfalls and unusual occurrences that can be expected in the course of the project. Steps are taken to screen risk situations, quantify identified risks, mitigate, and adapt the lessons learned to future project risk situations. At a detailed level, a variety of comprehensive risk assessment and management methods including statistical and computerized techniques can be used. These techniques help the project team to reduce the drudgery and time required in handling large amount of risk scenarios and data, and to carry out “what if” risk modeling assessments.

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[17] Generally defined by nuclear liability acts of the government.

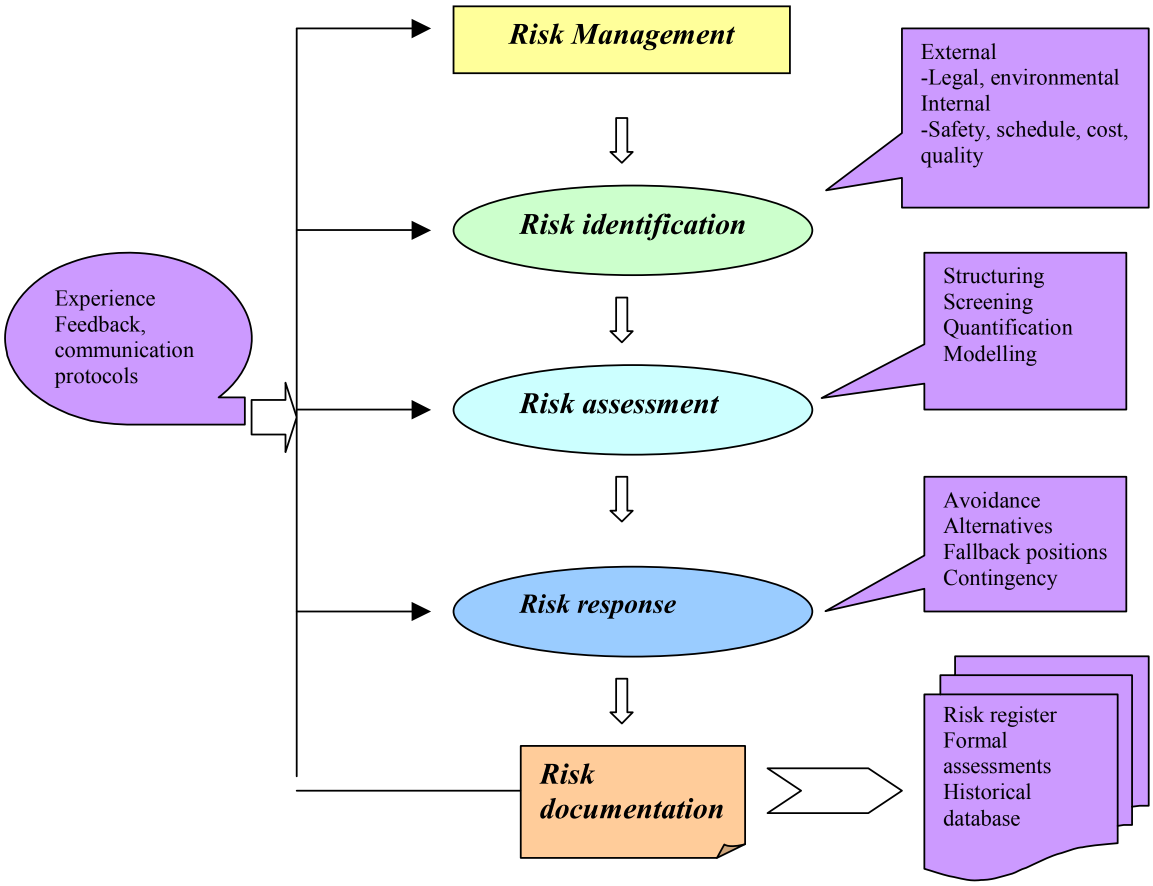

Fig. 2. Project risk management process.

The detail and extent of the risk assessment and management will depend on the complexity of the project, past experience with similar projects and benefits that can be expected from consideration of business risks [50].

Assessment of risks can be carried out from the formative stage of the project to the contractual stage, often with an iterative process through the project life cycle. Formal documentation in a risk register and structured assessments help the project in building a sound risk response capability throughout the project. A historical database of project risk information would be a valuable resource to quickly assess new risks in an ongoing project.

3.5. International obligations and cooperations

Whereas most of the activities for spent fuel storage have been exercised in the context of utility or national framework, some of the businesses in spent fuel management, such as reprocessing, may be conducted on an international level which might expand in the future with the current trends toward globalization of nuclear businesses.

There are a number of issues in nuclear businesses that are also subject to relevant international obligations or cooperation. A good example is the long history of international standards for the transportation of radioactive materials for which a good framework for cooperation has well been established since decades.

3.5.1. International treaties or conventions

There are a variety of existing international obligations that need to be considered. These become particularly important in the case of bi-lateral or multi-lateral arrangements for AFR storage [51].

Examples of various obligations are:

- International Safeguards;
- EU requirements (in Europe);
- Bilateral agreements or conventions;
- International legal instruments, e.g. the Joint Conventions (52);
- Trans-boundary issues and agreements; and
- Other international treaties, etc.

International agreements are often legally binding and can directly influence the project direction and technological choices to be made. With increasing private sector involvement and with globalization of the nuclear industry, AFR storage industry is showing signs of increased international activity and may require greater scrutiny in the years to come.

3.5.2. Regional or multinational approach

There have been a number of past initiatives on regional or multinational cooperation for spent fuel management looking for potential benefits that can be accrued for the cooperating partners. The benefits are especially attractive to the countries (or utilities) of small nuclear programs for which a suitable site to build facilities may not be available or may not be justified on the grounds of economy of scale.

Non-proliferation has also been an important rationale in support of regional or international management of spent fuel or plutonium that was extensively discussed at such forum as INFCE more than two decades ago. However, most of the multinational initiatives have not been successful for one reason or another. The revelations of continuing proliferation of nuclear technologies and materials have led the Director General of IAEA to call for a rethinking of the idea of multinational approach (MNA) in fuel cycle management [52].

4. SELECTION CRITERIA FOR AFR STORAGE OPTION

4.1. Introduction

The selection of technical options for spent fuel storage is a critical step in a project for spent fuel storage, not only because this is important in suitably meeting national policy goals with respect to storage, but also because of the penalties to be incurred afterward by making wrong decisions. It depends on a number of factors of various types, which can be grouped into two broad categories: technical and non-technical [53].

Traditionally, technical factors used to be the primary consideration in the selection of options. In an increasing number of countries, however, some non-technical factors have come into play with growing importance in the decision-making. A good example is the public involvement in the decision process that can bring influence to the selection of options [54].

An issue that makes the selection difficult in particular is the uncertainty of the future. These uncertainties relate to time concerns, nature of the final step in the management of spent fuel, and issues related to long term behavior of spent fuel and storage structures. As a specific example, as uncertainty grows with time, the meaning of discount rate wanes out as a function of time and economic comparison of options on a net present value basis becomes less certain and of less value as an indicator. To take into account the future uncertainties, project risk analysis and contingency planning are often required for long term issues like spent fuel storage or disposal.

There is a diversity of available methodologies, which provide a framework for the selection of AFR storage options [55]. Member States generally customize such methodologies for their own circumstances. It is not possible here to examine the various methodologies used by the numerous projects in the Member States. In this publication however we provide what we consider as in the methodology for selecting an AFR storage option, focused among other things to technical considerations in the selection of options and tendering and contracts, although other issues such as those of a social and ethical nature and economics have been touched upon. This information can be used as a framework and enhanced or altered as required according to the specific situations of the Member States.

4.1.1. Need for selection criteria

In the previous section, we discussed the various aspects that need to be identified at the start of a project for AFR facility. The project organization can identify the technology options that are available and generally develop some preliminary ideas as to how they can be incorporated into an AFR storage facility design or adapted to conform to the needs. However, to make a selection, it is essential to carry out a feasibility assessment to narrow down the choices available to a few most suited choices (about 1-3 options).

Final selection of the technology option can often be left to a later stage, i.e. to the time of selecting a supplier. Taking more than one technology option to the bidding stage facilitates larger participation from the bidding community, often beneficial to the project in terms of supplier selection.

The feasibility assessment usually tends to become a comprehensive study of the options available and an evaluation and screening of these options using a consistent set of criteria. In cases where the initial choices are many and somewhat poorly defined to start with, the feasibility assessment is carried out in stages such that the large number of choices is initially screened with a preliminary set of selection criteria at a conceptual level to yield a smaller set of alternatives. These are then further narrowed down with criteria specifically fine-tuned towards short-listing the options or the final selection.

To acquire the AFR storage system that is most appropriate for a given situation and that will interface best with the customer needs and requirement, the selection criteria for the AFR storage must be carefully established. The range of criteria must be broad enough to be of use not only in the comparison of technologies, but also in the selection of the AFR storage facility. These may include besides technology, site, transportation and various infrastructure which are sometimes critical to successful implementation of the spent fuel storage project in question.

4.2. Identification of criteria for AFR storage facility selection

The criteria for selection need to be effective and pertinent to the selection process. These indeed are detailed aspects with which one should be able to discriminate various options and be able to rank them after evaluating their merits and demerits. All factors affecting these items must be identified and described to such a level where the different storage system alternatives could be compared on a common reference.

This section provides a broad overview of the various areas for establishing criteria for selection of a most appropriate facility for a given project. This overview is aimed at highlighting the detailed requirements in each area, which can then be optimized and formulated so as to be applied as criteria and their detailed attributes in the selection process. The methodologies that are often used for such a formulation and the selection process are discussed in the next section (see Section 5).

4.2.1. Technical criteria

The key selection criteria relate to the acquisition of the site and transportation routes, safety and licensing, system flexibility in terms of design, construction, operation and maintenance, environmental impacts, decommissioning and of course associated cost which is often a determining criterion once all the other requirements and criteria are satisfactorily met.

4.2.2. Site conditions

Siting of the AFR facility is a critical issue to consider from the beginning, because of its important implications in various aspects associated with project implementation. The purpose of the site selection would be to ensure that a site that is selected is acceptable, not only from safety and environmental protection considerations but also from all other aspects such as access, transportation, and community and stakeholder acceptance. The site conditions could have some distinctive features applicable to the selection of storage options.

In the majority of AFR projects today, storage facilities are built on the NPP sites for various reasons. In this regard, selection of an off-site on a Greenfield location does not have much relevance in the reality of today.

4.2.2.1. Information on the site

Sufficient site investigation and assessment work requires to be carried out to quantify the characteristics of the site. The site information can then be used to compare the technology options available in terms of their siting advantages. Normally this would be carried out as part of a site characterization plan tailored to compile all necessary information on the site.

If the site has already been selected then the site-related factors affecting the storage technology selection must be identified. If the site has not been selected, a selection process could be developed incorporating potential technology constraints and the site selection carried out with such a ‘technology-based’ selection process (issues associated with non-technical factors are reviewed later).

4.2.2.2. Approaches to site selection

To secure a site, the project organization would carry out a site selection process based on site visits to potential sites, investigation of all site-related information, and consultation with affected communities and other stakeholders.

The aim of the site selection process would be to formulate a recommendation as to the best site for the AFR storage facility for approval by the proponent (NPP or WMO) and for land acquisition if new land is involved. Regulatory approvals may be required during the site acquisition process.

Traditional approaches of siting which rely heavily on scientific and technical criteria are now yielding to cooperative approaches in a growing number of countries where a comprehensive program for the public outreach and consultation form an important part of the selection process and sites are sought in cooperation with volunteering host communities. In cooperative approaches, regional information meetings are first held to inform communities about the proposed facility. Those communities that show an interest in hosting the facility enter into consultation with the project organization. Screening of potential sites is then carried out and a site selected with community involvement throughout the screening process (See Fig. 3).

4.2.2.3. Site selection considerations

- *Accessibility and transportation conditions*

The accessibility of the site, availability of routes and selection of modes of transportation, availability of the infrastructure, and various other site characteristics of importance to AFR storage design shall be considered in the screening process. In the case of an existing site (such as a nuclear power plant site), locating a facility shall take into account existing site layout and any interference with the existing facilities and ongoing operation. In the case of a new site, additional factors such as community and public preferences have to be taken into account. Suitable modes of transportation (e.g. by road, rail or water) would have to chosen. An appropriate transportation corridor may have to be developed in either case if there is none available.

- *Land size*

The area selected for the storage facility shall be sufficiently large enough to store the anticipated amount of fuel and all ancillary equipment and facilities. Provisions shall be made for any planned expansion. Some exclusion area, as determined by nuclear regulations in the Member States, may be required. Site-related impacts such as land-use impacts, socio-economic impacts, traffic, and other infrastructure, need to be identified. Also important would be land use and buildings acts pertaining to a site that would be needed in assessing the constraints on facility construction at a particular site.

The size of a land area could be a significant factor for some countries, especially in highly populated places, where land price is relatively high. In such sites, compact storage options would be preferred and the factor of land size would count much in the selection weighting. This condition could also drive to a consideration of building the storage system below surface in particular in a tunnel under hills or mountains, where geographical conditions are favorable.

- *Site characteristics*

For the study of public safety and environmental impact of the facility, knowledge of the basic site design factors is required. It should include site characteristics related to the geology, soil bearing capability, topography, hydrology, hydrogeology, meteorology, demography and civil design, including potential external natural and human-induced hazards particular to the site. Population and its distribution at the site would be an important consideration in terms of the ability to carry out emergency planning activities at the site (easier to implement such measures in less populated areas than in urban centers).

- *Protection of spent fuel*

The AFR storage has to be protected against external threats and environmental detriments of which impacts need to be eliminated or minimized. External hazards to be considered should include both natural phenomena (e.g. earthquakes and surface faulting, floods, winds, snow, ice and lightning) and man-made hazards (e.g. aircraft crashes and chemical explosions). Foreseeable evolution of these phenomena over the contemplated storage period in terms of frequency and severity would be necessary to assess the potential impact of such hazards. This is an issue that could make the protective conditions of the site or the storage options to be counted in the selection criteria. Placement of spent fuel storage system underground built in a tunnel, in case of favorable geological and geographical conditions, could be a consideration that could also save land requirement as mentioned above.

In terms of shore regions of coastal and littoral sites, potential for tsunamis or seiches and potential failure of water control structures such as dams and dykes would also be important.

Site conditions, processes and events described above will impose certain constraints on the AFR storage system. They may also merit consideration as screening criteria for technical options. The objective is to establish the normal or average situation and to identify the credible extreme events to be considered[18].

- *Collocation with other nuclear facilities*

If a spent fuel storage facility is to be located on the same site as, or adjacent to some other existing nuclear facility, the two facilities may share common services (e.g. electricity, water, access) if such sharing is acceptable. In general, however, the safety systems and safety related systems should not be shared between facilities, except in special circumstances approved after a thorough analysis.

Where the spent fuel storage facilities are located in the proximity of other industrial facilities (like nuclear power plants) the cumulative dose effects of the collocated facilities should be considered. Generally, these should not exceed allowable limits for individual facilities.

- *Centralized vs. decentralized site*

As mentioned above, it is to be noted that most of the new facilities for AFR storage of spent fuel are built on NPP sites (or on a contiguous piece of land acquired) for technical or non-technical reasons. This means a number of decentralized AFR facilities for storage of spent fuel at reactor sites until the spent fuel inventories are sent to further destinations. The issues associated with locating sites for spent fuel storage gives rise to a question on an optimal strategic approach on a national level for countries with a large scale deployment of NPPs, as was discussed in the literature [56].

The holistic rationales behind the comparative aspects between the centralized vs. decentralized siting may also be applied beyond national dimension to a multinational or

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[18] The IAEA documents on the siting of nuclear power plants, and on the Safety Assessment for Spent Fuel Storage Facilities contain criteria and methods that could be generally used in siting a spent fuel storage facility.

regional level between countries sharing common interest in such approaches. In fact, this topic has been examined by IAEA from time to time for various aspects on radioactive waste repository, spent fuel storage, and fuel cycle facilities.

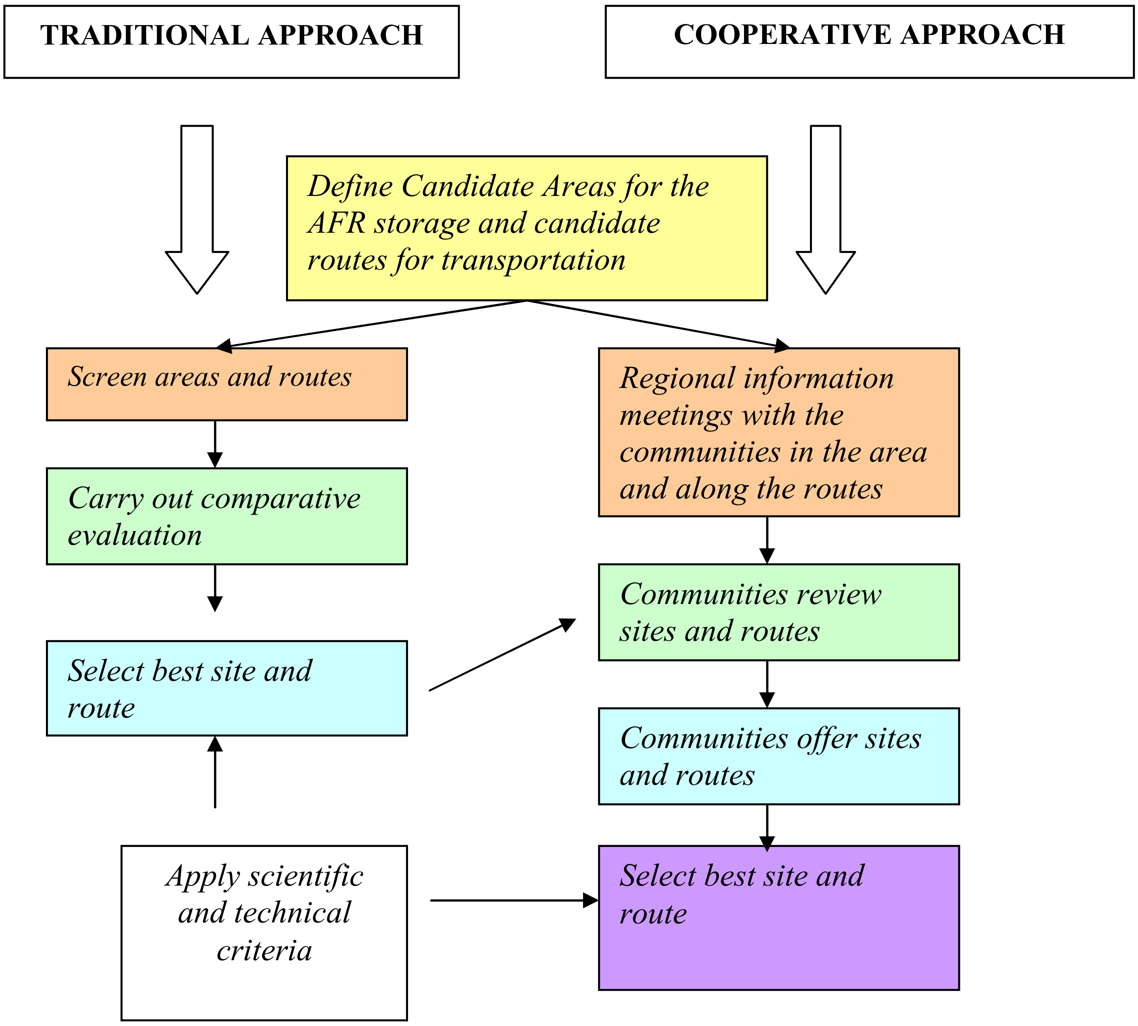

Fig. 3. Approaches for AFR storage siting and transportation route selection.

Traditional approaches may suffice in instances where suitable sites already exist and community involvement may generally not be required.

In most instances where new sites have to be acquired, however, the cooperative approaches are preferred or mandatory (see Section 6). In this approach the site selection process relies heavily, after screening of the candidate sites, on extensive communication with the communities that may be willing to accept such a facility.

