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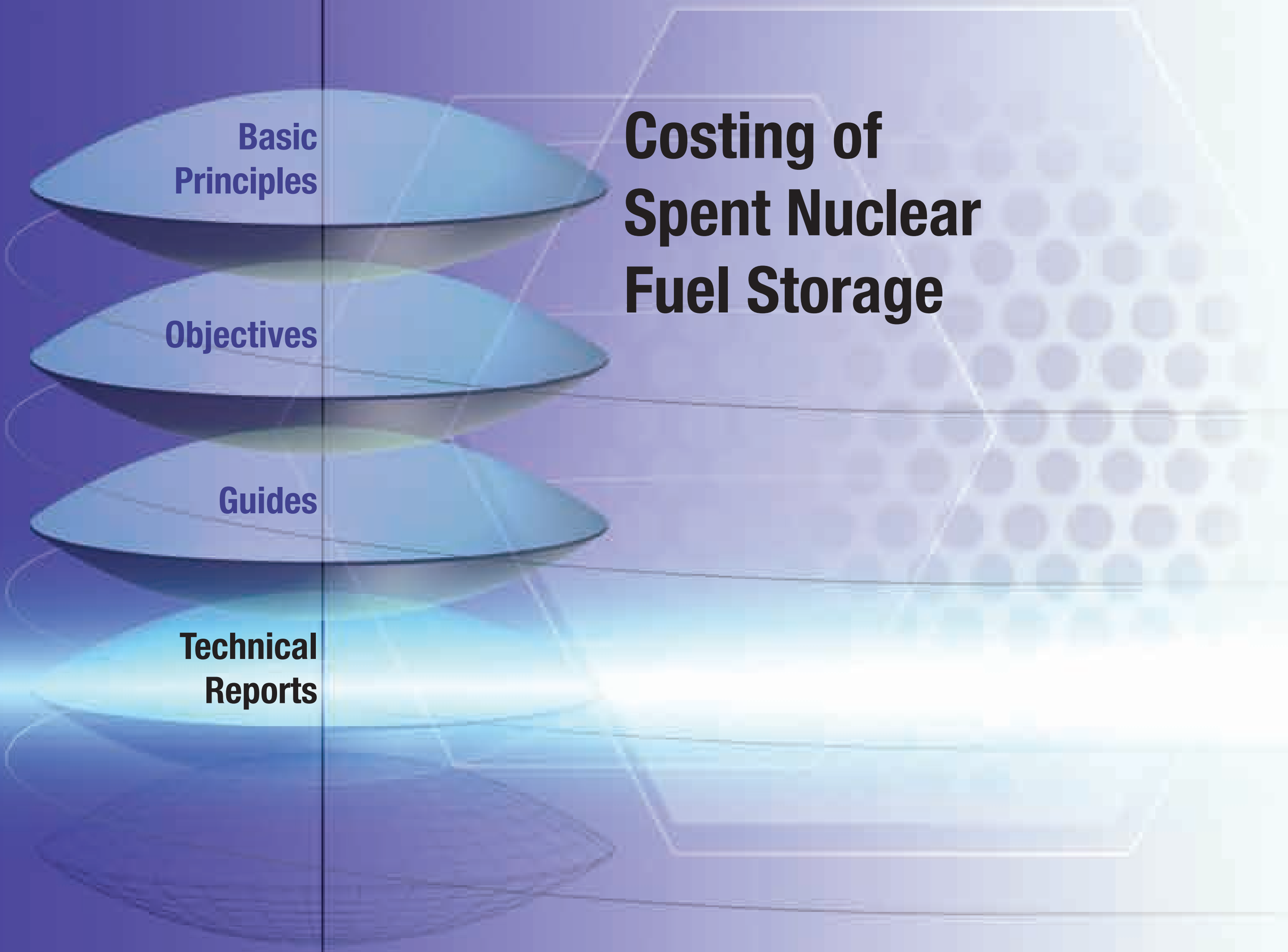

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Costing of Spent Nuclear Fuel Storage

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COSTING OF SPENT NUCLEAR FUEL STORAGE

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COSTING OF SPENT NUCLEAR FUEL STORAGE

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FOREWORD

Delays in implementing geological disposal coupled with a reduction of reprocessing activities have caused spent fuel inventories to grow. To manage this inventory, additional away-from-reactor (AFR) storage facilities are required.

While it can be said with confidence that competitive services for AFR storage are currently available from the market, it is often not evident how to choose the best option because of the complex issues and uncertainties involved in the decision. In addition, the focal issues in selecting spent fuel storage facility can shift from time to time due to policy changes, national strategies and technological advances. Global trends such as the privatization of the power generation industry and greater public involvement in nuclear matters are having profound impacts on the nuclear industry and, by association, spent fuel management.

In view of the large amount of spent fuel to be stored for a relatively long period of time, it is important to implement a safe, economic strategy for the best option. Also, even though the economic perspective is only one criterion among many, it is typically a key determining factor in any specific strategy for spent fuel management. For this reason, proper identification of economic factors and reliable estimation of spent fuel storage costs are becoming increasingly important for project planning and for comparison of alternative approaches.

The subject of costs of spent fuel storage was previously addressed in the IAEA publication Cost Analysis Methodology for Spent Fuel Storage (Technical Reports Series No. 361). This publication focused on the methodology for calculating the costs and cost analysis of spent fuel storage from power reactors. While it is still a unique guidebook on the subject, its scope does not cover comprehensive aspects of the economics involved in spent fuel storage costs as is done in the current report. This report also provides an update of cost analysis methods, including some examples of costs and cost calculations in the appendices.

This report deals with economic analysis and cost estimation, based on exploration of relevant issues, including a survey of analytical tools for assessment and updated information on the market and financial issues associated with spent fuel storage. The development of new storage technologies and changes in some of the circumstances affecting the costs of spent fuel storage are also incorporated. This report aims to provide comprehensive information on spent fuel storage costs to engineers and nuclear professionals as well as other stakeholders in the nuclear industry.

A variety of contributions have been made not only by the participants of the meetings, but also by a number of interested experts. Special thanks are due to C.K. Anderson from CKA Associates for helping in the final preparation of the report.

The IAEA officers responsible for this publication were J.S. Lee and Z. Lovasic of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The global community currently has the difficult but important challenge of meeting the growing demands for electric energy while reducing atmospheric emissions (greenhouse gases). In this context, nuclear power has begun to attract renewed interest in a growing number of Member States as a sustainable option to meet the increasing demand for energy, especially in the developing economies. Spent fuel management and disposal is perceived as one of the crucial unresolved issues.

The safe, economic management of the increasing inventories of spent fuel has a significant stake in the future of nuclear energy use due to its implications on economics, non-proliferation, nuclear safety and security, the environment, and other issues, which are, in fact, the criteria addressed in recent international initiatives for technical innovation, e.g. INPRO (IAEA), Gen IV/AFCI/GNEP (USA), MICANET (EU).

In the last few decades, spent fuel management policies have shown diverging tendencies among the nuclear power producing countries. Today, three major policy options for the management of spent fuel discharged from nuclear reactors have evolved as follows:

- The closed cycle, i.e. the reprocessing of the spent fuel for recycling of the separated plutonium and uranium as mixed oxide (MOX) fuel, and disposal of the treated wastes from the reprocessing operations;
- The open (once-through) cycle, i.e. the direct disposal of the spent fuel in a geologic repository with a perception of the spent fuel as a waste;
- The deferral of decision, i.e. ‘wait and see’ approach, with decisions postponed to a future time in anticipation of a better solution.

While some Member States have adhered to the classical strategy of reprocessing/recycle of spent fuel, some others have turned to a policy of direct disposal.[1] Many countries have taken a ‘wait and see’ approach in order to preserve the possibility of a better alternative in the future. But the ‘future’ for direct disposal may not be realized for several decades. In addition, when combined with a decline in the global use of reprocessing, these delays will increase the amount of spent fuel to be stored and prolong the storage duration while this issue is sorted out.

In any case, interim spent fuel storage must now be recognized as an essential part of the backend of the nuclear fuel cycle (see Fig. 1).

Moreover, the current situation in terms of spent fuel management is likely to persist well into the foreseeable future.