These approaches are suitable not only for an AFR storage site but also for making decisions on acceptable transportation routes for spent fuel. Transportation is often a formidable task in terms of public acceptance and requires considerable public and community interaction.

4.2.3. Safety, licensing, and security

Ensuring safety in spent fuel storage is the very basis of setting up criteria for licensing an AFR facility.

4.2.3.1. *Safety*

The main nuclear safety issues of an AFR storage facility are: protection of fuel integrity; heat removal; radiological shielding; containment; environmental protection; assurance of sub criticality, and safe management of radioactive waste.

The underlying policy is to reduce radiation exposures as low as reasonably achievable (ALARA) social and economic factors taken into account and take measures to avoid, reduce or eliminate any adverse effects on the environment and the public as well as to workers of the facility from the storage activities during the storage timeframe. The key attributes in ensuring safe performance of the overall storage system are briefly discussed below.

A set of IAEA safety standards [57] addresses safety issues all along the life cycle of nuclear facilities and subsequent period of institutional control until there is no significant residual radiation hazard [58].

4.2.3.2. *Licensability*

Licensing of spent fuel storage facilities differs from country to country and specific criteria apply for the selection of the storage system. Key regulations in most Member States deal with allowable doses to the public and workers generally based on internationally accepted recommendations on radiation protection such as those of the ICRP.

A storage concept that has already been licensed, for example in the country of origin, could make the licensing procedure easier, since compliance to regulatory criteria has already been tested in the original country. Existence of an operating prototype or demonstration facility or facilities could also be desirable, since prototypes provide an opportunity to observe actual effectiveness of the design in meeting safety objectives.

Relevant IAEA publications are available to provide guidance on the compilation of the Safety Analysis Report and on the design and operation of spent fuel storage facilities, providing detailed information for the licensee and for the authorities [59].

4.2.3.3. *Security*

This issue has become a topic of acute debate on nuclear facilities, including spent fuel storage, especially since the event on 11 September 2001. Apart from the nuclear power plant itself, effects of terror attack on the AFR storage facilities of wet and dry types have been in evaluation in a number of studies. In comparison to pool type storage facilities, dry type facilities are evaluated to be largely resistant to such damages as a large plane crash [60].

It is anticipated that the issue of protection from air crash will be increasingly considered in the future designs of spent fuel storage systems as a security measure.

Recent concerns on security measures for protection of spent fuel have prompted a renewed interest on the possibility of placing storage facilities underground. An example is the underground version of the Holtec's HI-STAR 100, for which licensing is being discussed with USNRC. Such possibility is being considered even for nuclear power stations [61][62]. This is an example that shows that future evolution of requirements and technologies will bring important impacts on spent fuel management options including storage.

4.2.4. System flexibility and adaptability

The processes for design, construction and fabrication directly affect the project expectations in terms of system flexibility. It is necessary to develop suitable selection criteria to compare options on the basis of these expectations.

The criteria should encompass the diverse design, construction and fabrication processes that are likely to be offered in the bidding process such that the most suitable processes are chosen.

With respect to the design, construction and fabrication, the following factors may need to be considered in acquiring the most flexible storage system:

- Overall constructability;
- Initial construction (modularity);
- Ease of expansion and technology availability;
- Possibility of changing the vendor;
- Participation of local or national contractors;
- Timescale of construction and ease of fabrication;
- Location of fabrication (e.g. on-site or off-site); and
- Potential impacts on NPPs (such as shared services in case of NPP sites).

Multi-purpose technologies (i.e. a single canister design for storage, transportation and disposal) have also been studied in some countries. Despite the benefits expected from standardization by the multi-purpose canister (MPC) concept, the uncertainty of the final form of the disposal package has deferred any definite standardization of concept for the MPC design.

4.2.4.1. Constructability, modularity, and ease of capacity expansion

- *Constructability*

Overall constructability refers to the ability to construct a particular facility in a given context. This could depend on a number of factors, such as compatibility with local construction practices and experience, problems that may be posed by the component size or weight, problems interfacing with existing systems (i.e. nuclear power plant), ability to fabricate or manufacture locally (e.g. containers manufactured in-situ).

- *Modularity*

Modularization of storage systems in separate units has an important implication in terms of several associated criteria for selection of options.

Initial construction is determined by the modularity of the system. It could be an important factor especially from the initial cost point of view. The characteristics with respect to modularity enable us to "start small" thus improving the affordability by minimizing the up-front cost outlay required to build the facility. The financial and technical risks are also minimized.

The modular approach for AFR storage could also provide the flexibility to be resilient to some unforeseen changes that could take place in the future including changes to fuel characteristics, containers, regulatory requirements, and the knowledge base of storage systems. A modular approach may also allow future improvements in storage systems themselves to be accommodated based on lessons learned in the initial stages and from feedback from storage operations.

- *Ease of expansion*

Ease of expansion refers to the possibility of further facility expansion with time, with extension of the facility done in different stages matching the spent fuel production rate and the amount of the spent fuel intended to be stored in the facility.

This aspect of modular systems has largely contributed to the mitigation of a concern on storage capacity shortage of a number of utilities in the sense that modular casks, for example, can be added as needed for additional capacities, provided relevant licensing and public acceptance are assured.

4.2.4.2. Adaptability to future needs

Adaptability relates to a range of future possibilities that may become reality as the national spent fuel management programs evolve over time. Such possibilities may include among other things: potential changes to storage period due to policy changes, changes to regulations in nuclear licensing and environmental impacts, evolving security and safeguards issues, and changes to anticipated behavior of storage structures and spent fuel. Some specific examples would be the unexpected need to reline wet pools, similarly need to refurbish storage containers, or make other system modifications as may be required for a variety of reasons.

In the selection of the technical option, although it may not be possible to determine every possible scenario, some overall consideration of the selected option ability to adapt to potential future circumstances would be useful. Such adaptability can be inherent in the design of some technical options, in others could be retro-fitted with simple modifications, design allowances, or change to operational procedures. Serious lack of adaptability could potentially lead to expensive solutions in the longer term.

In spite of the significant benefits anticipated by standardization of container design for dual or multiple purposes, the absence of the disposal package design and its compatibility with existing systems is a pending issue to be resolved in the future.

Ability of a site to host a facility in an underground setting may have advantages in some situations. Underground facilities may provide better protection against surface hazards at the expense of some extra cost and may have better advantages such as shielding; containment and security (see section 5.4.3).

4.2.4.3. Changing vendors

Possibility of changing the vendor could be an important factor to avoid dependence on a single vendor in the implementation of a facility. Participation of local or national contractors is also important from the price point of view, as the local labor is usually cheaper than the one acquired from abroad. Multiple vendors may better suit the owner's requirements in some cases in meeting supply constraints. There may also be instances where a vendor-based procurement (for example for containers) may have to give way to on-site manufacture by another vendor or by the facility owner to meet logistics or supply constraints.

There may also be other aspects particular to local economy that can influence the participation of the local or national contractors (such as foreign exchange reserves of the country and unfavorable exchange rates).

Financing conditions, quality compliance, and diligence may also need to be considered.

4.2.4.4. Construction timescale

The timescale of construction and the ease of fabrication may vary amongst storage technologies. The choice of storage technology should take into consideration such differences.

The technology should be durable reducing the need for retrieval, repacking, and re-storing of the spent fuel in succeeding facilities within the storage timeframe. More durable technologies generally tend to be difficult to fabricate (thicker containers, more expensive materials) and the selection of an appropriate technology may need a balancing of these conflicting requirements.

4.2.4.5. Fabrication site

Another factor could be the location of the fabrication. Fabrication of storage containers for example could be done either on-site or off site. On-site fabrication brings in the need to have expensive manufacturing facilities along with AFR storage, but would better provide for timely supply of containers as required. On the other hand, off-site fabrication of containers would eliminate the need for manufacturing facilities, but could be more subject to supply disruptions.

4.2.4.6. Impact on site services

Where NPP sites are considered for AFR storage, construction could have impacts on site services and ongoing operation of the facilities that need to be taken into account. Such impacts could relate to scheduling of fuel handling activities at the NPPs, (i.e. interference with core fuel handling, crane unavailability), common transportation corridors for NPP equipment and the spent fuel transporters, management conflicts, and worker-related issues.

4.2.5. Operation and maintenance

The operability and maintainability of storage facilities are important selection considerations.

Operability generally refers to the ability of the facility to be operated for specified periods of time without degradation and the need for repair or maintenance (also referred to as reliability).

Maintainability refers to the ability of the facility to be restored within a specified time to its full performance. Facilities should also be easily operable without the need for elaborate systems and procedures. Facilities should be easily maintainable without the need for complicated maintenance requirements.

The key attributes in terms of operation and maintenance for AFR facilities are:

- Operability and maintainability;
- Simplicity;
- Passive features to minimize operation and maintenance;

- Auxiliary systems to support operation;
- Trained personnel; and
- Safeguards monitoring.

4.2.5.1. Technical features of operation and maintenance

- *Simplicity*

Storage systems are recommended to be simple to operate. Systems that are intricate are generally more prone to failures, and demand lot more attention to keep them in working condition.

- *Passive systems*

Storage systems should be made as passive as possible to minimize operation and maintenance efforts and reduce human resource. The need for active process systems such as cooling and ventilation systems, water purification circuits, increase operation and maintenance needs should be minimized.

- *Auxiliary systems*

The necessary auxiliary systems shall be defined such as mechanical services, communication, control and instrumentation, fire protection, waste treatment, lighting and area and personnel monitoring. The needs for auxiliary systems are usually interrelated with the technical features mentioned above (simplicity and passivity).

Although auxiliary systems cannot be completely eliminated, the extent to which these systems are necessary can potentially increase operation and maintenance demands.

4.2.5.2. Trained personnel

Amount of trained personnel required and qualifications needed to operate the facility shall be considered. The number of staff increases operational cost of the facility.

4.2.5.3. Safeguards monitoring

Ability to implement safeguards requirements could be different among technologies. Where the spent fuel storage design is placing the fuel in a sealed containment, a means for safeguards monitoring or verifying the integrity of the sealing operation should be incorporated by design without impairing the integrity of the fuel.

Dry storage modules for spent CANDU fuel have, for example, a re-verification tube in the concrete wall (to insert a monitoring device) which might be a point of consideration in the future design of storage systems if it facilitates the safeguards activities.

4.2.6. Decommissioning

Most nuclear facilities are conceived and licensed with a lifecycle management including decommissioning at the end of life, for which relevant requirements such as financial and institutional provisions are set up [63].

4.2.6.1. *Design provisions*

A spent fuel storage facility should be designed so that at the time it is to be decommissioned, the decontamination and dismantling of structures and equipment together with the removal of waste can be facilitated, the quantities of waste arising can be minimized and occupational exposure can be reduced to as low as reasonably achievable. These design provisions shall be consistent with the safe and efficient operation of the facility.

4.2.6.2. *Decommissioning plan*

A preliminary decommissioning plan for the AFR storage system should be prepared as part of the planning and design of the facility. This plan should be able to indicate that the facility could be decommissioned meeting all safety and environmental requirements.

Data that are important from the decommissioning point of view should be identified. Such data could include records of occurrences that may lead to escape of radionuclides into structural materials.

Based on the AFR storage design, the detailed decommissioning schedule can be developed in terms of estimates of volumes of activated and contaminated materials or waste arising from decommissioning. As-built drawings of the facility and records of changes made to the facility during operation would also be important for decommissioning. This implies the importance of record keeping over the lifetime of the facility until the decommissioning of the facility is expected to commence [64].

4.2.6.3. *Decommissioning estimates and funding*

Estimates of the cost of the decommissioning activities could be an important factor in selection of an AFR facility. Inadequate attention to facility design could lead to radionuclide release into the structural materials, the facility and the site, making decommissioning much more expensive due to remedial activities that may be required at the time of decommissioning.

The decommissioning plan should also describe the funding arrangement for future activities involved in decommissioning. Such funding could be assured through a variety of methods, such as NPP's liability management programs, prepayment of money into a dedicated decommissioning fund or other surety methods, such as insurance or other financial guarantees. Although funding would generally be customer's responsibility, the type of facility design may influence the extent and amount of funding required [65].

4.3. Environmental impact and regulation

4.3.1. Environmental impact

Environmental impacts relate to the protection of the human and natural habitat. Processes for their assessment are developed in most countries as a deliberate and focused response to environmental pressures arising from development of new nuclear facilities.

Legislative and policy bases, conceptual framework for assessment and methodologies, and relationship between assessments and decision-makers differ among Member States and cannot be generalized. There could also be conventions on environmental impact assessments among neighboring countries in a trans-boundary context that may have to be taken into account. Most environmental assessment processes, include as a minimum, environmental effects from the project during the construction, operation and decommissioning phases of any undertaking. These should be evaluated and checked against the established criteria such as radionuclide releases, dose rates, heat emission and various environmental regulations applicable to the Member State. It suffices here to say that these assessments could influence the selection process and should be fully taken into account in the development of environmental criteria for selection.

In order to protect the public from radiological consequences of radionuclidee releases, both normal operation of the facility as well as operational transients or accidental situations would have to be considered.

4.3.2. Environmental regulation

Environmental regulations generally deal with a range of issues, such as biophysical impacts on biota, socio-economic impacts, and effects on environmental quality (such as of air and water) from any proposed undertaking.

Environmental assessments are interdisciplinary effort covering natural and social sciences and often consider many unquantifiable factors.

4.3.3. Assessment of environmental impact

Environmental assessments differ from country to country, and have been rapidly evolving due to environmental movements and public concerns in various countries. The assessments lead to a formal statement to the public based on the government enactment or guidelines on the effects of the undertaking, and often include public hearing. It would be necessary to thoroughly review the assessment needs in advance such that necessary environmental criteria for the selection process can be developed.

4.4. Economic considerations

Economics has been recognized as one of the key factors to be considered in the selection of a storage option. According to the widely adopted "polluters pay" principle, spent fuel is perceived as a liability factor in the cost side of the balance to the producer of spent fuel, i.e. utilities. However, the same expense of the NPP operators is the source of income to the business which provides great services in the equation of economics.

Because of the relatively long time span for spent fuel storage at AFR facilities (which stretches for several decades or could even stretch over several centuries), the time factor plays a significant role in the economic analysis [66].

4.4.1. Life cycle costs

Cost analysis is required for the comparison of options, both in terms of static engineering-economic cost estimates and project financing assessments.

A proper cost analysis of the various options requires identification of the detailed costs. These costs may be grouped into different categories and described in such a way that they can be applied to all the options. Consideration of the cost uncertainties is also essential in making proper comparisons of the competing storage options. The main cost categories are:

development costs (not normally required in case of purchase), capital investment cost, operation and maintenance (O&M) cost and decommissioning cost.

4.4.1.1. Capital investment cost

Capital investment cost can be defined as those expenses incurred towards capital assets from the time the owner decides to construct the facility up to the time the facility is retired from operation. Most of these costs however occur in the period starting with the time the decision is made to build the facility to the time the facility goes into operation. These costs could occur not only at the AFR storage facility, but also at the NPP because of the plant modifications that may be required to allow unloading of fuel from the AR pools. There may be opportunities for cost sharing among NPPs because of the possible joint ownership of the facilities involved in unloading spent fuel from the pools. The transportation system will have its own capital cost component if produced by investment costs.

Specific components of capital investment cost may include land acquisition, site preparation, infrastructure and site improvements, design and engineering, licensing, building and construction, process equipment, services (like water, electricity, etc.), commissioning and all other indirect expenses incurred during the implementation including, project management, quality assurance, insurance, taxes, public relations and other overheads.

With a staggered implementation of a modular storage facility, capital cost will arise at each extension of the facility, spread over the capacity expansion periods.

4.4.1.2. Operation and maintenance (O&M) cost

Operation and maintenance cost can be defined as all expenses associated with the utilization of the facility. These costs are relatively low for the storage system employing passive features.

O&M cost is usually specified on an annual basis. This cost may include direct and indirect labor (including administration and overheads), spent fuel transport and handling, material and goods required for operation, maintenance, services (like water, electricity etc.) support requirements (like environmental monitoring, physical protection, safeguards, etc.), waste conditioning and disposal, and insurance. Cost attributable to personnel radiation exposure is often included.

Cost of the fuel loading operations is generally considered to be part of the operational cost. Regarding the cost associated with the unloading of the storage facility, it can be counted as part of the operational cost or as part of the decommissioning cost.

4.4.1.3. Decommissioning cost

Decommissioning cost can be defined as all expenses associated with decontamination, dismantling, decommissioning waste management and site restoration subsequent to the spent fuel removal from the facility. Once all radiological materials are removed, the license of facility operation can be terminated and the site restored to other uses.

The factors affecting decommissioning costs are:

- Regulatory criteria (dose limits, criteria for exemption and radwaste disposal, etc.);
- Facility characteristics (scale, complexity, contamination, etc);

- Technical approach and plans (strategy, scope, etc);
- Infrastructure (availability of technology, and resources, site conditions, disposal conditions etc.); and
- Site environmental remediation requirements.

Decommissioning costs are often assumed 2~10 % of the base capital costs depending on the characteristics of the facility.

Since decommissioning costs occur usually far in the future, their present values are relatively minor and may not significantly influence the fund to be set aside, especially when the discount rate is low.

4.4.2. Cost analysis methodology

Among comparable spent fuel storage concepts, the life-cycle cost of each option may have a strong influence on the selection process. Life cycle costs refer to costs of all facilities and activities over the life of the facility in current value, often expressed in Levelized Unit Cost or LUC (expressed generally in US $/kg of fuel).

Computation of life-cycle cost for a system encompasses the size, type, and time distribution of the initial investment required the cumulative annual operating costs, and the costs to decommission the facility at the end of the operating life.

When comparing life-cycle costs, it would be important to have the cost bases tied to a common point in time, and to take into account the time-distribution of expenditures and the time-value of money (i.e. the Net Present Value of life-cycle expenditures).

4.4.2.1. Net present value (NPV)

The NPV (net present value) of current and future expenditures takes into account the fact that money not spent initially can earn interest until it is spent, assuming that the net rate of interest (i.e. Interest Rate - Inflation Rate) is greater than zero during the period under consideration. The NPV can be formulated as under:

$$NPV = \sum (C_i/(1+d)^i)$$

Where C_i is the cost or expenditure in the i-th year, d is the discount rate or the net rate of interest, and i is the year index.

Thus, future expenditures are discounted by the net rate of interest, reducing the size of their contributions to the net present value of the system life-cycle cost. However, the benefits of delayed expenditures can be reduced or possibly eliminated if the annual operating costs of the delayed system are significantly larger than those of a system implemented earlier.

4.4.2.2. Levelized unit cost (LUC)

The levelized unit cost (LUC) of storage is obtained by levelizing, the life cycle expenditures of the spent fuel stored in the facility and the storage fee, and is given by the following relationship:

$$LUC = \sum (C_i/(1+d)^i) / \sum (M_i/(1+d)^i)$$

Where M_i is the amount of spent fuel transported to the facility in the i-th year.

The cost analysis methodology provides the tool to comprehensively review and fully capture all the cost factors related to an alternative.

4.4.2.3. Factors of economics

Besides nominal factors such as the NPV and LUC, there are several other points of interest that would become obvious with a comprehensive analysis. Among these would be the economy of scale or cost improvements that arise by expanding the size of the facility, economy of scope achieved by such factors as shared services and resources, and cost improvements due to experience feedback, R&D and repetition of established designs.

4.4.3. Additional cost considerations

Detailed cost estimations should be prepared in the context of any decision analysis exercise on the choice of technological and management options, using a consistent methodology for ease of comparison.

4.4.3.1. Additional costs

The direct costs of site acquisition, construction, operations and maintenance, and transportation are not the only relevant cost factors for an AFR facility for spent nuclear fuel. Depending on the location of the preferred site, there may be substantial additional costs related to social impact mitigation, property value protection, training and compensation schemes, and so forth. Such costs should be included in the overall estimates so as to assure a realistic basis for the comparison among options (including both technologies and sites).