1.2. SPENT FUEL STORAGE REQUIREMENTS

As of the beginning of 2006, the bulk amount of spent fuel discharged from nuclear reactors in the world is about 290 000 t HM, with roughly less than one third of this amount having been reprocessed. The balance is in storage either in at-reactor (AR) pools or away-from-reactor (AFR) storage facilities. Projections indicate that the cumulative amount of spent fuel generated by 2020 will reach 445 000 t HM, only 25% of which might be reprocessed (see Appendix I). Under such circumstances, the current trend toward long term storage is expected to grow in the foreseeable future.

Meanwhile, many Member States have taken temporary measures at the existing AR pools (such as re-racking to a denser array or transshipment to another pool). However, as these readily available options are

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[1] Both the closed (reprocessing/recycle) and open fuel cycle (direct disposal) options for spent fuel management have been subject to a number of debates on various issues such as fuel cycle economics, proliferation risks and environmental impacts. 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.

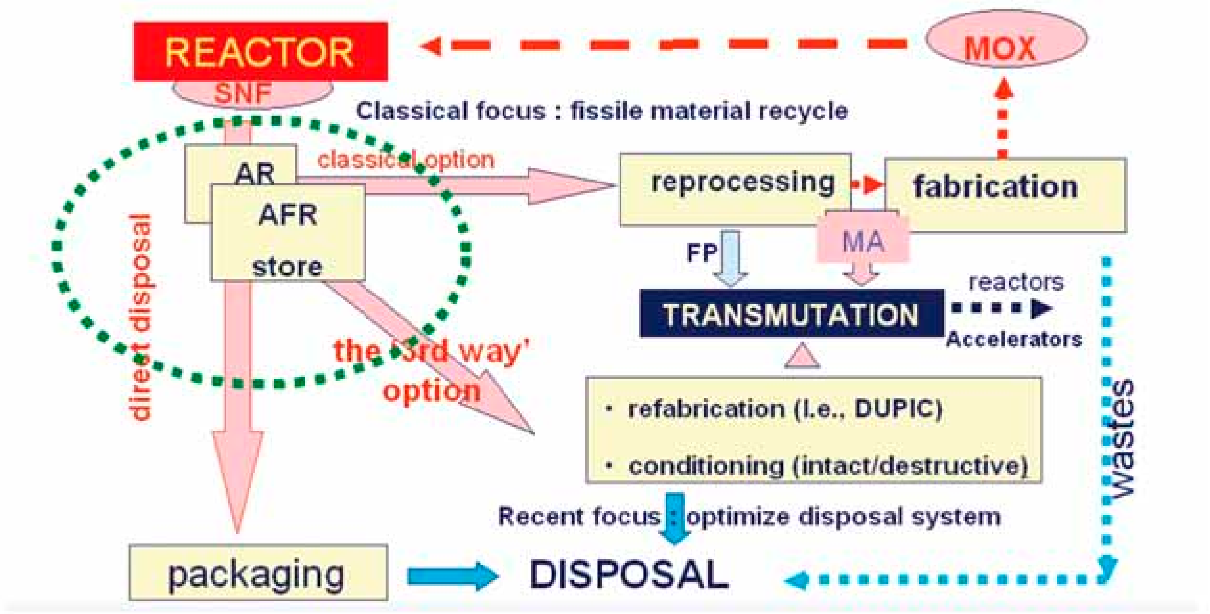

FIG. 1. Spent fuel management.

used up, additional storage in newly built AFR facilities will have to be provided. In these new storage facilities, consideration will have to be given to designs in which the storage period can be extended indefinitely until an endpoint solution becomes available, perhaps in 100 years or more.

Spent nuclear fuel has been stored safely in pools or in dry systems in over 30 countries for a number of decades. As a result of these achievements, it is clear that spent fuel can be managed without any detriment to the public health and safety. Given the major policy uncertainties, however, a further question arises as to which technology can accomplish this most efficiently and economically.

1.3. EVALUATION OF SPENT FUEL STORAGE

For new spent fuel storage facilities, various options can be considered on the basis of the owners' capacity needs, technical criteria and perceived contingencies. It is mainly a matter of defining the objectives and making a good selection from the available options. Today, nuclear plant owners, or implementing organizations on their behalf, can carry out the selection and acquire the AFR facilities through the tendering process among several competing technologies and suppliers. The tendering process, including development of relevant scope and appropriate requirements and criteria, is perhaps the most critical step in the process.

Whereas the final costs for a storage project will depend on the specific conditions and local factors, there are some factors that bring the prices closer to the global standard, such as common standards for safety control and internationalization of products and services. With the advent of these new realities, price comparisons have become much more expeditious and predictable for end users.

1.4. STRUCTURE OF THE REPORT

This report is meant to provide informative guidance on economic aspects involved in selecting a spent fuel storage system, including basic methods of analysis and cost data for project evaluation and comparison of storage options, together with financial and business aspects associated with spent fuel storage.

After the review of technical options for spent fuel storage in Section 2, cost categories and components involved in the lifecycle of a storage facility are identified in Section 3 and factors affecting costs of spent fuel storage are then reviewed in the Section 4. Methods for cost estimation and analysis are introduced in Section 5, and other financial and business aspects associated with spent fuel storage are discussed in Section 6.

The organization of this report is shown in Fig. 2.

As further information, there are three appendices at the end of the report containing an update on the status of spent fuel inventories and their management, information on commercial casks for spent fuel storage and transport. In Annex I, there are some examples of spent fuel storage costs, followed by Annex II, which includes a survey of software tools, and Annex III, which provides some case studies using an analytical tool (COMFAR III Expert).

2. SPENT FUEL STORAGE OPTIONS

In the early period of nuclear development, the pools for storing spent fuel at the plant were built with small capacity for only a few years' storage, on the assumption that spent fuel would be shipped to a reprocessing