4.4.3.2. Financial factors

Typically, management options for AFR storage of spent nuclear fuel all have long timeframes. It follows that estimates for costs, cash flow, financing, and contingencies (provision for cost escalation, etc.) will be projected far into the future. Governments, regulators, and private industry must all be involved in devising appropriate contribution schedules and acceptable forms of long term financial security for such facilities.

The financial health of a supplier would be an important consideration in ensuring that the supplier is not likely to face financial crises such as bankruptcy, during the course of the project.

4.4.3.3. Long term considerations

It may be necessary to review future costs and their timing based on the logistical considerations of future handling. A total time period for analysis should be chosen that allows ease of comparison among the competing options, where both initial expenditures and required later expenditures are included. Careful attention should be paid to the number and complexity of any waste repackaging or facility reconstruction needs, relevant to each particular option. There may be costs associated with the eventual retrieval and transport of spent fuel from the storage facility. Since transportation costs may vary with the type of option, they should be included in the overall estimates for each option.

4.5. Public acceptance/involvement

The can be a variety of complex public acceptance issues of non-technical nature that arise in the process of project implementation, with significant consequences on the success of a project[19].

5. PROCESS AND METHODOLOGIES FOR SELECTION OF AFR FACILITIES

This section will discuss briefly aspects of the body of knowledge available in the industry and the profession of project management which are adapted in the selection of AFR storage facilities, not only in terms of the traditional practice of project management but also in terms of the status of understanding as it relates to a decision-based selection methodology.

5.1. Generation of spent fuel and need for storage

The procurement cycle for an AFR facility for spent fuel storage is initiated generally by the nuclear power plant (NPP) owner (or operator), who recognizes the need and has the authority and resources to fulfill such a need.

The operators of NPPs, as generators of spent fuel, are usually the appropriate organizations to initially define the problem such as in terms of legislative and policy basis, operations outlook, fill dates of AR pools, AFR storage requirements, timing and preferred sites and technologies that may be available within the organization and ensuring that necessary R&D information is available or could be found through international cooperative programs (such as the IAEA's SPAR Programs). Any implementing organization could also take up this role on behalf of the NPPs if so charged, in which case, the NPPs would be obliged to provide necessary support to the contracted organization.

According to the 'polluters pay' principle, the nuclear power plants take the necessary steps to meet the need and generally become the project sponsors or proponents for AFR storage as well as its ultimate customers and operators.

Because of the long-range system planning and strategic studies normally carried out by most NPPs on a continuing basis, the need for AFR storage is well foreseen in most of these organizations, and need assessment studies for AFR storage are often initiated well in advance of the project, often carried out on an annual basis.

5.1.1. Institutional responsibility

In some Member States, however, responsibilities for spent fuel storage are set up, often assigned on a legislative basis, to a specially established organization which is charged with the task of spent fuel management [67].

Private sector companies could also provide such a service, depending on the institutional arrangement in the Member State. These organizations then take over the "ownership" for the spent fuel to be managed and act on the behalf of the nuclear power plants in planning and acquiring AFR storage and eventually operating the AFR storage system.

These organizations generally fall into three categories:

[19] The importance of this and associated aspects have become so critical to many projects in Member States that a separate discussion is provided in more detail in Section 6.

- Government-administered organizations;
- Government-owned companies; and
- Private sector companies and consortiums.

5.1.1.1. Government-administered organizations

In the case of government-administered organizations, government may directly take title to the spent fuel and take direct control of the spent fuel management programs, including not only disposal but storage as well. Such organizations provide centralized government control both in terms of implementation and regulation and provide a suitable organizational system for Member States where a highly qualified and motivated private sector specialized in spent fuel services may not have well been developed. However, the globalization of market economy has reached such an extent that setting up the private sector for spent fuel storage services may be feasible in an increasing number of countries.

5.1.1.2. Government-owned companies

In the case of government-owned companies, organizations could be set up by the government along the lines of business corporations, incorporated as a legal entity, which take direct responsibility for the development of the facilities under the broad direction of the government. Such organizations provide a strong alternative to direct management by the government with the flexibility to be organized as a company and with sound financial backing from the government.

This arrangement assumes taking over of the title of the spent fuel from the generator (utility) and levying a relevant fee needed for the project implementation by the company. Governments, however, would set up an oversight mechanism and reporting relationships to such companies including approval mechanisms to use fund dedicated to this purpose. With such arrangements and close control, these companies function independently on daily basis.

5.1.1.3. Private sector companies

Private sector companies could form themselves solely for the task of spent fuel storage, or alternately companies involved in similar technology businesses could expand their product lines to include spent fuel storage. Utilities could also form a consortium to establish a spent fuel storage business in the private sector. As in the case of radioactive materials transportation, which in most instances is provided by the private sector as a service business, the private sector could provide spent fuel storage as a service business to utilities or governments.

In an evolving spent fuel storage business, and in the light of current market globalization, the private sector could play an increasing role and perhaps have the maximum flexibility to function in a globalized market. Competitive business attitudes are generally considered favorable in many countries as evidenced for example by the recent Regulation Law (1999) in Japan, which allows opening up of new business ventures to provide the storage service company, The recyclable Fuel Storage Company has recently been established, based on this law, by joint investment from Tokyo Electric Power Co. (Tepco) and Japan Atomic Power Co. (Japco). The company will build and operate a joint spent fuel interim storage facility with a capacity of 5 000 tHM at Mutsu site (Hokaido, Japan) with a view to provide storage service for some 50 years.

In all these organizational arrangements, the fundamental need to meet regulatory and environmental requirements, and to obtain public support for the undertaking is a common requirement. Whereas government organizations and utility consortiums would depend on financing from the government or the utilities, the private sector businesses would compete in the open market for the storage business from the utilities. National preferences, political structures, technological infrastructure and economic policies may influence the route to be chosen or that may evolve for the spent fuel storage business depending on the circumstances in a Member State.

5.1.2. Make or buy choices

Depending on the resources available to the organization responsible for implementation of the project, there would be a choice to make on the procurement of necessary services, particularly if there are adequate resources for a particular technology developed by in-house capability. In such circumstances, utilization of internal resources would be preferred to implement the AFR storage project need rather than outsourcing a new option to a vendor.

In most cases, however, the NPPs or implementing organizations, while being directly responsible for AFR storage, may not have invested in such development of internal capabilities. They may also not have the technical resources required to accomplish the project or not have competitiveness sought by the project management. Therefore, they may prefer or be obliged to acquire the necessary service by outsourcing of acquiring an AFR storage system. In circumstances where an implementing organization is responsible for AFR storage, a similar lack of resources could lead the organization to acquire external resources to carry out its obligations with regard to AFR storage.

5.1.3. Project management

An effective project management is necessary to carry out the key required activities to put in place an AFR storage system. These relate to a variety of activities to implement the project such as feasibility studies, licensing, environmental assessment, public consultation, design, tendering, construction and commissioning. The work scope of the project management service would vary from a full scope turn-key service to a minimal specialty, depending on the agreement between the contractual parties. A project management service could be set up or hired by the implementing organization to carry out the initial planning process. or project management team could be appointed from within the organization (See Section 4).

The project manager in turn will act on behalf of the NPP or the implementing organization and establish a project delivery strategy identifying the key components such as a project plan, technology selection, regulatory approvals, bids invitation and evaluation, awarding the contract, detailed design, procurement, construction, commissioning including training of staff for operating the AFR storage system, and turning over the system once completed to the organization charged with the task of operating the AFR storage system. The project manager could also establish expert advisory groups to advise the project organization in various specialized areas.

5.2. Selection process framework

The steps involved in the implementation of a project for procurement of a facility for AFR storage can be broadly divided in two phases: firstly, the technology selection phase which focuses on the selection of the appropriate conceptual alternative and its use in an AFR storage facility leading to a contract award, and secondly, engineering and construction phase which focuses on the implementation of the physical assets by the contractor[20].

The selection of an AFR storage facility is a key activity in the procurement cycle of an AFR storage facility. The selection process could take from several months to several years depending on the scope of work and the complexity of the situation in a particular case. It entails a methodology and a process starting generally with the definition of the problem and ending with the award of a contract. Figure 4 shows a simple framework for the selection process.

Irrespective of the organizational differences, the four key steps in the selection of an AFR storage system are: (a) defining the need, (b) selecting the technology, (c) inviting bids, and (d) awarding the contract.

5.2.1. Defining the need (work scope)

The first step in the process would be to develop a vision for the project and establish goals. This would include clarifying the need and its potential priority. The need for storage has to be fully defined before proceeding with the identification of possible solutions. Such need would have to be consistent with the policies and strategies for the spent fuel management, which are often national (or sometimes international) in scope, and may have a legislative basis.

The identification of the need would often be based on a systems analysis of the back end of the fuel cycle. Caution should be exercised in avoiding premature solutions, i.e. solutions without a comprehensive understanding of the problem potentially leading to inappropriate selection. Solutions would also require that all necessary R&D based information to qualify the solution is either already available or could be acquired on short notice within the scheduling constraints through partnerships with academic and R&D organizations.

5.2.2. Selecting the technology

Based on the formulation of the need, an organization charged with AFR storage can set out to examine the opportunities available in terms of technology, supporting R&D, and select the most suited technology. This would include briefly the following steps.

5.2.2.1. Clarifying what is needed

With the need defined, preliminary functional needs can now be identified such as in terms of spent fuel information, location and infrastructure, facility needs in terms of design, fabrication, construction, pre-operational testing, performance needs and regulatory compliance, regulatory requirements and project management.

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[20] The scope of this document is focused on the former, i.e. the selection of the AFR storage and therefore excludes the engineering and construction phase that primarily involves contract management following the award of the contract.

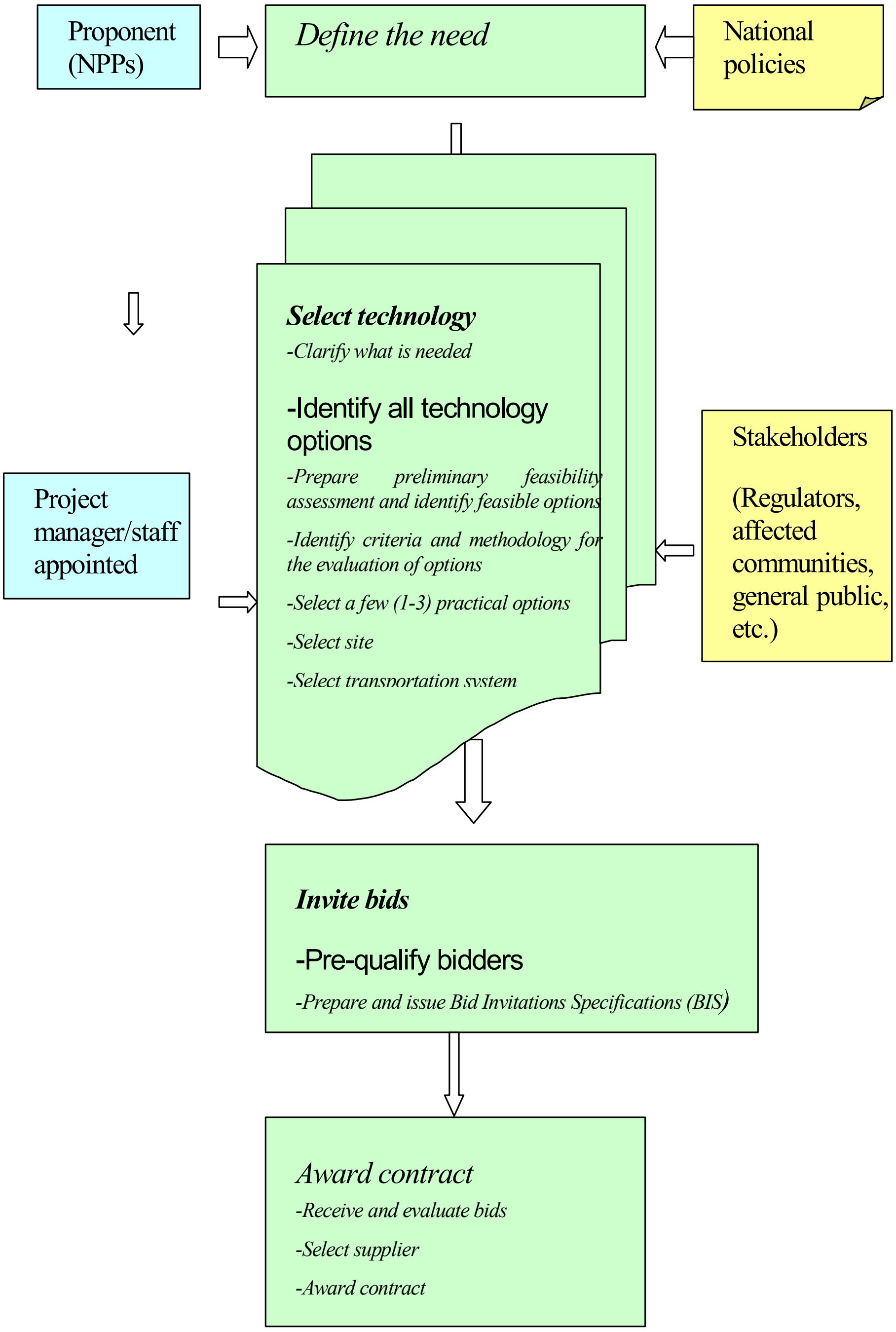

Fig. 4. Selection process framework.

At this stage, needs are defined on a general conceptual basis for lack of details. These concepts then lead to a project plan or strategy for working out the details, filling in any gaps such as in R&D, choosing a technology, and implementing of the chosen solution.

5.2.2.2. Identifying technology options

In selection the AFR options there may be possibilities, ranging from technologies already licensed and experienced within the organization to commercially available new technologies that may be less familiar to the organization. All the available technologies would be researched and catalogued for detailed screening and selection. Based on these technologies, there may be a variety of vendor-based designs and technology variations, often untried yet innovative, which are available in the spent fuel storage industry together with construction and operational experience database. Such information could be deployed for developing a full outline of an AFR storage system solution.

5.2.2.3. Identifying criteria and methodology for the evaluation of options

The screening of technology options would require not only the knowledge of the functional needs, but also a consistent set of criteria and desired attributes and a methodology for their evaluation. These are developed and refined in a stage-wise manner, as the selection process proceeds, such that the final selection could be based on a set of fully developed needs and criteria. The methodology would have to allow for the integration of all the criteria and objectives and ensure that it takes into consideration, so integrated, all the essential objectives, policies and principles, technical, social, regulatory and environmental, and financial considerations and public input. We later discuss the multi-criteria decision tools to carry out technology selection, once the criteria and methodologies have been firmed up.

5.2.2.4. Preparing a feasibility assessment and identifying candidate options

The technology options are screened based on developed criteria and the evaluation method, and a few feasible options (generally 1 ~ 3 options) are chosen for further evaluation for use in an AFR storage system. Often the screening will be a step-wise process, each step designed to narrow the choices available with a further refinement of the criteria and methodology leading to the final selection.

The scope of the feasibility assessment would include not only technological studies, but also studies on site-related feasibility, regulatory and environmental feasibility, and stakeholder and public acceptance. The overall purpose of the feasibility assessment is to develop a strong business case, defendable in all respects for proceeding with the project.

5.2.2.5. Selection of a site

In the ideal case of this step, the project organization will carry out a site selection process with the aim of selecting a suitable site. Based on the site characteristics, the technological option would be developed to arrive at a site-suitable design. Site characteristics could also play a role in the initial stages in the selection of the technological options.

In reality, however, selecting a site for AFR storage of spent fuel is a big challenge in most cases mainly because of the socio-political factors involved in the site selection and approval process. As there is often little chance in realizing a new site away from the NPP site, many of the criteria for site selection are limited in the majority of projects for building AFR facilities for spent fuel storage.

5.2.2.6. Transportation of spent fuel

An off-site transportation system will be defined and the route and mode of transportation chosen for transporting the spent fuel from AR pools to the AFR storage site.

Transportation of spent fuel could be a challenge, depending on the circumstances, because of the similar reason as site selection.

5.2.2.7. Obtaining regulatory approvals

Approvals will be needed from the regulatory body such as the ones responsible for nuclear licensing, environmental assessment, and transportation. In many cases, a number of governmental agencies from the federal, provincial and municipal levels would have specific responsibilities in various areas which would have to be taken into account in a comprehensive and timely manner. The processes may include formal consultation with the public and other stakeholders. Regulatory studies and approvals may take a significant period of time, and are often taken up in parallel with other project activities in a harmonized manner, if the project risks of such fast tracking are considered acceptable.

5.2.2.8. Making the business decision and assessing project risks

In this step all aspects involved in the project are reviewed including technical, financial, legal and commercial aspects, and a business decision is made. All project risk factors will be identified and steps taken to mitigate such risk both in terms of immediate project risks in undertaking the AFR storage project and later project risks in the use of the facilities during operation.

The business decision will be supported by a budget and procurement of funds. Approvals will be sought from the project sponsor (NPPs or the implementing organization management as may be applicable) for proceeding with the project.

5.2.2.9. Preparing functional specification

In this step, all technical and contractual information needed for the invitation of bids will be compiled. The functional specification will provide the bidders a full outline of the work to be done, including specifications, drawings, site details, and any special conditions affecting the work.

5.2.3. Bid invitations

Bid invitation includes pre-qualification of bidders and suppliers and issuing of Bid Invitations Specifications (BIS). The objective of the BIS is to request for quotation by soliciting appropriately prepared bids from suppliers or vendors, complying with the scope of supply and services desired by the project and as outlined in the functional specification.

5.2.4. Awarding the contract

In this step, the bids are evaluated for their economics and other merits, and the supplier and the technology offered by the supplier are finally selected.

The main objective of the evaluation is to establish costs of procurement of the AFR facility in each bid and rank the available bids based not only on an economic figure of merit but also other non-economic evaluation criteria. Negotiations are conducted as may be needed. The contract is then awarded[21].

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[21] With the expanding globalization of market economy, goods and services are increasingly subject to internationalization of trade rules requiring transparency of the evaluation process and thus sometimes leading to legal debates.

The contract is then managed through its various stages such as detailed design, procurement, construction, technology transfer and commissioning. Contract specialists in the project organization carry out the management role in the procurement cycle throughout the various stages of procurement. As mentioned earlier, this phase of the work is not elaborated in this publication.

All the above steps would need to be carried out in the context of national policies and consultation with various stakeholders as earlier discussed. These activities could substantially influence the direction of the AFR storage project and significantly increase the level of activities required. Examples of such influence are regulatory licensing, site selection activities, environmental assessment and public and community consultation. It is necessary to ensure that various activities are appropriately integrated with the selection process such that the process is well coordinated and efficient, and ensures that input from all stakeholders is received in a timely manner and is taken into consideration in the project decisions.

Some Member States may have experience in similar projects, such as AFR storage of vitrified high-level waste or for low and intermediate level waste (ILW), pre-closure stage of disposal facilities, AFR storage of, etc. In countries where these experiences are available or projects are being planned, this can be a good reference for implementation of the AFR spent fuel storage project.

Value judgments are an essential part of the selection process not only at the stage of identifying essential needs and relevant criteria but also in evaluating technologies based on them. These needs and criteria must therefore be representative or responsive to the constituency on whose behalf these evaluations are being made. Such a constituency includes not only the customer (NPP operators) and its representatives, but also a whole range of stakeholders from various regulatory and government agencies to affected communities and the general public. The organization charged with the selection process will have to ensure that appropriate measures are in place to bring into consultation the range of groups or individuals who may have a contribution to make as legitimate stakeholders. The project organization must strive to resolve conflicts that may arise, and ensure transparency and traceability of all decisions made.

5.3. Technology selection method

Whereas there are a variety of technical options available for spent fuel storage as described elsewhere, the customer needs are usually determined by a specific set of requirements, conditions and constraints. Therefore, the purpose of the selection process is to find the most suitable solution to the given project.