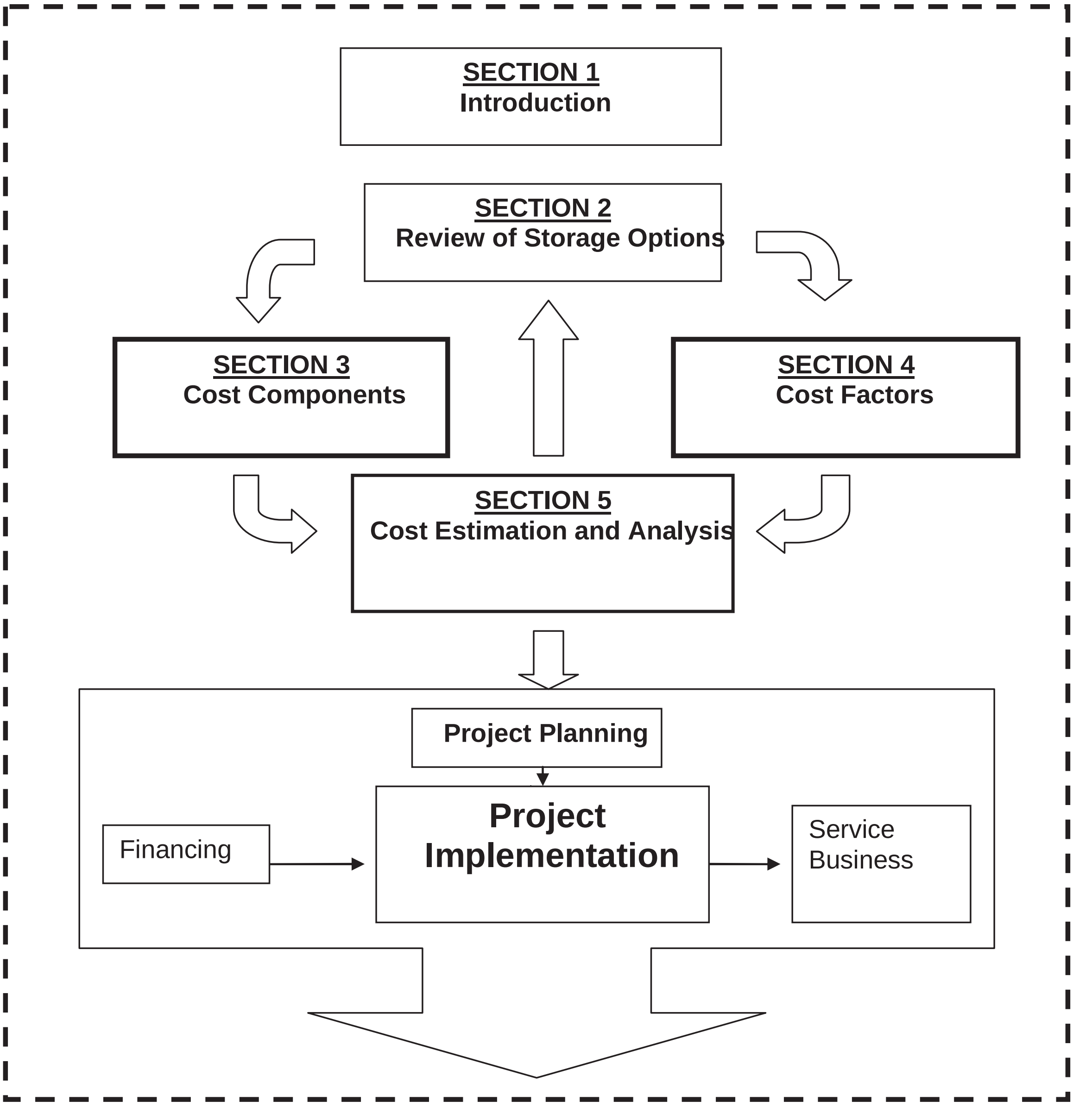

FIG. 2. Organization of this report.

plant for recovery and reuse of contained uranium and plutonium. However, the advantages of reprocessing came under international question in the late 1970s and since then reprocessing has been limited to a small number of countries. This gave rise to a need for new storage technologies, especially of dry types, in addition to the classical method of storage in water pools.

A historical evolution of storage technologies is summarized in Table 1.

A global cumulative summary of spent fuel storage inventory indicating storage quantities is provided in Appendix I.

2.1. REVIEW OF ALTERNATIVES FOR SPENT FUEL STORAGE

There are several aspects that are used for categorizing spent fuel storage facilities:

— AR versus AFR;
— AFR: on-reactor site versus off-reactor site;
— Wet versus dry.

Some general remarks about these different aspects are contained in Table 2.

TABLE 1. HISTORICAL EVOLUTION AND DEPLOYMENT OF SPENT FUEL STORAGE SYSTEMS

Option	Year					
	1950	1960	1970	1980	1990	2000
WET	Most of the AR and AFR pools					
DRY			• Vault (1971, Wylfa)			
			• Concrete Silo (1977, Whiteshell)			
				• Metal Casks (1986, Surry)		
				• Gorleben (CASTOR)		
					• Concrete Casks (1992, Surry)	

TABLE 2. ALTERNATIVES FOR SPENT FUEL STORAGE

	Options: WET
AR	All AR storage has been of wet type (water pools). The small capacities of older plants were mostly expanded by re-racking.
AFR	AFR pools have been built on reactor sites in order to provide additional storage of spent fuel. Large pools built for buffer storage of spent fuel received at reprocessing plants or at an anticipated disposal site.*
Remarks:	*Classical option, which has been universally used until late 1980s. Tihange and Goesgen are examples of AFR wet pools added at the reactor site. CLAB, La Hague and Rokkasho Mura are examples of AFR wet pools built at other (disposal/recycle) sites.
	Options: DRY
AR	Wylfa (UK), PAKS (Hungary) and Fort St. Vrain are examples of on-reactor site storage of dry (vault) type
AFR	Most recent choices for AFR storage are on-reactor site additions of dry cask type.
Remarks:	—

As mentioned, AR storage capacity expansion is limited today and most new storage is AFR. But the question remains as to whether or not to construct these facilities on reactor sites or at a new site (e.g. off-reactor site). Today, most new AFRs are built on-reactor sites, or within the exclusion zone of a reactor site. In either case, the technology used needs to be sorted out according to the particular situation.

2.2. TECHNICAL OPTIONS AND APPLICATIONS

The technologies currently available for spent fuel storage fall broadly into two categories, wet and dry, distinguished according to the cooling medium used (see Table 3).

The wet option has historically been used for temporary storage and cooling AR sites and in some interim off-site storage facilities generally associated with disposal or reprocessing sites (in anticipation of the next step in the cycle). More recently, however, a variety of dry storage options have been developed and applied in the international market. A list of commercially available casks for storage and for transport is given in Appendices II and III.