There is no single prescriptive method to select the "best storage" concept. There are many factors to be taken into account during evaluation and selection. There are many parameters and issues that significantly influence selection of a storage concept that are not directly related to its technical merit or its cost, and often, stakeholder groups could unduly sway the decision based on considerations other than these factors.

Figure 5 illustrates a generalized methodology for the selection of the AFR storage. Following the identification of the need for AFR storage normally carried out by the project sponsor (usually the NPP or the implementing organization), a project manager is chosen and a project management team is established. During the project-planning phase, the project organization will identify general technical needs, technological options available, scope and schedules, and various management processes (such as stakeholder involvement, public consultation, regulatory processes, quality and risk management) required for the successful completion of the project. The role of the project management is to apply the appropriate knowledge, skills, tools and techniques to the AFR storage project in order to meet or exceed customer and stakeholder needs and expectations. By the end of the project planning phase, the project organization would have integrated the schedule, budget and a comprehensive work description for the proposed AFR storage, all of which would continue to be updated and elaborated as the project moves forward, increasing the overall level of understanding of the project.

As discussed earlier, a key role of the project management would be to carry out a feasibility study of all the technological options available and select a few options for initiating the tendering process. The techniques to achieve such as a selection is described later (see 5.4).

The selected options would have to meet, in addition to broad policy directives, all key requirements such as technical suitability, regulatory and license conditions, environmental regulations, and stakeholder acceptance. Managing stakeholder acceptance often tends to become complex because the stakeholders sometimes could have different objectives that come into conflict with the project objectives. Stakeholder involvement therefore requires special attention to ensure that appropriate resolutions are applied[22].

Following the completion of the technology selection phase, the project is taken to the tendering phase. A functional specification document, based on the outcome of the technological selection process, provides a contractual basis for the potential bidders.

The last stage in the AFR storage selection is a process that involves pre-qualification of suppliers, bid invitation and receipt, and evaluation of bids leading to the selection of a supplier and a technology. The selection concludes with the award of a contract.

[22] We choose here to discuss public involvement, which indeed is a key component of the stakeholder involvement, as a separate activity in view of the greater attention it requires, in dealing with conflicts and uncertainties.

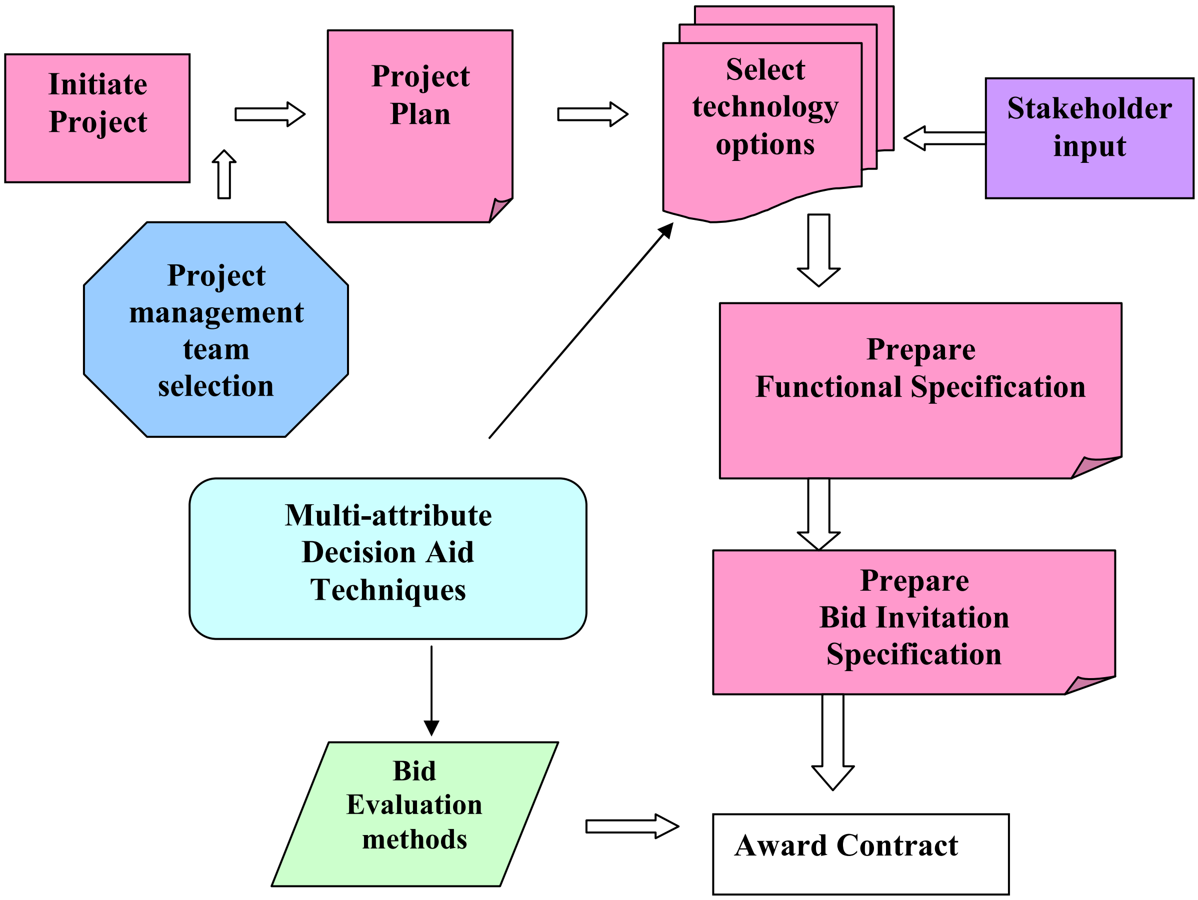

Fig. 5. Selection Methodology.

5.3.1. Project team selection

The project team headed by a project manager and authorized by the proponent (NPPs or implementing organizations) becomes responsible to execute the project from initial evaluation of options to not only the selection of a supplier for the facility and the award of the contract, but also the construction and commissioning of the facility and its turn-over to AFR storage operations organization (often NPPs or the implementing organizations).

Attention should be paid to the expertise, experience and personalities of the core team assembled by the proponent to steer the evaluation and selection process. The project manager should also identify those departments or divisions in the NPP (or the implementing organization) who will need to be involved in the project (such as plant engineering and spent fuel handling staff) and obtain their commitment and support in managing the project. The project staff should be fully aware of the project management methodology, which is now well advanced as an industrial discipline and as a body of knowledge. They should also be committed to effective teamwork, which is the primary characteristic of any good project team.

A typical project team in an implementing organization will consist of:

- Operational staff with spent fuel handling and storage experience and qualified to provide support in developing in-plant modifications at the NPP.

- Research and development staff with knowledge about the fuel characteristics and the behavior of spent fuel in different storage conditions, material scientists with knowledge about the structural materials and their chemistry in operating conditions.

- System design staff including chemical, mechanical, civil, electrical, instruments and layout engineers.

- Safety staff including specialists in nuclear technology, heat transfer, seismic analysis and safety assessment.

- Environmental assessment staff including biophysical, hydro geological and social scientists.

- Staff experienced in developing public communication and consultation plans and in implementing stakeholder programs.

- Project staff including project engineers, cost estimators and planners.

The primary criteria for establishing a core team for the project should be expertise and experience. However, in order for the team to work optimally some consideration should be given to the various qualities required of the project team[23]. Generally, it is preferred to have teams with a blend of people who take on various roles, for example, co-ordination, communication, technical and commercial investigations, financial evaluation, public and community relations but if progress does not seem to be made, it may be worthwhile to review the team composition and qualities to match the task on hand.

5.3.2. Application of methodology to select an AFR facility

As described in Section 5, the whole selection process starts with the identification of the problem and finishes with the award of the contract[24].

Main steps in the selection methodology starting from the identification of the needs to the award of the contract to the selected supplier can now be listed. The key steps involved in the methodology are as following:

- Statement of need;

- Preparation of a project plan or strategy (functional needs were introduced in Section 3);

- Identification of possible technologies and screening (selection criteria were introduced in Section 5; screening discussed in this Section); and

- Regulatory studies and approvals;

- Environmental assessments and approvals;

[23] For example, a team composed of too many people with a passive, cooperative nature may not achieve an end result as they may avoid making balanced decisions if they fear their views will be negatively perceived by others. On the other hand, a team composed of too many hard driving "shapers" may not suit as well if they tend to be inflexible and not able to reach a consensus view, particularly in a multi-stakeholder decision environment.

[24] Activities following the award of the contract such as managing the contract, turnover the facility to operations and training of operators, while important, are considered to be beyond the scope of this document.

- Achievement of publicly acceptable site, transportation routes and technical concepts;
- Preparation of functional specifications;
- Preparation of pre-qualification document;
- Evaluation of the pre-qualification responses to identify preferred suppliers;
- Selection of preferred suppliers;
- Preparation of Bid Invitations Specification and their issuing;
- Receipt/response to the suppliers' questions prior to the bid submission;
- Receipt and evaluation of bids to select preferred supplier(s) and technology;
- Post-bid/tender discussions, and issue of clarifications if necessary; and
- Selection of the supplier and award of contract.

Although many of the steps listed earlier are self-evident and may not require elaboration, some of the key steps are discussed in this Section.

Throughout the preparatory activities the customer has to identify the relevant intentions and constraints and cooperate with the project management organization in choosing an appropriate strategy extending to contractual activities and project financing.

5.3.2.1. Feasibility studies

The purpose of the feasibility studies is twofold:

- To select a limited number (1 to 3) of design concepts, which fully meet the functional requirements and are based on selection criteria discussed in Sections 4 and 5.
- To resolve all issues with respect to the design concepts in terms of technical, regulatory, environmental, public acceptance and other areas so that the design concepts can provide the basis for the tendering process.

The key steps in the feasibility studies can be summarized as follows:

- To generate options based on market research, brainstorming and other techniques, that have the best potential to meet the functional needs. Generally option development studies are carried out by setting up a team that is well experienced in developing technical solutions and in carrying out their assessments. The strength of the team in generating ideas with a systematic approach and in providing valuable insights is crucial to identifying a comprehensive range of viable options consistent with the functional needs.
- To evaluate options with the aim of narrowing down the choices. Each technical option is tested against the functional needs and a range of selection criteria. The evaluation of options is often carried out in stages.

The decision to acquire a spent fuel storage facility shall be based on the result of initial planning and feasibility studies. In these studies the advisability of acquiring the facility and the main characteristics of the project shall be investigated, the results constituting the background of the project.

5.3.2.2. Screening of options

The approach to the evaluation of the options in stages generally consists of a coarse-screening stage, and a detailed evaluation stage. Where the issues warrant, additional stages can be used to narrow down the choices.

- In the coarse-screening stage, the available range of options is tested by means of judgment of an expert team. The options are scanned for obvious drawbacks with respect to functional requirements and key selection criteria. Such drawbacks could involve not only technical issues, but also broader issues such as public acceptability, constructability or licensability of the concept. In a creative setting, the coarse screening will not only provide initial screening, but also be able to suggest technical solutions in terms of hybrid or modified options that might not have originally surfaced in the generation of options.

- In the detailed evaluation stage, the coarse screened options are further developed and subjected to a detailed evaluation and selection. Unlike the coarse screening stage, the options in this stage of evaluation are subjected to a more methodical evaluation and scoring of options. Much iteration may be needed to resolve all the issues and test various trade-offs between parameters, such as cost, safety, project risk and various uncertainties.

5.3.2.3. Relevance of applicable criteria

Many criteria and desired attributes (or subsidiary criteria) may influence the choice of the most appropriate solution. Not all are relevant for each customer. Nor may they be relevant for each stage of the selection process. Thus the selection of a relevant set of attributes and the corresponding weighting factors for these criteria and attributes, at each stage, is one of the most important steps in the selection process.

Table 3 provides a summary of the various functional needs and selection criteria and their suggested applicability in the various stages of the selection process based on the discussions in Sections 4 and 5. Development of such a reference table has its own shortcomings in that each context is different and the development of any set of criteria would have to carefully examine its specific conditions and constraints. These criteria should therefore not be taken as a comprehensive list or as a list of mandatory criteria, but only as a guide and a specimen for the preparation of a suitable list in a given context.

Table 3. Selection criteria and attributes

Attributes		Options					Options weighted				
Criteria 1		Option 1	Option 2	..	Option N	Weighting factors	Option 1	Option 2	..	Option N	Reasoning /remarks
	Attribute 1.1.										
	Attribute 1.2.										
	Attribute 1.n.										
Criteria 2	Attribute 2.1										
	Attribute 2.2.										
	.										
	Attribute 2.n.										
Criteria 3	Attribute 3.1										
	Attribute 3.2.										
	.										
	Attribute 3.n.										
…	…										
Criteria m	Attribute m.1										
	Attribute m.2										
	.										
	Attribute m.n										
Aggregate						-					

5.3.3. Learning from experience

Experience and the precedents set by approaches in countries that have already built AFR storage facilities give a reference point for any nation or organization embarking on the selection of an AFR storage system to meet its own specific needs. Such cases also act as models and benchmarks for successful approaches that are already licensed in other jurisdictions and have met public acceptance. They are providing a sound basis for consideration.

5.4. Problem solving techniques

Technological and a management solution need to be chosen for the storage of spent nuclear fuel through the application of a decision framework which can handle multiple criteria simultaneously – criteria that are, moreover, qualitatively different from each other. These criteria may be grouped into a number of sets, the details of which will vary in particular cases, such as:

- Human health and safety factors (including transportation);
- Environmental protection, over very long time periods;
- Social factors (economics, community acceptance, political and institutional stability, distributional fairness); and

- Management capability and technical expertise over the long term.

Each of these sets may be disaggregated into its subcomponents in accordance with the particular cases. As explained below, these criteria are translated into more specific sets of *objectives* which must be met, up to the minimum level of demonstrated performance standards, in order to satisfy the public's goals for assurances of a requisite degree of safety in the operation of a spent nuclear fuel storage facility.

5.4.1. Commonalities and particularities of methods

In one sense these criteria and objectives are the same as those used in most other domains in the risk management of hazardous substances, such as industrial chemicals, medical waste, and pathogens – including both transportation and facility operation risks. On the other hand, the extremely long timeframes during which performance parameters are relevant in the case of spent nuclear fuel, present unique challenges in this case.

The purpose of any decision making is to increase the level of confidence of key stakeholders (government bodies and regulators, the general public, interest groups, industry, affected communities, and independent experts).

5.4.2. Screening methodology

In order to analyze the various options in a systematic way, it is necessary to evaluate the characteristics of all the elements that make up an option. A screening of options based on the selection criteria is a complex process and not all criteria and their attributes are easy to quantify.

As noted earlier, the relevance of applicable criteria need to be carefully evaluated. Table 3 provides a summary of the various criteria and their attributes and their suggested applicability in the various stages of the selection process.

5.4.2.1. Identifications of criteria

Besides the many criteria that are either quantified or cannot be quantified in terms of absolute known values, there will be a large number of intangible factors that must be taken into account to proceed with the selection. Furthermore to ensure that no important factors are overlooked and credibility is established, an independent third party validation may be necessary.

5.4.2.2. Screening

Screening is carried out to reduce the number of possible options. This could be done in stages from the preparation of the feasibility studies to the bid selection process.

If the number of the possible options is large and the range of criteria and attributes wide and complex, screening carried out in stages facilitates a cautious approach to be taken in narrowing of the choices. In each stage, only a partial screening is carried out to the extent that it can be carried out based on the available information relevant to criteria. The number of options is reduced in each stage, which allows for more detailed evaluation of the options and better definition of criteria as the selection progresses. This process can be carried through until the degree of screening required is achieved and selection process completed.

Table 4. Summary of stakeholder issues and their resolution

ISSUES / PROBLEMS	STRATEGIC CONCERNS	RESOLUTION APPROACHES
Different perspectives on legislative basis, general policies and AFR storage policy	Tradeoffs Interpretational difficulties	Balance, compromise, clarifications
Relationship issues	Organizational conflicts	Cooperative approaches Identification of shared value
Changing conditions/incomplete or inadequate information	Uncertainty e.g. with respect to risk perception	Adaptive, flexible, extended consultation, relaxed time management
Multiple interests among stakeholders, orchestrated opposition and conceptual gaps	Conflict, equity issues	Team work, partnerships and coalitions
Conflicting objectives	Breach of confidence, trust	Addressing legitimate concerns, mitigation and compensation for adverse effects

5.4.3. Decision aid techniques

Many decision aid techniques and analytical tools are available to assist with the screening and the selection of the most suitable option. A commonly used method is the multi-attribute, multi-stakeholder decision aid methodology that can be used where a large number of criteria as well as a large number of stakeholders are involved. An example of approach in dealing with the stakeholder issues is given in the Table 4.

5.4.3.1. Multi-criteria decision analysis

A multi-criteria decision analysis (MCDA) is designed primarily to help the participants, and those who review their work to assign *comparative rankings* to a predetermined set of options. It facilitates integration of many threads of information and earlier decision analysis results in order to make a comparative evaluation of alternatives or options on the basis of weighted and hierarchical criteria. These options might include, for example, different locations, different geological media or topographical criteria; and different storage technologies. In other words, the group will be seeking to classify options in terms of expected performance along a scale of better or worse. The group does not need to specify a threshold of adequate performance, although it may do so. The exercise is more practical; however, if some prior screening of the full set of potential options has been undertaken, for example by a regulatory body, which makes a determination about the set of options that appear to comply with such a threshold. Only those options which exceed the minimum threshold are then the subject of the decision analysis. A multi-criteria decision process is an exercise in *considered judgment* by reputable persons. The basis of informed judgment should be the existing consensus of expert opinion with respect to each criterion to be evaluated.

Typically it is not a forum where disagreements among technical experts should be discussed, or where an expert consensus on particular technical matters should be sought. Each of the participants could have a somewhat different level of confidence in the quality of expert opinion on a particular point; if so, this will be reflected in the differences among their scores during the exercise. These scores represent *subjective judgments*, in the sense that the participants are asked (by other members of the group) to give general reasons for their scores, but without reference to a detailed body of evidence. In this way the process mimics the form of ordinary discourse among citizens about issues of public policy – and this is precisely why it can be as useful as a contribution to both governments and the general public.

- Expert versus public frameworks

The most basic question to be answered is: Whose judgments are to be counted? In other words, what types of people should be considered for participation in the exercise? One solution is to allow all of the key stakeholders to designate a representative to participate. Another is to have an agency (such as a regulator) name a group made up of recognized experts in the technical disciplines directly relevant to the criteria. A third option is for the appropriate agency to choose a diverse group of individuals, with varied professional credentials (but who are not necessarily technical experts), who have high standing in their profession or community. Taking into consideration the main purpose of the exercise, namely, to build broad public confidence in a preferred option, the third option is recommended.

- Quantitative and qualitative judgments

Each of the criteria or objectives may be described in either quantitative or qualitative terms, or both. For example, public health and safety may be defined as either a "safe level of exposure" (as determined by relevant international radiation-protection standards), or in specific numerical terms for a variety of exposure scenarios. For a multi-criteria analysis, however, the use of detailed quantitative information for any specific objective should be minimized. Where disputes among the participants as to "where is the case made" arise, and cannot be easily resolved, the participants may call for more information to be tabled, for a briefing by experts, etc.

- Level of detail in the information package for the decision analysis

Since there is a huge amount of information on the set of relevant objectives, some hard choices have to be made about what is "tabled" for the participants in this exercise. The responsible authority should attempt to have independent experts prepare summaries of the information base in each case. A set of more detailed analytical papers on each topic should be available for examination, if the need arises.

5.4.3.2. Using a formal multi-criteria decision analysis (MDCA) method

The sets of criteria mentioned in 5.4.3.1 would normally give rise to a number of objectives, which also might have differential weights attached to them. There may be different timeframes to consider as discussed earlier. Also, the analysis team would have more than one type of technological or management option to choose from, which had passed the preliminary screening. It is difficult, if not impossible, for participants to keep this many variables "in play" purely on an intuitive basis. Therefore, the preferred course of action is to select a proper MCDA tool from among the available array of formal tools that have been developed for this purpose [53].