2.2.1. Wet storage (water pool)

Water pool storage has been used for storage of spent fuel as an established practice since the early days of nuclear power, due among other things, to the excellent properties of water for heat removal and shielding. Today, wet storage of spent fuel is a proven technology that can meet all storage requirements through proper engineering.

2.2.1.1. Water pool storage technology

Pools are designed to the following basic principles:

- To retain water and minimize leakage, which should be, as far as reasonably practicable, detectable, collectable and quantifiable;
- To be operable at all times during its design life and with as low as reasonably achievable radiation dose to site personnel;

TABLE 3. TECHNICAL OPTIONS AND APPLICATIONS FOR SPENT FUEL STORAGE

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/HI-STAR
	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 commercialized

- To be operable in the event of extreme weather conditions or pool water temperature increases following a prolonged loss of cooling system;
- To maintain safe storage conditions even after the occurrence of a seismic event.

Some of the technical features of a pool storage facility are as follows:

- Most pools have a stainless steel inner pool lining, which can be 100% X rayed during construction, with a permanent monitoring of the welded seams and X ray inspection capability to locate and detect any leak during pool operation. Some pools were coated in the past with the epoxy based paint and experienced paint degradation after a number of years.
- Leakage from the pool is monitored either by an integrated leakage collection system or via the inter-space in pools with two walls. In both cases, any recovered pool water may be cleaned up and returned to the main pool.
- The pool water is cooled and purified with heat exchangers and ion exchange units, either in-pool systems or systems installed outside of the pool. Normal water temperature is below 40°C and the pool bottom is cleaned (with a vacuum cleaner) to prevent any accumulation of settled particles.
- Activity concentrations in pool water are kept at very low levels, on the order of $1.85\ 10^7$ Bq/m^3 to $3.7\ 10^7$ Bq/m^3. While cobalt-60 is the principal source of radioactivity in the pool, failed fuel assemblies are generally stored in specially designed canisters to prevent further contamination of pool water, especially by Cs-137.
- In addition to control of activity by ion exchange, some pools are operated with an imposed chemical regime for: (a) pH control, (b) the maintenance of boron levels for criticality control where necessary, and (c) the maintenance of low levels of aggressive anions, such as chloride and sulphate, to minimize fuel corrosion/degradation. Maintaining good water chemistry provides good water clarity and prevents the formation of microbiological organisms in the pool water. If they do occur, they are treated with specific biocide chemical dosing.
- At properly maintained pools, average operator dose rates can be as low as 1 mSv/year/operator.

While there are many common features between wet pools, some differences in design concepts still remain as a result of local operational and/or regulatory requirements.

2.2.1.2. Functional configuration

Whereas the technical concepts for AFR wet pool facilities are similar, there are notable differences in terms of configuration, mostly as a consequence of some pre-existing site condition for spent fuel handling and storage.

Single pool

This is the simplest layout adopted for most AR pools with small capacity. Because of their location in the plant, a physical (i.e. dimensional) expansion of a single pool to a larger capacity is difficult, if not impossible. Generally, the only available option for storage expansion of AR wet pools is re-racking with maximum density storage racks (see Section 2.2.1.3).

Serial pools

In a few cases, a multiple number of additional pools may be connected in series by water gates on the walls between those pools (or underwater tunnels, conveyers, etc.). This could likely be the case when an additional segment of pool(s) is constructed as an addition to the existing pool(s) for expansion of capacity. Spent fuel will have to be moved through the pools for which a passage space is needed. In such a case, isolation of a pool would be difficult in case of leak or any other emergency.

Parallel pools

In a similar manner, a multiple number of pools may be connected in parallel by water gates on the wall shared by a water channel. It is possible to separate any one of the pools with a view to emptying for regular repair work or in an emergency, independently of other pools.

In either case, water tightness is required for the water gate operations during fuel transfer to and from the water channel, as well as for storage.

2.2.1.3. Compact storage methods

Re-racking

As spent fuel storage needs have increased, most spent fuel owners have found that the easiest and least expensive way of increasing storage capacity is through re-racking of pools so that fuel assemblies could be stored closer together. This requires replacement of racks with higher density, ‘poisoned’ (for absorption of neutrons) storage racks. Re-racking can result in an increase in the storage capacity of the pool by 40% to over 100%, depending on the specific situation.