- Choosing the requisite set of objectives

The most important requirement for the decision analysis is that the team assigned to this task must define specific performance objectives. These are derived from the more general criteria against which the options are to be measured. This provides a sense of “ownership” for the group and is a necessary feature of the method. Members can only evaluate carefully those objectives, and the options that can satisfy their requirements.

- Explaining the objectives

The group must be able to articulate the multiple “pathways” through which various factors, both social and environmental, can exert a decisive influence on the realization of each objective. The group should construct what are called “influence diagrams” in as much detail as is required in order to account for all of the key factors, which are the determinants of how well any proposed solution can satisfy what is required to achieve as an objective to some acceptable level of performance.

- Assigning weights and scoring

Normally the group will be asked to assign relative importance weights to the objectives which have been specified. In addition, numerical scores, reflecting the belief of each member to how well some option will perform on some objectives, will be assigned by each group member, in order that a composite score for the group as a whole can be computed. There are technical requirements relevant to both of these aspects, and it is advisable for the group to obtain guidance from a professional who is skilled in its application.

- Presenting the results

The results of the group decision exercise may be peer-reviewed and validated by a third party before being released to the public. In addition, great care should be taken in writing up the results of the exercise for public dissemination and comment. The exposition of both the method and the results should be given with a level of detail sufficient to ensure that interested members of the public can grasp easily how the group arrived at its conclusions. Ideally, the exposition should enable a member of the public to follow each step in the decision exercise, reproducing the process for him or herself and noting specific points of agreement or disagreement with the group consensus.

5.4.3.3. Tools for analysis

There are a number of software tools for decision analysis available in the market, which is especially useful for analysis of complex problems. A survey of these tools, which was published in the literature, is provided in the Annex III.

5.4.4. Sensitivity analyses

A set of weighting factors can be applied to reflect the range of views that may be held about the relative importance of the criteria and their attributes. Such weighting factors can be so chosen as to reflect people’s preferences where relevant in terms of issues such as safety and environmental protection. In order to assess the robustness of the results a sensitivity analysis can be carried out by modification of weighting factors. In sensitivity analysis, the effect of changing a particular attribute or the weighting factor is assessed for its effect on the selection. The analysis could be repeated for a range of possible outcomes by changing different criteria and attributes or their weighting so that and the robustness of the solution is checked. A weakness of the method is that variables are changed individually limiting the extent to which combinations of variables can be assessed. Probability analysis (such as Monte Carlo analysis) techniques are often used to overcome the limitations of sensitivity analysis by specifying the probability distribution of each variable. By performing the analysis several times a range of solutions can be obtained with their respective probabilities. With Monte Carlo simulations, different sets of criteria and weighting factors with a distribution of the probable range can be used to assess the probable results in terms of scoring of options. The scientific and practical aspects of this discipline have significantly matured in terms of both real-life applications and specific software implementations.

It is important that the criteria and attributes as well as the weighting factors are chosen on a well-defined and documented basis. The reasoning for the value judgment to rank the un-quantifiable attributes must also be well established and recorded.

The ranking procedure could start with the definition of the criteria and their weighting. Usually these can be grouped as essential and desirable ones. These are then further divided into attributes to represent the different factors or features. It is also important to identify the factors not included explicitly in the comparison. Weighting factors can be determined on the basis of the relative importance of the criteria and attributes. The complete set can be used for scoring and ranking of all options. Aggregating these numbers will lead to the final result providing the ranked list of the different options.

It is necessary to evaluate the result, with the sensitivity analysis to identify the sensitive criteria and attributes and their effect on the result. Probability analyses using computerized techniques will provide information on the confidence level of the decision when the criteria and attributes and their weighting are likely to change.

5.4.5. Scoring of options

Table 7 shows a typical form for the scoring system. Each option must be ranked or scored against each criterion and attribute. The table includes a column for weighting factors to express the relative importance of the criteria and attributes. The repeated ranking or scoring of each option follows this column. This approach makes the comparison of the options with and without the weighting factors easier, which contributes to the sensitivity analysis of the results. The last column is for the reasoning or remarks regarding to the specific attributes.

With the computerized decision aid techniques, sufficient iterations could be carried out to resolve all the issues and to minimize the uncertainties related to criteria and attributes and their assumed importance, and to differences in opinions or judgments common to most multi-stakeholder issues.

5.5. Tendering Process

For selection of the product or service to be procured, the most widely used approach is tendering, based on the principle of fair trade for procurement of goods or services, which is often required or mandated by national or international rules[25].

There are several methods of tendering to be chosen depending on the type and value of procurement:

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[25] For example, the European Union adopted EC Procurement Directives according to which all public sector contracts no matter what their value, within the EU are covered by a treaty which incorporates the free movement of goods and services and which prevents discrimination against firms on the grounds of nationality.

Open tendering is a single-stage bidding process where all interested candidates may respond to the advertisement and submit a tender.

Restricted tendering is a two-stage bidding process in which potential contractors expressing an interest with response are evaluated in the preliminary stage for the sole purpose of screening. A shortlist is drawn up from the preliminary evaluation and the successful contractors are then invited to bidding.

Negotiated tendering is when a few bidders are chosen by a process of pre-qualification, in order to reduce numbers to a manageable level for the purposes of tendering (when using either the restricted or negotiated procedures). Application of this approach is under restricted conditions and subject to limited circumstances.

In order to preserve the integrity of the competitive process, it is imperative that the evaluation of proposals is undertaken objectively, consistently and without bias towards particular suppliers. Tenders are usually evaluated against a pre-determined set of criteria. Scoring and weighting of criteria is determined at the same time the tender is compiled.

A prerequisite for formulating the scope of tendering by the project management, on behalf of the client, includes:

- Tendering format (request for proposal/bid);
- Essential terms and conditions to be included in the tender document;
- Selection criteria and evaluation methods/process;
- Requirements for bidders (or qualifications);
- Definition of roles and responsibilities of the parties involved in the tendering; and
- Any other issues to be clarified between the stakeholders.

As noted earlier, there are some commonalities and particularities in the applications of such processes and methods to the particular business case of projects for AFR facilities for spent fuel storage. Despite the generic aspects of the art, there could be a lot of variances in the actual practice of business depending on the place and time.

In view of the above, it is neither necessary nor advisable to propose a prescriptive approach for the procurement process and in most cases; such a process will be customized to the need on hand. Some generic features of the process may however be summarized as below.

5.5.1. Preparatory stage

It is assumed that a decision has already been made to implement a project for procurement of an AFR storage facility based on the spent fuel management strategy. The aim of the selection process is to find the most suitable storage system and its implementation, which extends to the tendering process.

The review of available information at the beginning of the project such as customer‘s needs and the review of options in the light of the spent fuel management strategy will determine the preparatory stage. This could range from a very simple process where the customer already has a working concept and where the main focus is to identify a supplier, to a fairly complex one where detailed feasibility studies are carried out and preferred options are to be chosen.

Depending on the specifics of the licensing and environmental assessment processes in Member States development of safety assessment reports and environmental assessment (EA) reports and their approval through the relevant regulatory processes for licensing and EA become major activities in the preparatory stage.

Based on the information available at the beginning of the selection, it is of high importance to identify the steps of the selection and the decision making process, and define the participants of each step and their tasks in it. The interfacing relationships among various participants such as NPP management, plant engineers, project engineers and safety analysts are often complex and bring into focus project management skills such as in directing, planning, organizing, and integrating the disparate elements of the project.

Similar challenges arise also in the interfacing of various stakeholder groups, which may often include special interest groups who may not be readily favorable to the project. The skills of the project organization in getting overall stakeholder acceptance will often determine the success of the project as a whole.

5.5.1.1. Functional specification

One of the main aims of the preparatory stage is to prepare a business case and the functional specification. While the business case is generally an internal statement of project justification prepared primarily for approval of the NPP or the implementing organization, the functional specification is to provide all functional requirements of the facility and criteria for its selection for use of the potential bidders. The functional specification will necessarily include a schedule, statement of the work to be done, specifications, drawings, delivery dates, special conditions that may govern the work and necessary approvals for carrying out the work. To compile the functional specification it is necessary to go through all the functional and related requirements and issues that could affect the selection process. Section 3 provided an outline of the main requirements and boundary issues that have to be reviewed during this process.

Specific topics that provide the content for a functional specification could be as under:

- Reason for needing the facility;
- Outline of criteria for selection and desirable attributes;
- Strategic requirements or project boundaries (design and build; design, build and operate, etc.);
- Descriptions of the spent fuel and quantities and schedule of arising;
- Capacities of the facility;
- Facility needs and conditions;
- Site information (geographical, infrastructure, meteorological, ground conditions etc.);
- Services available at the site (power, infrastructure, human resources, transport etc.);
- Health and safety issues;
- Operating philosophy (human resources available, shifts, unions, client's experience);

- Design and quality standards (Codes of practice, national codes and standards);
- Operational needs;
- System flexibility requirements;
- Safety and licensing;
- Environmental impacts;
- Safeguards;
- Inspection and maintenance;
- Physical security;
- Interfaces (such as transportation, NPP modifications, transport to disposal etc.);
- Radioactive waste management;
- Decommissioning; and
- Costing and their tabulation.

The project sponsor (somebody from the NPP or the implementing organization) is normally the authority for the project and holds responsibility for the project. The Functional Specification will be submitted to the sponsor for approval of the project and its funding for proceeding with the tendering process and project implementation.

5.5.1.2. Design information

It is common practice that the project management organization develops various design guidance packages and specific needs and general specifications in the first phase, following which an appointed architect/engineer develops various detailed plans, site utilization drawings, topographic surveys and detailed engineering information of use to potential bidders. Any early design and development phases or prototypes required to prove the design will be identified in cases where the selected technology is not fully 'off-the-shelf' and requires proof of concept by the bidder. Various constraints would be defined and assumptions made in the feasibility study would be listed.

5.5.1.3. Work breakdown structure

The project would be defined in terms of its work scope with a detailed work breakdown structure (WBS) to facilitate the bidders in appreciating the scope of the work involved. The WBS, besides breaking up the project into manageable pieces, will describe the hierarchical relationships of various activities in the project to the lowest level possible. Together with written descriptions of each work, it provides a powerful specification of the project size, its nature and interrelationships of activities within the project. This also provides flexibility in contractual approaches allowing split or multiple package bids and in organizing bid information. An appropriate accounting system attached to the work breakdown would be very useful for the cost estimation and reporting.

5.5.2. Contractual approaches

Prior to tendering, the project implementation strategy has to be worked out. It is necessary to identify the possible contractual approaches at this stage [68]. The scope of the project plan or strategy can vary significantly, depending on the contractual approach. This will influence the amount of work, and the degree and depth of the information required from the customer.

One of the key decisions, which have to be made by the project team before the preparation of the bid invitations, is the choice of the contractual approach. It should be kept in mind that the selection of the type of contract will fundamentally affect the key aspects of project implementation. For example, split or multiple package contracts may involve geographic dispersion of responsibilities, even involving overseas suppliers, with consequent additional challenges to the project organization in managing the project.

However, the type of contractual approach to be adopted for a particular project can only be determined once all the main factors have been carefully evaluated. The balance of advantages and disadvantages for a given project has to be reviewed. One of the main issues is to review the participation of domestic and foreign organizations as well as costs of service.

When the functional specification is ready, the next step is to identify the sources of commercial storage technologies and their suppliers in the marketplace. The feasibility evaluations would have already catalogued the available information and carried out the market research for new vendors and their technologies.

Basically three main types of contractual approach have been applied in the past:

5.5.2.1. Turnkey contract

A single contractor or consortium of contractors takes overall responsibilities for completing all parts and all phases of the project design and construction. Although it is an ideal situation in terms of managing, it may not be practical in all cases. The AFR storage systems consist of different specializations such as container manufacture, facility design and construction, transportation and modifications to the NPP, often requiring more than one contractor. With a turnkey contract, the contractor may have to subcontract key areas with associated managerial and administrative problems.

5.5.2.2. Split package contracts

The overall responsibility for the design and construction of the project is divided among a relatively small number of contractors, each contractor being separately in charge of a large section of the work. Although ideal in most cases of AFR storage systems, split package contracts require larger effort on the part of the project management organization in managing and coordinating the spilt contract packages. Often the project organizations hire individual consultant or architect/engineer firms depending on the scope and nature of work to provide this service to the project organization.

5.5.2.3. Multiple package contracts

The project organization assumes overall responsibility for managing the design and construction of the project. A large number of contracts are issued to various contractors who carry out parts of the project. This approach requires a complex and large project organization with a wide range of specialized expertise to manage and coordinate numerous contracts and integrate them to deliver the stated goals.

5.5.3. Pre-qualification of suppliers

The purpose of this step is to identify the most suitable suppliers. The usual method to reduce the numbers of the potential technologies and their suppliers is to carry out a pre-qualification process. The pre-qualification of suppliers and invitational bidding from pre-qualified suppliers as opposed to public bidding is often adopted for AFR storage projects in consideration of the complexity and tight functional requirements generally involved in these projects. General criteria in the selection of suitable suppliers include technical competence, financial soundness, track record and provision of suitable references from previous customers. An invitational bid call limits suppliers to those best qualified based on determined parameters.

To carry out the pre-qualification process it is necessary to define the content and prepare the pre-qualification document. The content of this document should be in accordance with the project plan and strategy, and the functional specification. It should include enough information to evaluate the possible technologies and their suppliers. Such information could include: project description, scope of services, required expertise and resources, contract terms and pre-qualification submission requirements.

Initial evaluation of the responses is done by testing the supplier's capabilities against the range of criteria specified for the supplier pre-qualification process. Direct interviews could be used to further evaluate supplier capabilities and narrow down the list of suppliers if needed. The result of the evaluation will lead to a short list of pre-qualified suppliers for the project implementation.

5.5.4. Bid invitations specifications (BIS)

Once the pre-qualification process is complete, the tendering process can start. The first stage in the competitive bidding process is the preparation of the bid invitations specifications (BIS). The purpose of the BIS is to provide the necessary information to the prospective suppliers. The BIS outlines requirements, conditions and circumstances under which the supplier will have to perform his task, the information required (such as technical, financial, licensing, environmental and legal), the form of presentation of this information in the bids, and the basis on which the bids will be evaluated.

It is in the interest of the project organization to provide complete and precise information since this will facilitate the preparation and subsequent evaluation of the bids. It is also in the interest of the project organization to provide comprehensive and relevant information on all aspects that may affect the project and clearly express specifications, conditions and expectations. Normally, the project organization will assemble a bid evaluation team consisting of technical, contracts and legal staff and price and cost analysts so as to cover all areas of a bid evaluation process. Arrangements are specified to have the potential bidder visit the proposed site, the NPP, and any fuel handling arrangements and infrastructure at the NPP in order to facilitate the bidder in understanding the context in which the bid is to be prepared.

The BIS on the one hand shall include all the information that makes it possible for the potential bidder to prepare his bid. On the other hand it shall request all the information from the potential bidders, which are necessary to carry out a comprehensive bid evaluation and comparison of the bids. The desired contractual approach must be also specified in the BIS.

A typical BIS includes the following:

- General information;
- Administrative instructions;
- Functional specification;
- Scope of requested supply and services;
- Overall project schedule and delivery dates;
- Financing information;
- Training requirements of customer's staff;
- Bid evaluation criteria;
- Requested terms and conditions for the contract (draft outline could be requested);
- Commercial conditions;
- Guarantees and warrantees;
- Terms regarding intellectual property rights; and
- Bid security requirements.

A detailed structural constitution of the BIS is discussed elsewhere which provides useful information in any BIS that could be applied for AFR storage.

In the case of multiple package contracts, the project organization would be responsible for the overall management of the work, in which case the bidder would be required to provide detailed and quantified data of its portion of work.

The BIS could include technical and commercial conditions and scope of supply and services for service contracts. Such service contracts could range from simple maintenance contracts to full operational services contracts. Full operational services contracts would consider not only the interrelationships with the NPP but also detailed operational needs such as a period over which such services are requested, plans for periodic maintenance and refurbishing, transfer of such services to the project organization at the end of the contract, and the training of staff.

The BIS could include a comprehensive account system such that it provides guidance on the systematic specification and a breakdown of the scope of supply and services. It also helps the various bidders to develop their bids to some conformity that would prove beneficial both to the bidder in bid preparation and the project organization in evaluating the bids.

Evaluation of the bid evaluation criteria parallel with the BIS preparation is an important activity. The evaluation criteria are initially developed during the beginning of the selection process. However, these criteria should be reviewed and extended as necessary during the BIS preparation stage [69].

It is possible that bidders will request clarification from the customer if they find discrepancies or are in doubt about the meaning of any part of the BIS. It is general practice to consider only written requests for clarifications and to answer these requests also in writing, with copies sent to all bidders. Such clarification may lead to modifications to the BIS. Pre-bid meetings either regular or *ad hoc* with all bidders may be useful for complementing the written communications.

Bidding procedures could include negotiated bids from pre-qualified suppliers, bids submitted as closed proposals, and open bids.

5.5.5. Evaluation of bids and award of contract

Having received the bids, the next main step is to evaluate them to make the final selection of a supplier. It includes a review of the bid vis-à-vis the BIS requirements highlighting a number of key areas, such as:

- Degree of compliance with the technical and commercial specifications;
- Identification of deviations from the BIS;
- Investigation of the competence of the bidder and the subcontractors;
- The quality of the bid from an implementation perspective; and
- Price and cost features.

The conflict that may arise in the evaluation of the bids relate to choosing between the least cost option that may meet the immediate needs and more expensive options that may have greater future benefit or other advantages not available in the least cost option. This classic question is further complicated by the uncertainties with regard to the future, such as in terms of evolving regulations and changing political climates.

The bid evaluation criteria provided with the BIS provide for a methodical comparison of various bids which can be evaluated using a multi-criteria decision analysis process to help in the decision-making. Evaluation of the bids is usually done by scoring and ranking against all criteria and attributes defined for the selection process. Problem solving techniques described earlier in this Section provide a systematic approach for evaluation of the bids as well.

During the bid evaluation process, all aspects of technical, financial and contractual approaches must be considered (see Fig. 6). Different staff must review each of these areas with expertise in those areas. Any contingent events that are likely to arise during implementation should be reviewed and any conflicts resolved. Glossing over such details in the evaluation stage leads to difficulties and expensive recourses after the contract is signed. Legal advice is necessary either through referral to a legal advisor or through having a legal expertise in the evaluation team.