Before re-racking can be performed, it is first necessary to establish that the pool has the structural capability to accept the added weight involved. To satisfy criticality requirements, neutron poisons are generally used in high density rack designs. There are several different poison concepts that distinguish the designs of various vendors.

As the easiest and cheapest method, re-racking already has been used extensively at most nuclear power stations. There is little opportunity for further accommodation of spent fuel by re-racking at existing plants.

Other methods

There are several other methods for storing more spent fuel at existing facilities, such as double–tiering and rod consolidation.

Application of the double-tiering technique is only possible in rare cases where the pool conditions are adequate for such stacking operation. It raises questions of weight and seismic stability, and since access to some spent fuel is difficult, complex accountability and safeguards issues arise.

In principle, rod consolidation could double the capacity of the pool by underwater placement of spent fuel rods from two assemblies into a rod storage canister of the same dimension as for one assembly. Conceptually, the non-fuel bearing components (NFBCs) of the assemblies are compacted and stored separately or disposed after decontamination. A number of feasibility demonstration projects were conducted in the 1980s, both in wet and dry conditions (mostly in the USA), but there have been no commercial applications for reasons to be discussed below (see Section 2.2.3).

2.2.1.4. Advanced concept for pool storage facility

Some advanced pool concepts for spent fuel storage incorporate features intended to ameliorate some known drawbacks of the wet storage systems. Such advancements include, for example, cooling and purification systems modularized and located inside the pool itself by using submersible equipment (as in the Nymphea system used in the storage pool at the La Hague reprocessing plant).

Some security enhancements have also been reported (e.g. protective concrete cover over the water pool, etc.) for the new pool facility design at the Gösgen station in Switzerland.

However, neither of these concepts increase capacity or improve costs.

2.2.2. Dry storage options

There are several dry storage designs available from vendors in the international market that differ in design details. However, discussion here will be limited to **generic** technologies, in order to develop a context for the selection process described later.

The four generic types of dry storage are:

- Metal cask;
- Concrete cask/module;
- Vault;
- Other (drywells, tunnels, etc.).

The technologies are 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. They also differ in terms of materials of construction, size, modularity, spent fuel configuration, layout of the storage containers (horizontal, vertical, etc.) and methods for fuel handling.

2.2.2.1. Metal casks

Metal casks can be designed either for storage only or as dual-purpose casks, i.e. for both storage and transportation. Shielding is provided primarily by the cask structural material, which may be either forged steel, nodular cast iron, or composite materials. Casks are generally stored in the open on a concrete pad in an upright vertical position. However, in some countries in Europe such as Switzerland, Belgium and Germany, casks are stored within a building, which could be a thick concrete wall enclosure, like the concept developed by Wissenschaftlich-Technische Ingenieurberatung Gmbh (the WTI concept) or the KONVOI concept in Germany.

A typical metal cask consists of the following components:

- A basket assembly, which locates and supports the fuel assemblies, transfers heat to the cask body wall, and provides neutron absorption to satisfy nuclear criticality requirements;
- The containment vessel consists of an inner shell, which is usually a welded, carbon steel cylinder with an integrally-welded carbon steel bottom closure; a welded flange forging; a flanged and bolted carbon steel lid; and lid penetration assemblies with bolts. There are two penetrations through the containment vessel, both in the lid: one is for draining and the other is for venting. A double-seal mechanical closure is provided for each penetration. Double metallic O-ring seals with inter-space leakage monitoring are provided for the lid closure. To preclude air in-leakage, the cask cavity is pressurized above atmospheric pressure with helium;
- A gamma shield provided around the walls and bottom of the containment vessel by an independent shell and bottom plate of carbon steel, which is welded to the closure flange;
- A neutron shield surrounding the gamma shield, enclosed in an outer steel shell, for additional radiation shielding against neutrons. Neutron shielding is provided by a borated polyester resin compound;
- A protective cover for weather protection for the closure lid and seal components;
- A pressure monitoring system;
- Sets of upper and lower trunnions for lifting and rotation capability for the cask.

Metal casks are used in a number of countries.