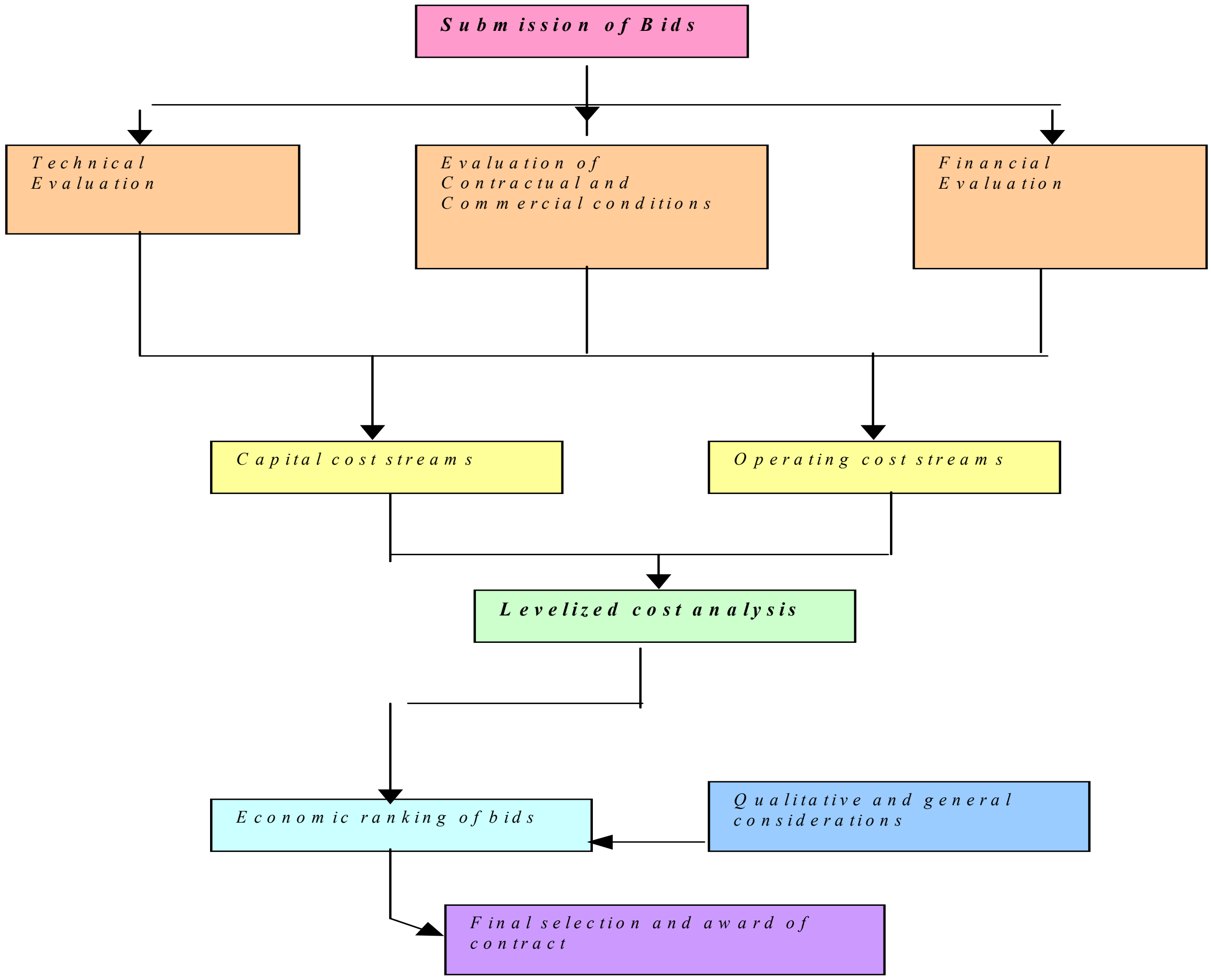

Fig. 6. Bid evaluation process.

An economic evaluation of bids may be applied to bring them to a common basis in terms of levelized costs using methodologies for levelized cost analysis discussed earlier (Section 4.4). In addition to these aspects, all factors that may have an influence on the selection are subject to careful analysis and evaluation. Typical questions involved in the bid evaluation could include:

- Have all technical specifications and criteria been met in the bid proposal?
- Have the requested scope of supply and services been met?
- Are the overall project schedule and delivery dates acceptable?
- Are the contract and commercial conditions acceptable?
- Have guarantees and warrantees been provided as required?
- Are the terms regarding ownership or intellectual property rights adequate?
- Have the bid security or surety bonds been provided as specified?

To minimize the uncertainties of the selection, the results of the evaluation process have to be carefully analyzed and sensitivity analysis carried out. From the final results the potential suppliers can be ranked to prepare the final decision. At this stage it is possible that some qualitative considerations may have to be taken into account, which due to their intangible nature might have been excluded from the evaluation process. In addition to this, sometimes post-bid discussions or further clarification may be necessary with the suppliers providing the most suitable solutions.

If a draft outline of a contract were requested, such drafts would have to be reviewed in detail as to their technical and commercial conditions and their agreement with the BIS. Exceptions should be identified for discussion and resolution with the bidders.

Based on the ranking of the possible suppliers and the above-mentioned general consideration and discussion, the final decision can be made. Any price negotiations if required may be carried out in support of the final decision.

The last step of the selection process is to award a contract to the selected supplier. Contract, by definition, is an exchange of promises, by the successful bidder to do the work as promised and by the customer to pay the agreed amount according to a payment plan agreed to by the two parties.

The contract will state the duties, conditions, obligations and responsibilities of the parties involved. The legal staff generally has a standard set of terms and conditions around which a specific contract gets drafted. Often, draft contracts would be requested from the bidder as a part of his bid, which would then be revised to make it consistent with customer requirements. The contract will specify all conditions and requirements relevant to the project, acceptance tests to be performed and standards to be used to measure the results against the stated expectations.

The AFR storage contract will generally be a firm price contract (as opposed to cost reimbursement contract) subject to economic price adjustments for inflation and consideration to contingencies and financial risks in a contract.

The contract will be a legal document and will be interpreted in case of disputes according to the rule of law in the Member State where it is applied. Legal advisors may be called in to draft the agreements and to participate in the contract negotiations. The final contract will be the binding document governing the AFR storage project.

The endpoint of the selection process and award of the contract signifies the beginning of the contract administration phase during which the contractor will carry out the work specified in the contract. The procurement cycle ends when the contract is completed, the technology is transferred to the customer (NPP or the implementing organization), and the work carried out by the supplier(s) is accepted.

6. STAKEHOLDER INVOLVEMENT

A decision to construct an AFR spent fuel storage facility cannot be made without the full participation of all relevant stakeholders. Depending on the national, legal and regulatory framework, this could include the need to meet local community concerns, concerns of the general public or concerns expressed at national or even regional levels.

Stakeholders are individuals, formal or informal groups, communities, corporate entities, and organized interest groups who have a *prima facie* entitlement to be involved in public decision-making processes.

Implication of stakeholder involvement must be envisaged at a very early stage as it could deeply influence storage plans, degree of regulatory and political support to storage plans, public and community support, etc. Therefore it is important to identify early who might be the stakeholders involved, and design a process to involve all stakeholders in order to reduce project risks related to stakeholder acceptance in various stages of the project life cycle. It might be a daunting task in an increasing number of cases to obtain public participation where needed if proper attention is not given to public involvement. Lack of public support could delay or even prevent the implementation of any AFR storage solution. There may be specific requirements in Member States to involving the public in necessary consultation activities and decision-making. This area is currently subject to many discussions at various local, national and international levels that could result in evolving future requirements.

6.1. Identification of stakeholders and their concerns

There will usually be a number of stakeholder groups who could have a say in the selection of an AFR storage facility design. Just as there are a variety of choices to be made in selecting a technology, there are a multiple and often conflicting interests among participants having a legitimate stake in the selection process. In the public and government sector, these participants could include the politicians, and the bureaucracy. In the private sector, there could be numerous special interest groups and business interests. There could be groups such as farmers and fishermen affected by the project. Finally, there are the general public and affected communities who will express their interest through local governments, various organizations and associations. Stakeholder representation could sometimes be overlapping due to the manner in which their responsibilities are shared or divided.

6.1.1. Provision of information

Information should be provided to all stakeholders in an open and timely manner in order to solicit their feedback. Besides direct dialogue or meetings with stakeholders, various communication media and opportunities such as open houses, information expositions, conferences and symposia, brochures, fact sheets and web casts could be used to disseminate information to a diverse group of stakeholders. The stakeholder groups could be provided with project documents and studies for review and feedback.

6.1.2. Issues of stakeholders

The key concern among stakeholders is often equity or the need to ensure that people with appropriate interests are given an opportunity to present their views, and to press for an equitable resolution. Many of the sensitive issues that arise must be given a place in a systematic selection process.

Key issues could be different perspectives on legislative bases and national policies, various relationship issues among groups, incomplete and often ambiguous information causing confusion among stakeholders, multiplicity of interests among groups, and conflicting objectives. Often, there is confusion in people's mind in distinguishing storage from disposal and the issues that this can cause in getting the AFR storage accepted by the public need to be recognized and addressed in public consultation programs. Such issues require analysis in terms of their strategic concern and potential resolution techniques.

Potential approaches in resolving conflicts could entail balancing of different perspectives, cooperative approaches in dealing with interrelationship issues, flexibility in case of issues arising from incomplete information or changing conditions, and teamwork and partnerships to deal with multiple interests. Some jurisdictions use a variety of mitigation and compensation measures for dealing with adverse social effects that may result from the undertaking. Political, socio-economic and public acceptance aspects play a significant role in the decision-making processes for an AFR storage facility.

Clearly, the project team as well as the proponent or the customer who has the ultimate responsibility for AFR storage selection must take into account all legitimate views and facts resulting from stakeholder involvement. As much information as possible should be gathered in advance for the stakeholder reviews. The views from all stakeholders must be openly and consciously taken into consideration, with a transparent consultation and review process. Such an open process allows for the development of a consensus and explicit justification for dismissal of views considered inappropriate relative to the specific circumstances of the proponent. Legal recourses and political intervention or support may be required in exceptional circumstances [70].

6.2. Modalities of stakeholder involvement

Normally, a designated organization will have the responsibility for the liaison function with stakeholders, for any specific decision process. Providing information related to operating experience is responsibility of both the operator and regulatory organization. The summary of objectives and means of the Stakeholders Involvement in Nuclear Issues is given in the INSAG-20 Report [71]:

- In many Member States the means of involving various stakeholder groups in licensing of nuclear projects are defined by legislation.
- General information on nuclear safety issues provided by authorities and regulatory organizations is of vital importance in increasing public knowledge of nuclear safety and radiation protection. This information is often accompanied by dialogue and direct interaction.
- Information on successful operations should be communicated. Such information may refer to a single installation, to set of installation or to the industry as a whole.
- General education on nuclear issues should start as soon as possible, even at the elementary school level.
- Information on potentially harmful consequences of the normal operation of various nuclear facilities should be openly discussed.

In what follows is a set of suggestions for managing the actions of responsible agencies in their dealings with stakeholders.

6.2.1. Inclusiveness

The first rule for effective stakeholder engagement is to be as inclusive as possible, rather than the opposite, in determining which persons and groups are entitled to be “at the table” in particular circumstances. Rarely is it advisable or necessary to exclude anyone who is prepared to make a case for inclusion. However, the body charged with oversight of the stakeholder engagement process has the responsibility, on behalf of all interested parties, to maintain an orderly and constructive atmosphere for the proceedings. Therefore the agency is responsible for setting fair rules of engagement (such as mutual respect) and for excluding those who are not willing to abide by them.

6.2.2. Level of engagement

The minimum level of engagement is "careful and respectful listening" – what is sometimes referred to as "consultation" – by the agency, together with dissemination of the results. However, as expectations for meaningful participation have increased over the years, this bare minimum is unlikely to be fully satisfactory to most stakeholders. At present stakeholders' desire concrete evidence of the ways in which the inputs they provide may influence, at the very least, the shaping of the agency's evaluation of risks, benefits, and trade-offs. To satisfy this demand the agency should be prepared to demonstrate how it has sought to apply stakeholder contributions to the issues under consideration. The appropriate level of engagement is defined by the nature of those issues. On the one hand, where the issues are conceptual in nature (i.e. how risks are characterized), a series of meetings at which differing viewpoints are explored may be sufficient. On the other, where siting decisions are on the table, the agency will be expected to present and discuss concrete mitigation measures for social, economic, and environmental impacts.

6.2.3. Scope of engagement

Over the course of recent decades in all developed economies, the trend has been to more, rather than less, intensive and extensive stakeholder engagements. This trend may be expected to continue. The reasons for this are many, including rising education levels among the population, improved communication and ready access to information (especially via the Internet and e-mail), and a rising level of wealth and personal well-being, which causes individuals to take keen interest in issues having to do with protection of health and the environment. The scope of the agency's responsibility for stakeholder engagement increases as a function of, for example: larger numbers and differentiation of stakeholder groups, demand for more elaborate rationales and for the consideration of broader sets of key issues, wider geographical areas, as people in rural and remote communities demand opportunities for policy input equal to that of their fellow-citizens in cities, and the greater diversity of ethnic communities within many nations.

6.2.4. Resources

The costs of participation to stakeholders are largely a function of the level of engagement. Community and public interest organizations often do not have paid staff and can command resources sufficient only to support the most basic level of activities. It is therefore unfair to expect them to be full participants in a process with others, such as salaried representatives of industry and governments, whose time and expenses are paid by their employers. The agency is responsible for creating a level playing field, within each type of engagement, in which all invited participants have access to the resources that will enable them to function competently.

6.2.5. Third-party facilitation

Almost without exception stakeholder engagements, at whatever level, benefit from access to professional facilitators representing neutral third parties. The agency in charge is responsible for providing this service. Stakeholder engagements usually take place when there are controversial issues and a wide range of viewpoints on them; in such circumstances emotions run high and face-to-face meetings can be difficult to manage. In almost every case, some stakeholders may imply the agency as being biased or as representing the interests of certain parties to the detriment of others. Professional facilitators can act as a buffer for these feelings and increase the chances of deriving genuine value from the engagements.

6.2.6. Due process

The participants' perception of the fairness with which stakeholder engagements have been conducted is the single most important element in their success. This is largely a matter of having clear rules of engagement known to all, and accepted by all, at the outset. Simple logistical requirements, such as providing adequate notice of meetings and keeping accurate records of proceedings, are as vital as more complex matters, such as ensuring a respectful treatment of the views of all participants. In view of the importance of due process, agencies are well advised to solicit in advance the assistance of professionals in the field of stakeholder participation to design the appropriate rules of engagement.

6.2.7. Feedback

Adequate and well-considered feedback to stakeholders from the agency, on the outcomes of the engagement exercises, is another key test of the agency's good faith. The feedback should be prompt, complete, and also responsive to further inputs from the participants, with respect to correction of errors, clarification of views and rectifying omissions in the record. A permanent record of the proceedings should be kept for future reference, since stakeholder engagements can occur in cycles. Learning from previous rounds allows everyone to re-engage in more productive ways.

6.3. Public Consultation

The role of public consultation in developing an AFR storage facility was discussed in several chapters and can be generally stated here as achievement of a "buy-in" from the affected communities and the public at large requiring the resolution of social and ethical issues, as much as scientific and technical ones. In this concluding chapter, the focus is again on this critical activity, which has been evolving over years in many Member States.

6.3.1. Evolution of public consultation: public's right to know and participate

In the past, projects were largely focussed on scientific and technical characteristics and the public consultation were minimal in many cases. This approach is now being re-considered as outdated and inadequate in seeking broad public acceptance as well as acceptance of affected communities to the project. There is recognition in some Member States that consensus with the public should be sought before implementing a chosen policy which would pose the need for a front-end public engagement process. There is a general recognized need that the public needs to be listened to and lessons learned from the dialogue and agreement needs to be actively sought before the project can advance to the implementation phase. The general public should be able to get information, share their views and involve themselves in the decision-making. The modalities of such engagement are rapidly evolving due to the introduction of computers and the Internet.

Voluntarism on the part of willing communities to host a facility could play a significant role in the public consultation process. In a voluntary process, a broad-based public consultation program is used to seek out interested communities for hosting the facility. Specific agreements may need to be put into place with the local governments (such as Municipal Councils) representing interested and volunteering communities and a *modus operandi* established for site selection and project acceptance (or rejection) such that public participation can proceed in an orderly and non-confrontational manner. Detailed consultation will take place with interested communities in parallel with scientific and technical investigations to short-list the volunteered sites to one or two sites based on technical criteria.

This will then lead to referenda by the hosting communities as to whether or not to accept the proposed sites. A successful referendum by a community will then lead to final selection of the site.

To achieve such an objective, social and community inputs may be integrated into the project activities primarily the site selection process. Some of the public input necessarily falls into policy and other overarching public and societal considerations, while some of the input would relate to specific local levels where affected communities at the site and along the transportation route would have a say in the consultation. The public consultation would also include the future generations on whose behalf the current generations could be expected to exercise certain responsibility.

Public consultation would have a wide range of perspectives on the project arising from how to perceive the need for the project and the policy alternatives to the expectations and fears about negative consequences, and public's non-scientific view of what constitutes risk and how the project addresses their perceptions of risk. The public may have concerns on scientific issues, socio-economic issues (such as employment, property values etc.), environmental effects and effects on the communities' social environment. Various pressure groups may have specific concerns that bear on the mission of such groups. Although scientific and technical assessments need to be still the mainstay of AFR projects in consideration to human safety and environmental protection, the decisions as to whether the assessments are adequate and the resulting findings are sound are considered inclusive societal decisions rather than sole decisions of the implementing organizations.

The recent Canadian NWMO study[26] identifies a number of fundamental social considerations based on the recognition of international experiences to obtain a social and ethical "buy-in" which includes: credibility, transparency, legislative compliance, sustainability, security, ethics, aboriginal perspectives, learning by doing, and institutional and governmental mechanisms to protect present and future generations. These considerations provide an overarching view of existing concerns in most societies that need to be approached in public consultation program

There is significant experience in public consultation which is still evolving. Experiences of many countries such as Sweden, United States, United Kingdom[27], Canada, and Germany, to mention a few, provide valuable lessons for the new implementing organizations. Forums such as the NEA's OECD Forum for Stakeholder Confidence also provide valuable information that has been accumulating in this area.

6.3.2. Issues and their resolution

Decisions made by the implementing organizations necessarily have to be responsive, i.e. take into consideration societal notions and choices. The presence and continuation of the radioactive and other hazards into multigenerational timeframes make the role of public consultation all the more complex since the current generations are confronted with decisions with respect to future generations. The issues are further complicated by the frequent public antagonism to nuclear power, opposition to current waste management policies, political

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[26] For a detailed review of how the Canadian NWMO public consultation program was carried out, see the Canadian NWMO web site, www.nwmo.ca

[27] The UK Government has started a consultation process which will look at the whole issue of managing radioactive waste including surface and underground storage of HLW.

factors, and the NIMBY (not in my backyard) syndrome. The public's view of risk tolerance is very subjective and a precautionary approach may be chosen in dealing with issues related to health and safety and environmental protection.

Resolution of all such issues often require *a priori* sound development of shared values, relationships and a sustained dialogue between the implementing organization and the general public that may include also aboriginal communities or nations and various special interest groups. In several Member States such a public involvement in decision-making is included to various degrees through the legislation such as nuclear waste acts, regulatory requirements and various other instruments such as government laws and aboriginal treaty rights. With such provisions, the judiciary systems can adjudicate if the implementing organization has met the legislative requirements with respect to public input and the resulting decisions acceptably meet the rights of the public in the eventuality of a conflict. There are numerous instances in the radioactive waste management where a lack of adequate public consultation have brought projects to a protracted delay and sometimes even to a halt. It is always in the interest of the implementing organization to ensure that the engagement with the public is thorough, that the insight of various special interest groups are comprehensively brought to attention throughout the various phases of the project.

6.3.3. Communication and consultation: plans and tactics

Public involvement or engagement would require on the part of the implementing agency, as a minimum, a communication plan and a consultation plan. Mechanisms may be put in place to assure the public to know and to participate not only in terms of consultation but also meaningful input to decision-making. It will be necessary to obtain social and ethical "buy-in" on all the controversial issues relevant to the project demonstrating transparency and credibility throughout such a process.

The communication plan may be designed to provide information to the public using established ways of communication (information campaigns through mail-out literature, libraries, public meetings, open houses, radio and TV media and more recently on-line internet-based consultation). Specific studies may have to be conducted to review socio-economic effects and quality of life issues.

The consultation plan will involve the general public and particularly the affected public such as communities at the potential sites and transportation routes and will be tailored to seek public input through two-way interchange of information. The extent to which the general public will be contacted would depend on the specifics of the project. There are a number of methodologies and tailored research methods for public consultation including standard surveys, focus groups, dialogue and deliberations, conjoint analyses, radio talk-shows, consensus conferences and citizen's juries. Experts and lay people of the public may have to interact in workshop settings to gauge public views and values that may influence the project.

In the initial stages of a project where policies and conceptual ideas are to be discussed, a broader public would be more suitable, whereas, in the later stages where siting and transportation routing choices are being narrowed down, specific communities affected by the project could be focused upon. In situations where a public hearing is required by virtue of legislation or political factors, the public would have a general forum where various issues would be discussed and resolutions will be sought. Once the project is defined and a willing community has come forward to host the facility, the public consultation can be further focused to the community hosting the site.

The design of the public communication and consultation plans would evolve in step with the scientific and technical evaluations of the project options and the site and route selection processes. In the initial stages, the information would be of a general policy nature with some conceptual information in the form of artist renderings, preliminary feasibility studies, site maps etc. As the project evolves and the site selection process advances, more specific information would require to be made available with site-specific engineering studies and investigations.

6.3.4. Sustaining support

It is important that the trust with the community that has agreed to host the facility be maintained and nurtured throughout the project. Employment to local communities, property value protection by the implementing organization, follow-up environmental monitoring programs, and contribution to the well-being of the community by being an active partner in the community would go a long way in sustaining community support to the project throughout the project lifecycle.

7. CONCLUSIONS

This TECDOC was prepared with the aim of providing information on the approaches for the selection of Away-From-Reactor (AFR) spent fuel storage facilities. It is often not evident how to choose a suitable option because of the complex issues and uncertainties involved in the decision-making. This publication provides some information by identifying the functional needs and selection criteria, which would have to be considered in the selection of the AFR facilities. It then outlines the process and methodologies for the selection from the early stages of need definition to the award of the contract for the acquisition of the facilities.

It should be noted that the focal issues in selecting an AFR storage facility can change from time to time as spent fuel management strategies and technologies advance. They can also differ from one country to another due to considerations such as legislative factors and public preferences. There may also be international obligations to take into account.

Because of the recent trend in market globalization, the practice of the tendering process is perhaps the most critical step in the procurement of facilities. Currently several of the nuclear plant owners or the implementing organizations on their behalf carry out the selection of AFR facilities and acquire them through the tendering process. As markets become more and more globalized, the services available would likely further increase, potentially with the market sector providing spent fuel storage services in their entirety.

Since AFR storage is not the final stage in the disposition of spent fuel, retrieval is important at any time during the storage period and in particular at the end of the lifetime of the storage facility. To this end, fuel handling and loading systems and equipment would be an integral part of the storage system, the need for spent fuel handling during long term storage may arise from the transfer to another storage system for various reasons. The lifetime of the AFR storage facility should be determined based on the necessary storage period prior to any future disposition, be it reprocessing or disposal. In cases where such a period is undefined or very long, one may be constrained by the achievable design life of the facility, in which case the spent fuel may have to be transferred from one facility to another during the storage period. Transferring of stored spent fuel from one facility to another may take several years, even decades, depending on the amount of fuel and loading and handling constraints at the facility. Such limitations would have to be given consideration in developing AFR storage, particularly in terms of facility durability, licensing conditions with regard to facility design life, and any licensing agreements with respect to extending the use of an existing storage facility beyond the licensed period.

Most of the countries continue to focus on energy sustainability and sustainable development of nuclear power and in that context, spent fuel management will continue to remain a vital issue. Trends towards deferred decisions worldwide on disposal facilities are likely to continue to put pressure on spent fuel storage in the years to come.

It is hoped that this publication will provide useful information by identifying the functional needs and selection criteria, both of which would have to be carefully considered in the selection of the AFR facilities. Particular attention is given to the recent trend in market globalization, which is expected to impose on the industry the practice of the tendering and contract management processes, which is the most critical step in the achievement of acceptable solutions in the procurement of facilities. The IAEA will continue to highlight the importance of AFR storage and the selection of facilities in the future perspective of spent fuel management.

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ANNEX I.
PROJECT NEEDS AND SELECTION CRITERIA FOR AFR STORAGE

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	Feasibility Evaluation	Functional Specification	Evaluation of Bids
A. PROJECT NEEDS					
1	**SPENT FUEL INFORMATION** AFR system should be adequate in meeting the quantity and characteristics of the spent fuel — Are the quantities and characteristics adequately defined? — Have the post-irradiation changes to spent fuel been considered? — Are procedures in place to identify and can defective fuel? — Will the spent fuel be consolidated prior to storage? — Has allowance been made to accommodate future changes to spent fuel?	X			
2	**LOCATION AND INFRASTRUCTURE** Site needs to be selected and identified — Have siting policies been considered (national, local, regional etc.)? — Has the site selection been carried out? — Has site information been compiled for AFR design, safety and environmental assessments?	X			
3	**FACILITY NEEDS** Have needs been identified for handling of spent fuel? — At the NPPs — During transportation — At the AFR storage — At the time of retrieval of fuel from AFR storage Have needs for transportation been reviewed? — Are transportation containers available? — Have transportation modes been identified?	X			

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	**Feasibility Evaluation**	**Functional Specification**	**Evaluation of Bids**
4	**RESOURCING NEEDS** AFR system should be adequate for future management of spent fuel — Has a staged approach been developed for storage? — Has the required lifetime of the facility been considered? — Has a design life for the AFR been identified? — Have the ageing mechanisms in the AFR been taken into account? — For the spent fuel — For the structures Emergency provisions for the AFR storage and transportation operations. — Does the planning include extra capacity for spent fuel at the AFR storage for emergencies? — Are there systems for emergencies in transportation? Arrangements to ensure safeguards objectives are met. — Have nuclear material accountancy and control procedures been identified? — Have provisions of equipment and systems been defined? — Have operational needs been identified? Physical security is required in meeting safeguards objectives and for protection of physical assets. — Have physical protection needs been identified? — Have design features been considered? — Have administrative controls been considered?	X	X		
5	**REGULATORY NEEDS** Licensing and environmental impact assessment requirements need to be identified. — Have the licensing needs and relevant regulatory authorities been identified? — At the NPPs — For transportation — At the AFR storage — At the time of decommissioning	X	X		

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	**Feasibility Evaluation**	**Functional Specification**	**Evaluation of Bids**
	— Have the licensing activities been scoped to determine their impact on project timelines? — Have the environmental impact assessment needs been identified? — Have activities been put in place for licensing studies? The AFR system is expected to meet any environmental assessment requirements required by regulatory authorities. — Have the environmental assessment needs been defined? — Have the regulatory authorities and their processes for environmental assessment been reviewed? — Have activities been put in place for carrying out the assessment?				
6	**MANAGEMENT OF PROJECT, QUALITY AND RISK** AFR storage project requires proper management. — Has a project manager been appointed? — Has project staff been identified? — Does the project organization have access to experienced consultants and architect/engineer? Participation of various stakeholders for successful implementation. — Have all the stakeholders been identified? — Are processes for public and community participation identified? A quality assurance (QA) program to ensure that the storage system will perform satisfactorily during service. — Are all planned and systematic actions needed for quality assurance identified? — For activities — For systems — For components — For materials — Is the QA compatible with safety and licensing needs? Project risk management.	X	X		

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	**Feasibility Evaluation**	**Functional Specification**	**Evaluation of Bids**
	Business risks need to be evaluated throughout the project and mitigated. — Has a project risk assessment scope been identified? — Has a process been put in place for project risk assessment?				
7	**INTERNATIONAL OBLIGATIONS** International obligations taken into account in all project activities. — Have the international obligations been identified? — In Safeguards — EU or any multi-lateral agreements — Bilateral agreements — Joint conventions — Treaties — Have procedures been put in place to address such obligations in the project?	X	X		
B. SELECTION CRITERIA					
8	**SITE** If there is no available site, a site selection process is required to find a site. The characteristics of the site should be identified. — Has a site selection process been put in place? — Is the following information available? — Site geography — Accessibility of the site — Transportation routes and modes to the site — Site infrastructure and services available — Acceptability of the site — Site geological/hydro geological and physical characteristics — External hazards, natural and human — If the site shares some other facility such as the NPP, — Are there services to be shared?	X	X	X	

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	Feasibility Evaluation	Functional Specification	Evaluation of Bids
	— Are the cumulative effects acceptable?				
9	**SAFETY AND LICENSING** The facility should be able to protect the fuel, shield and contain it, assure sub criticality and manage the waste **Structural performance** — Ability to withstand loads — Ability to last for the required period — Compatible with site and environmental conditions — Ability to withstand accident conditions — Potential for massive collapse of structures and their impact on safety should be known **Heat removal** —Temperature limits should be established — Adequate heat removal required **Sub criticality** — Inadvertent criticality should not be possible — Neutron absorbing material if used should last for the life of the facility — All credible situations affecting criticality safety should be reviewed. **Shielding** — Adequate shielding — Appropriate measures to prevent loss of shielding — Storage should maintain its shielding for all fuel handling activities		X	X	

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	Feasibility Evaluation	Functional Specification	Evaluation of Bids
	— Occupational and off-site doses should be acceptable **Containment** — Radionuclides should be contained during normal and accident conditions — Accumulation of radioactive material in fuel handling areas should be controlled — For water pools, process systems should be adequate for containment of radioactivity. **Handling** — Appropriate handling and transport systems required — Spent fuel should be retrievable — Fuel damage from dropping of spent fuel should be prevented — Dropping of objects onto spent fuel should be prevented — Should provide for decontamination — Verification required of all operations and detection of potential safety problems — Minimization of radioactive waste generation — Management systems required for radioactive waste — Preventing the migration of radioactivity from the facility — Ability to handle damaged fuel **Monitoring and inspection** — Accessibility needed for inspection and monitoring — Storage and handling systems should be monitored — Fuel integrity should not be compromised — Appropriate features needed for safe unloading of damaged fuel if needed — Fuel clad and structures monitoring over the design life **Licensability** — Licensing needs to be met				

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	Feasibility Evaluation	Functional Specification	Evaluation of Bids
10	**ENVIRONMENTAL IMPACT** — Effects of construction, operation and decommissioning should be evaluated — Environmental regulations to be met		X	X	
11	**SYSTEM FLEXIBILITY** Facility should have acceptable construction and fabrication characteristics. — Ability to be constructible — Modular — Flexible to expand as required — Possible to change vendors — Support national contractors — Easy to fabricate — Able to fabricate on-site — Minimum impact on existing facilities (NPPs)		X	X	
12	**OPERATION AND MAINTENANCE** Facility should have acceptable operation and maintenance characteristics. — Should be operable and maintainable — Passive in operation — Auxiliary systems should be defined and provided as needed — Safeguards monitoring required		X	X	
13	**DECOMMISSIONING** Facility should be able to be decommissioned — Facilitate decommissioning — Minimize quantities of waste — Minimize occupational exposure — Decommissioning plan prepared — Operating history of importance to decommissioning — Funding arrangement planned		X	X	

No.	Project Needs and Selection Criteria	Stage at which needs and criteria are developed			
		Project planning	**Feasibility Evaluation**	**Functional Specification**	**Evaluation of Bids**
14	**COST AND FINANCING** Cost and financing terms should be acceptable. — Detailed costs and broken down into categories — Cost uncertainties — Life cycle costs on present value basis — Financing sources and conditions		X	X	
15	**BID EVALUATION** Suppliers will be pre-qualified. — Technical competence of the supplier — Financial soundness of the supplier — Track record — References. The bid should meet all requirements identified in the BIS. — All technical needs and criteria — Scope of supply and services — Overall project schedule and delivery dates — Contract and commercial conditions — Guarantees and warrantees		X	X	X

ANNEX II.
COMMERCIAL CASKS FOR SPENT FUEL STORAGE (AND TRANSPORTATION)

(listed by alphabetical order of supplier/owner names), as of 2005

P=PWR, B=BWR, C=CANDU, W=WWER (440/1000), R=RBMK, H=HTR

SUPPLIER/ OWNER	CASKS/CANISTER		TECHNICAL REQUIREMENTS		
	Product Model	Number of Fuel Element	Maximum Burnup (GWd/tHM)	Maximum Heat Load (KW)	Total Wt. (MT)
AECL	Concrete Silo[28]	360C	9	1.8	
		342C	9	1.71	
		486C	9	2.4	
		540C	9	2.7	
BNFL Fuel Solutions metal cask and concrete cask	TS-125	21P/64B	?	22	139
	VSC-24	24P	51.8/45	24	144
	W-150	21P/64B	?	24.8/25.1	160
	W-21 (Canister)	21P	15~60	22/25.1	
	W-74 (Canister)	64B	15~40	17.6/24.8	
	MSB	24P	45	24	?
ENSA	DPT	21P	40	27.3	113/114
GNS	CASTOR 1C	16B	35	14.4	81.1
CASTOR family Metal cask and	CASTOR-V/19	19P	65	39	125.6123.4
	CASTOR-V/52	52B	65	40	126.2110.4
	CASTOR-Va	21P	75	40	133
	CASTOR-Vb	24P	75	34	108
	CASTOR-X28	28P	37.5	17.2	107.3
	CASTOR-V21(Surry)	32	60	32	116
	CASTOR X33F	33P	60	16.6	32
	CASTOR-440/84	84W440	42	21	30
	CASTOR THTR/	2,100H[29]	114	Ca.0.2	
	CASTOR-AVR	1,900H[2]	114	Ca. 0,2	
CONSTOR family concrete cask	CONSTOR-440/84	84 WER	41	20	120
	CONSTOR- 1000/19	19WWER	49	21	125
	CONSTORRBMK	102R[30]	24	7.0	84,4

[28] Also called concrete canister, NWMO Background Paper 6-1 (2005).
[29] Number of spherical ('pebble') fuel element.
[30] The 10m-long assembly of RBMK fuel halved for size fitting into a basket which was also used for emplacement into the metal cask CASTOR at Ignalina site.

SUPPLIER/ OWNER	CASKS/CANISTER		TECHNICAL REQUIREMENTS		
	Product Model	**Number of Fuel Element**	**Maximum Burnup (GWd/tHM)**	**Maximum Heat Load (KW)**	**Total Wt. (MT)**
Hitachi-Zosen Metal cask	Storage Cask	61B	50	17	118
MHI (+GA) MSF family metal cask	MSF-21P(*1) MSF-57B(*1) MSF-69B(*2)	21B 57B 69B	60 63 40	41 49 19	121 123 119
Holtec International metal reinforced concrete cask	HI-STORM 100 (storage) and HII-STAR 100 (transport) (HI-STAR 100U)[31]	MPC-24 MPC-32 MPC-68 UMS	61/63 50 54 36	20/28.2 28.7/NA 18.5/28.2 12.5	
NAC International metal cask and concrete cask	NAC-STC NAC-C28 S/T NAC-S/T NAC-MPC NAC-UMS MAGNASTOR	26P (BF) 56P (CF) 26P / 28P 36P / 26B 24P / 56B 37P //87B	45 35 45 36/43 50 60	22.1 20 17.4 12.5 / 17.5 23 35(P)/33(B)	127 161
OCL Corp	NEO-2521/2561	21P/61B	55	20	
OAO Izhora	TUK-104/M TUK-108/1	6/9 tHM R 5/7 W1000	? ?	? ?	95/93 39.6
OPG	DSC (CIC[32])	384 C	9	2	70
REA(*3)	REA-2023	24P/52B	33	24/20	105
KSL(*5)	TN-24	52B/37B	33	28/20	115/100

[31] Maureen Conley, "Holtec to ask NRC to approve underground design for dry storage facility", Nuclear Fuel, 26 April 2004).
[32] Prototype model.

SUPPLIER/ OWNER	CASKS/CANISTER		TECHNICAL REQUIREMENTS		
	Product Model	**Number of Fuel Element**	**Maximum Burnup (GWd/tHM)**	**Maximum Heat Load (KW)**	**Total Wt. (MT)**
Transnucleaire	TN-24 series (P)	24P	35/45	24	100
(TN family	TN-32 A/B	32P	35/45	20.6/32.7	115.5
metal casks	TN-40	40P	40/45	27	113
	TN-52L	52B	53	?	?
	TN-68	68B	40	21.2	115
	TN-97L	97B	26 (av.)	?	?
	TN-REG	40P	15	4.2	116.6
and	TN-BRP	85B	25	6.4	111.4
NUHOMS	TN-FSV				
Family	NUHOMS-07P	7P/18B		7	48.6
Canister-based	NUHOMS-24P	24P	45-62	24-40.8	
concrete module	NUHOMS 32P S	32P	45-62	24-34.8	
	NUHOMS-52B	52B	35	19.2	
	NUHOMS 61B	61B	40	15.8/18.3	
	NUHOMS-F	13-24P	40	9.9/13.5	133/136
	NUHOMS-MP	21P/61B		9.9-15.8	
	NUHOMS 56V	56 WWER	42		
	NUHOMS RBMK	95 RBMK	25		
Westinghouse	MC-10	24P/49B	35	13.5	?

(*1) Type MSF-57B is now in licensing stage in Germany. Type 21P is in preparation stage for licensing in Germany.

(*2) The design of type MSF-69B was approved as the type B (M) package in Japan. However it has not been in practical use yet.

(*3) REA2023 was originally developed by REA and its design right has been alienated to MHI.

(*4) The NEO family is now in design stage. Therefore OCL suggests withdrawing it from the list.

(*5) KSL (Kobe Steel Ltd.) is a licensee of TN type in Japan. This TN-24(52B/37B) was customized for Japanese utility by KSL.

ABBREVIATIONS FOR SUPPLIER/OWNERS:

AECL=Atomic Energy of Canada Limited

BNG=British Nuclear Group

GA=General Atomics

GE=General Electric

GNS=Gesellschaft fuer Nukleaire Services

OCL = Ocean Cask Lease OCL Corporation

OPG=Ontario Power Gen

NAC= Nuclear Assurances Corp.

NFT=Nuclear Fuel Transport Co., Ltd.

NFT=Nuclear Fuel Transport

REA=Ridihalgh, Egggers and Associates

TN= Transnucleaire

DAE= Department of Atomic Energy of India

MHI=Mitsubishi Heavy Industries, Ltd.

KSL=Kobe Steel Ltd.

MHI Comments

ANNEX III.
GLOBAL STATUS OF AFR STORAGE OF SPENT FUEL

(As of: End of 2004)

COUNTRY	**TYPE**		**STORAGE SITE**	**REMARK**
	WET	DRY	**(Pool Capa. in tHM / Dry Store Method)**	
Argentina	1	 1	Atucha (1,100) Embalse (concrete silo):120 silo	Dry system in plan for Atucha
Armenia		1	Metsamor (NUHOMS)	NUHOMS since 2000 (now being expanded)
Belgium	1	 1	Thiange (1,000) Doel (metal cask) : 65+165 casks	*Reprocessing terminated and disposal examined*
Brazil				
Bulgaria	1		Kozloduy (600)	*Some reprocessed in Russia*
Canada		9	Whiteshell, Chalk River, NPD, Douglas Point, Point Lepreau, Gentilly1 (concrete silo) Gentilly2 (MACSTOR) Pickering, Bruce (DSC)	Darlington DSC in plan for 2007
China	1		Lanzhou Pilot Reprocessing Plant (550)	Daya Bay spent fuel shipped in 2004 (by NAC-STC cask)
Czech Republic		1	Dukovany (metal cask) : 600 tHM	Capacity expansion in preparation to 1,340 tHM
Finland	2		Olkiluoto (245) Loviisa (204)	Storage capacity of Loviisa expanded, Olkiluoto in plan
France	1		La Hague (14,400) UP2 : NPH(2,000)+HAO(400)+C(3,600)=6,000	*Reprocessing policy pursued*

COUNTRY	TYPE		STORAGE SITE	REMARK
	WET	DRY	(Pool Capa. in tHM / Dry Store Method)	
			UP3 : D(3,500)+E(4,900)=8,400	
Germany		20	Gorleben (metal casks) Ahaus (metal casks) Juelich (metal AVR casks for HTR fuel) at all 18 NPP sites (see the attached list)	Some in operation , some others in construction or in plan *(see ADDENDUM below for more details)*
Hungary		1	Paks (vault)	Further expansion of capacity being evaluated
India	1	 1	TAPS (280) RAPS (concrete cask)	commissioned in 1991 commissioned in 1995
Italy				Interim storage of spent fuel in plan
Japan	2	 2 (1)	Tokai Reprocessing Plant (140) Rokkasho-mura Reprocessing Plant (3,000) Fukushima-Daini (metal cask) Tokai-2 (metal cask)	*Reprocessing policy pursued* A private AFR storage facility in plan at Mutsu, near Rokkasho
Korea (Republic of)		1	Wolseong (concrete silo)	Capacity expansion by MACSTOR in plan
Lithuania		1	Ignalina (metal and concrete cask)	72 CASTOR and CONSTOR casks storage since 1999
Mexico				
Netherlands		1	COVRA (vault)	*Some pent fuel reprocessed*
Pakistan	(1)			An AFR (pool) store in plan for Kanupp

COUNTRY	TYPE		STORAGE SITE (Pool Capa. in tHM / Dry Store Method)	REMARK
	WET	DRY		
Romania		1	Cernavoda (vault)	MACSTOR Commissioned in 2003
Russia	6		Kursk (3,400), St.Petersbug (4,048), Smolensk (1,564), N.Voronezh (400) Mayak, (560) Krasnoyarsk (6,000)	
		(1)		Vault storage facility in construction for Krasnoyarsk
Slovakia	1		Bohunice (600)	Further expansion option in study
Slovenia				
South Africa		1	Koeberg (metal cask)	Demonstration scale
Spain		1	Trillo (DPT metal casks)	80 casks capacity
		(1)	Jose Carrera	HI-STORM in construction
		(1)		Centralized AFR (vault capacity of 6,875 tHM) in plan for 2010
Sweden	1		CLAB (5,000)	CLAB Operation since 1985 Capacity to be expanded to 8,000 tHM
Switzerland		2	ZWILAG (200 metal casks) ZWIBEZ (48 metal casks)	Commissioned in 2001
	(1)			Goesgen (pool) in plan

COUNTRY	TYPE		STORAGE SITE	REMARK
	WET	DRY	(Pool Capa. in tHM / Dry Store Method)	
Ukraine	1	1 (1)	Zaporozhe (concrete cask) Chernobyl (NUHOMS)	VSC-24 in operation since 2003 (380 casks) NUHOMS for RBMK in construction A centralized AFR facility in plan for WWER
United Kingdom	1	(1)	Sellafield Reprocessing Plant (pool) B205 : Fuel Handling Pool for Magnox /AGR(2,650) AGR Buffer Pool (1,445) Oxide Fuel Store Pool (2,300) THORP : Thorp Receipt & Store (3,800) *Wylfa (modular vault : 958 tHM)*	Total capacity at Sellafield :10, 195 tHM *Wylfa is an AR facility*
United States of America	1	1 33	Midwest Reprocessing Plant at Morris (750) Fort St.Vrain (vault for HTGR) AR Sites : 34 dry storages licensed now (to be increased to 50 around 2010)	*West Valley reprocessing facility pool decommissioned* *See ADENDUM below for details*
TOTAL	**21**	**71**	**AFR Pool Capacity (55,227)**	

ANNEX IV.
DRY AFR FACILITIES IN USA AND GERMANY

SUMMARY OF DRY STORAGE STATUS IN THE USA (END OF 2005)

P=PWR, B=BWR

REACTOR SITE	STORAGE SYSTEMS	YEAR	CASKS (Inventory tHM)	*REMARK*
Arkansas Nuclear One (P)	VSC-24, Hi-STORM MPC-32	1996	24 (273.6)	
Big Rock Point (B)	Wesflex (W-150)	2002	7 (87.3)	
Browns Ferry (B)	MPC-68		3 (40.4)	
Calvert Cliffs (P)	NUHOMS-24P/-32PT	1993	49 (562.4)	
Columbia (B)	MPC-68	2002	15 (202)	
CT Yankee (B)	MPC-26	2004	40 (484)	
Davis-Besse (P)	NUHOMS-24P	1996	3 (72)	
Dresden (B)	Hi-STORM MPC-68 Hi-STAR MPC-68	2000	25 (336.6)	
Duane Arnold (B)	TN NUHOMS-61 BT	2003	10 (30.4)	
Fort. St. Vrain (HTGR)	Foster MVDS	1992	?	
Fitzpatrick (B)	HI-STORM MPC-68	2002	9 (121.2)	
Hatch (B)	HI-STROM MPC-68 HI-STSTAR MPC-68	2000	23 (309.7)	
McGuire (P)	TN-32 NAC UMS-24	2001	9 (102.6)	
Maine Yankee (P)	NAC UMS-24	2002	60 (681.2)	
Millstone	TN NUHOMS-32PT	2004	2 (30.4)	
North Anna (P)	TN-32	1998	23 (349.6)	
Oconee (B)	TN NUHOMS-24P	1990	84 (957.6)	
Oyster Creek (B)	TN NUHOMS-61 BT	2002	16 (193.2)	
Palisades (P)	BNFL VSC-24/ TN NUHOMS-32PT	1993	18 (205.2)	

REACTOR SITE	STORAGE SYSTEMS	YEAR	CASKS (Inventory tHM)	*REMARK*
Pale Verde (P)	NAC UMS-24	2003	34 (387.6)	
Peach Bottom (B)	TN-68	2000	28 (377)	
Point Beach (P)	BNFL VSC-24 TN NUHOMS-32PT	1995	20 (243.2)	
Prairie Island (P)	TN-40	1995	20 (380)	
Quad Cities (B)	Hi-STORM MPC-68		3 (40.4)	
Rancho Seco (P)	TN NUHOMS-24 (Modified)	2002	21 (234.2)	
River Bend (B)	Hi-STORM MPC-68	2004	1 (13.5)	
Robinson (P)	NUHOMS-7P / 24PTH	1989	12 (72.2)	
San Onofre - 1	NUHOMS-24PT1	2003	17 (187.6)	
Sequoyah (P)	Hi-STORM MPC-32 CASTOR-V21/X33 MC-10	2004	4 (60.8)	
Surry (P)	CASTOR V/21 / X33 MC-10 NAC-I28ST TN-32	1987	53 (668)	
Susquehanna (B)	NUHOMS-52B /-61 BT	1999	36 (296.7)	
Trojan (P)	Holtec MPC / BNFL TranStor	2003	34 (370.5)	
Yankee Rowe (P)	NAC MPC-36	2002	15 (256.5)	
US TOTAL			**793 (9,502)**	

ANNEX V.
SUMMARY OF AFR CASK STORAGE FACILITIES IN GERMANY

Site	Storage capacity	Storage capacity	Status		Emplaced
	(Number of storage positions)	(tHM)	Applied for	Licensed	(tHM) as at 12/04
Fuel pools in reactor buildings					
Nuclear power plants total	19776 positions[1)]	approx. 6119 tHM [1)]		X	3358
Onsite interim storage facilities					
Biblis	135 container positions	1400 tHM		X	
Brokdorf	100 container positions	1000 tHM		X	
Brunsbüttel	80 container positions	450 tHM		X	
Grafenrheinfeld	88 container positions	800 tHM		X	
Grohnde	100 container positions	1000 tHM		X	
Gundremmingen	192 container positions	1850 tHM		X	
Isar	152 container positions	1500 tHM		X	
Krümmel	80 container positions	775 tHM		X	
Lingen/Emsland	120 container positions	1250 tHM		X	153
Neckarwestheim	151 container positions	1600 tHM		X	
Obrigheim[2)]	980 positions	286 tHM		X	44
Philippsburg	152 container positions	1600 tHM		X	
Unterweser	80 container positions	800 tHM		X	
Temporary storage facilities					
Biblis	28 container positions	300 tHM		X	234
Brunsbüttel	18 container positions	140 tHM	X		
Krümmel	12 container positions	120 tHM		X	9
Neckarwestheim	24 container positions	250 tHM		X	149
Philippsburg	24 container positions	250 tHM		X	99
Centralised interim storage facilities					
Gorleben	420 container positions [3)]	3800 tHM		X	38
Ahaus	420 container positions	3960 tHM		X	58[4)]
Local storage facilities outside the reactor sites					
ZAB Greifswald	4680 positions	560 tHM		X	150
ZLN Greifswald	80 container positions	585 tHM		X	407
Jülich	158 containers	225 kg fuel[5)]		X	0,075[5)]

1) Part of the storage capacity has to be kept free for unloaded cores.
2) The storage facility at Obrigheim is a wet storage facility outside of the reactor building that was commissioned in 1999.
3) Including the positions for HAW canisters.
4) Total amount from power reactors; an additional approx. 6 tHM from the THTR.
5) Excluding thorium.

ANNEX VI.
DECISION ANALYSIS SOFTWARE SURVEY

Source: OR/MS Today, Oct. 2004, Lionheart Publishing, Inc, USA (http://www.lionhrtpub.com)

Product	Specific applications for which software is most widely used?	Comments
@RISK	Insurance & re-insurance, Oil & gas exploration, Financial analysis, Engineering & high technology, Academic	@RISK adds Monte Carlo simulation to Microsoft Excel. @RISK allows users to model uncertainty and variability with 38 probability distribution functions. Reports include dozens of charts and graphs, sensitivity analysis, scenario analysis, and more.
Analytica 3.0	Business modelling, financial analysis, risk analysis, R&D project evaluation, portfolio management, and more.	Provides a powerful, and easy-to-learn visual environment for building, analyzing and distributing small or large models, without a spreadsheet, offering clear hierarchical influence diagrams, efficient Monte Carlo treatment of uncertainty, and Intelligence
Crystal Ball Premium Edition (v. 7.0)	financial risk analysis, real options analysis, strategic planning, project management, portfolio allocation, valuation, business case analysis, demand forecasting, sales forecasting	Crystal Ball Premium Edition transforms your Microsoft® Excel spreadsheets into through the application of Monte Carlo simulation, stochastic optimization, real options, and time-series forecasting methodologies.
Crystal Ball Professional Edition (v. 7.0)	financial risk analysis, project management, portfolio allocation, tolerance analysis, cost estimation, Six Sigma, Design for Six Sigma, valuation, business case analysis, demand forecasting, sales forecasting	Crystal Ball Professional Edition transforms your Microsoft® Excel spreadsheets into dynamic models through the application of Monte Carlo simulation, stochastic optimization, and time-series forecasting methodologies.
Crystal Ball Standard Edition		
Crystal Ball Standard Edition (v. 7.0)	financial risk analysis, project management, portfolio allocation, tolerance analysis, cost estimation, Six Sigma, Design for Six Sigma, valuation, business case analysis, demand forecasting, sales forecasting	Crystal Ball applications transform your Microsoft® Excel spreadsheets into dynamic models that solve almost any problem involving uncertainty, variability, and risk.
DEA SOlverPro	Examples include site selection, bankruptcy forecast, comparisons of international electric utilities, and comparisons of university activities.	DEA SolverPro is an Excel-based data envelopment analysis tool. It is easy-to-use and comprehensive DEA software.
Decision Explorer®	Strategy development, stakeholder analysis, project definition, competitor analysis, risk definition/ management.	Software for analyzing qualitative data. Build, navigate and analyze causal maps of complex problems or issues. Structure thinking, see thoughts and ideas in context, examine causes and consequences and manage complexity.
DecisionPro 4.0	Business modelling; forecasting; and, risk assessment.	Desktop software for integrated decision-support applications - supporting decision tree analysis, Monte Carlo simulation, LP optimization, forecasting, expert systems, etc.

Product	Specific applications for which software is most widely used?	Comments
DecisionScript	Web-based/thin client decision support systems.	Build Web-based, thin client decision support systems that perform tasks such as Decision Tree analysis, Monte Carlo Simulation, Forecasting, Expert Systems, and Predictive Analytics.
Decision Tools Suite	Insurance & re-insurance, oil & gas exploration, financial analysis, engineering & high technology, aerospace & defence, academic	DecisionTools Suite is an integrated set of products that provides Monte Carlo simulation, genetic algorithm optimization, decision trees, and sensitivity analysis all in one package.
DPL 6.0 Professional	oil and gas applications; pharmaceutical applications	Syncopation Software took over the DPL business from PricewaterhouseCoopers in 2003. DPL has a long sales record and large installed base. Syncopation's focus is to ensure DPL's continued success.
Enterprise Miner	Decisions re scoring, credit, loans, fraud, purchase, cancellation policies, up sell or cross sell, CRM, pricing, assessing performance metrics.	identify trends, opportunities and threats in an integrated, collaborative environment so statistical modellers, IT and business professionals can effectively make key strategic business decisions
Equity 3.2	Portfolio Optimisation, R&D Investment, Project Evaluation/Appraisal, Portfolio Management & Optimisation, Project Prioritisation, Budget Allocation, Resource Allocation, Capital and Revenue Budgeting, Planning, Sales Territory Reorganisation, supplier se	A Multi-criteria decision modelling tool focussed on constructing your most efficient portfolio of expenditure/investment. Investments can be money, people, time, materials or other scarce resources.
Evolver	Optimization	Palisade Evolver turns Microsoft Excel into a powerful optimization tool. Evolver uses innovative genetic algorithm technology to quickly solve complex optimization problems.
Frontier Analyst®	Performance measurement and benchmarking for improved resource allocation and process improvement	Performs efficiency analysis based on comparisons between similar business units. Designed to provide graphical and numerical output for professional presentation of results to managers and decision makers.
GoldSim	Radioactive waste management, water management at mines, water resources planning, long term strategic planning, and evaluation of the risk and reliability of complex engineered systems.	GoldSim is a powerful and flexible probabilistic, dynamic simulation platform used for visualizing and dynamically simulating nearly any kind of physical, financial or organizational system.
HiPriority	Resource allocation, project prioritisation, IT investment, R&D budgeting, design for best value, consortium creation, post merger rationalization.	Searches for the best combination based on benefit/cost ratio. Allows 3 types of interaction between options to simulate "Synergy", "Dependency" and "Alternatives".
Hiview 3	Option Evaluation, Capital Projects, Policy Setting, Strategy Selection, Site Selection, Investment Appriasal, Relocation Issues, Problem Solving, Procurement Guidance and Budget Resourcing	Hiview is a Multi-criteria decision modelling tool that supports the appraisal and evaluation of options. Models can include non-monetary and even qualitative decision criteria.
IDS	Supplier Assessment, Quality Management, Risk and Safety Assessment, Engineering System Design Evaluation, Product Selection, Policy Consultation	The Evidential Reasoning approach does not require the stringent preferential independence condition which is hard to check when there are a large number of attributes.

Product	Specific applications for which software is most widely used?	Comments
Impact Explorer?/FONT>	Risk analysis, option prioritization, policy setting, human resource/ training applications in perception gathering and testing learning outcomes, resource allocation	A powerful audience response system allowing various forms of voting, ranking, matrix assessment and multiple choice Q&A. Uses hand-held keypads for group/ audience response.
InSight	Personal choices, experimenting with value mappings, education on MCDA theory.	True front end to On Balance or free decision making on simple problems.
JBi Javabean Decision Tree	classification tasks	Decion tree Java component for use in applications, includes CART, CHAID, C4.5. Also available as a low cost application interfacing via text files in NeuJDesk
Joint Gains	Multiple stake holder negotiations	Multi attribute negotiation support Web software based on the Method of Improving Directions. Continuous decision variables with linear constraints. Negotiators, most preferred directions elicited by value comparisons.
Logical Decisions for Windows, Version 5.1	alternatives evaluation, purchasing selection, engineering analysis and trade studies, environmental analysis, R&D selection, proposal evaluation, preference structuring and modelling	Models decisions requiring many evaluation criteria, and critical value judgments. LDW's many features and displays make it the most powerful software in its class.
Logical Decisions Portfolio, Version 1.0	R&D Evaluation, budget allocation	Companion to LDW that lets users select sets of alternatives. Finds the optimum portfolio of alternatives that maximizes value while meeting complex budgetary/structural constraints.
Netica	Financial risk management, decide insurance risk, environmental modelling, military command and control, diagnosis of aircraft, power plants, industrial processes, medical diagnosis and patient simulators, oil exploration...	Good for desktop use or to build systems. Full Bayesian networks system. Possible to represent relations with arbitrary equations.
NoRegrets	Too new	NoRegrets combines features and file structure from OnBalance and HiPriority to give support in moving towards Win-Win solutions.
OnBalance	Location planning, supplier selection, environmental impact, product choices, mergers & acquisition.	Advanced MCDA tool supporting multiple trees for different stakeholders and explicit value functions. Totally visual and interactive. Cut down or Run-Time versions available at lower prices.
Opinions-Online	Course evaluation, participatory policy analysis, voting	Platform for group collaboration on the Web, with interactive polls, surveys, voting and multi attribute rating. Online results can be viewed under different questionnaire fields.
Optimal Manager	optimal product investment, optimal product manufacturing, optimal product distribution, optimal product pricing and advertising	Comprehensive business optimization and applied decision support system of 47 program units; helps to project demand, plan production levels, and allocate funds.
Precision Tree		Palisade Precision Tree turns Microsoft Excel into a powerful decision analysis tool. Precision Tree users can build decision trees and influence diagrams in a spreadsheet.

Product	Specific applications for which software is most widely used?	Comments
PRIME Decisions	Evaluation of discrete choice alternatives under incomplete information. Can also be used for models with precise point estimates. Based on the PRIME method. Supports the analysis of interval-valued preference statements in value trees.	
Qualrus: The Intelligent Qualitative Software	health care, media analysis, political campaigns, human resources, corporate reputation studies, focus groups	Qualrus uses qualitative reasoning and intelligent strategies to make decisions based on unstructured data from diverse sources.
Quantitative Methods Software (QMS)	Instructing students on how to formulate a problem and how to interpret the results of a solution.	QMS is accessed as a hosted web application; no software to install. QMS is an inexpensive, easy-to-use teaching aid that provides a revenue share to instructors.
RICH Decisions	Examples include selection of risk analysis methods at energy utilities. See: O. Ojanen, S. Makkonen and A. Salo: A Multi-Criteria Framework for the Selection of Risk Analysis Methods at Energy Utilities. (to appear in International Journal of Risk Assess	Implementation of the RICH method, based on incomplete ordinal preference information. See: Salo and Punkka: Rank Inclusion in Criteria Hierarchies. (to appear in EJOR)
RISK Optimizer	Optimization Simulation	
RiskSim	Monte Carlo simulation of spreadsheet models.	RiskSim provides random number generator functions as inputs for a spreadsheet model, automates Monte Carlo simulation, and creates charts.
Roadmap GPS		
Roadmap GPS	Technology Roadmapping, Technology Off-roadmaping, New Product Forecasting, Risk Analysis, Competitive Analysis	
SensIt	Sensitivity analysis of spreadsheet what-if models.	SensIt performs single-factor sensitivity analysis by automatically varying the input values, tabulating the corresponding output values, and creating a tornado or spider chart.
Smart-Swaps	Multiple criteria evaluation of a set of alternatives	The first software supporting the Even Swaps method. Support includes identification of dominated alternatives, suggestions for applicable even swaps, and report and backtracking of the process.
StatTools	Statistical analysis, six sigma	Palisade StatTools adds an advanced statistics toolset to the industry-standard data analysis package Microsoft Excel. StatTools combines Excel,s ease-of-use with 36 wide ranging statistical procedures and 9 built-in data utilities.
TreeAge Pro Suite	Cost-effectiveness analysis of healthcare and treatment options, environmental remediation, protection of facilities from terrorists	TreeAge Pro models can be customized and distributed over the internet using TreeAge Pro Interactive. Remote users can access models, change values and perform analyses using a web browser.
TreePlan	Sequential decision problems under uncertainty.	Decision tree add-in for Microsoft Excel 97 and later for Windows and Macintosh.

Product	Specific applications for which software is most widely used?	Comments
Web-HIPRE	Evaluation of discrete choice alternatives, multiple stake holders	General purpose MCDA software on the Web. Supports SMART/Swing, SMARTER, AHP, direct weighting and value functions. Possibility to combine individual models into a group model.
WINPRE	Evaluation of discrete choice alternatives under incomplete information	Workbench for interactive preference programming; runs value tree and AHP models with incomplete interval type preference statements. SMART can also be used by point estimates.

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Advisory Group Meeting

Vienna, Austria: 14–17 May 2001

Consultancy Meetings

Vienna Austria: 27–30 March 2000, 27–30 May 2002, 24–27 March 2003