2.2.2.2. Concrete casks, silos and modules

Concrete casks

Concrete casks are similar in shape to metal casks except a concrete overpack provides shielding and the steel liner in the inner canister cavity of the concrete cask provides containment. A typical concrete cask includes the following components:

- A transportable storage canister (TSC), which is a circular cylindrical shell with a welded bottom plate designed to contain the spent fuel assemblies;
- A fuel basket;

— A shield lid;
— Two penetration port covers;
— A structural lid.

The concrete overpack for the TSC provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the TSC during long term storage. It is usually a reinforced concrete structure with a carbon steel inner liner, and has an annular air passage to allow the natural circulation of air around the TSC. The air inlet and outlet vents take non-planar paths to the cask cavity to minimize radiation streaming.

Concrete silo

Silos are large monolithic structures, usually constructed of reinforced concrete. The concrete provides the shielding, but an inner steel liner provides containment. The steel liner is sealed after loading with irradiated fuel. The use of internal cooling allows a significant amount of heat to be removed from the vessel and prevents overheating and degradation of the concrete material in the shield. Similar to concrete casks, specially designed equipment and systems would be required for loading (and unloading) the spent fuel from and to transportation containers.[2]

Concrete modules

The NUHOMS storage system is an example of a horizontal concrete module system. The system uses sealed metal canisters to contain the spent fuel. Fuel is loaded vertically into the sealed metal canisters, which are stored in a horizontal orientation inside the concrete storage module. An on-site transfer cask is used to transfer the fuel bearing canister to the horizontal concrete storage module. The fuel bearing metal canisters use a double lid closure. They are seal welded and tested for leak tightness. Some sealed metal canisters may be licensed for transportation as part of a transportation package.

2.2.2.3. Vaults

A vault is a reinforced 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 can contain one or more spent fuel assemblies stored in metal 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 for the reception and handling of the spent fuel assemblies. The storage concept permits modular construction and incremental capacity extension.[3]

Drywell

A dry well is a stationary, below ground, lined, individual cavity. Each storage cavity may be designed to contain several spent fuel assemblies. The actual number of fuel assemblies is determined by the fuel and storage media. Shielding is provided by the surrounding earth and closure shield plug. Primary heat removal is by conduction into the earth. Each of the dry storage concepts has storage cavities filled with a cover gas which can be air, nitrogen, carbon dioxide or any of the inert gases — helium, argon or neon.

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[2] A typical example of a silo system is AECL's concrete canister, which is built on-site using regular reinforced concrete and is fitted with a steel inner liner.

[3] Examples of vaults located at reactor sites are the Wylfa facility (Magnox dry storage) in the United Kingdom, the Modular Vault Dry Store (MVDS) facility at PAKS in Hungary, and the Fort St. Vrain MVDS facility in the USA. Examples of vaults that are located away from reactors and receive pre-loaded containers are CANSTOR/MACSTOR at the Gentilly-2 NPP in Canada and another design to store CANDU fuels.

Twin tunnel concept

This is a subsurface storage method that combines the drywell concept with borehole type emplacement in geological disposal repository, with a view to long term interim storage before final 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 lid sealing in a hot cell facility located at the tunnel site. The canister package is then brought by remote control through drifts 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.

2.2.3. Methods involving disassembling of fuel elements

There are several technical concepts developed or proposed for compact storage (or disposal) packages that have not been widely used.

2.2.3.1. Rod consolidation

LWR fuel

Rod consolidation was conceived as a further step beyond re-racking for dense storage of spent fuel, to a compaction ratio of 2:1. At first, the techniques used for fuel inspection, repair and reconstitution were thought to be applicable and were used in demonstration programmes of spent fuel rod consolidation conducted in storage pools in the USA during the late 1980s. However, the reality of the process proved to be more difficult and expensive for the following reasons:

- New specialized equipment had to be developed to achieve the desired rod compaction ratio of 2:1;
- Managing a large number of 3–4 m fuel rods remotely was problematic and increased risk of damage;
- The process required a long time to complete;
- Occupational exposures and pool contamination risk increased;
- Logistics of in-pool consolidation were complicated and interfered with other priority activities;
- Required degrees of compaction of the non-fuel bearing components were not achieved;
- The consolidated rod package was incompatible with the developing transportation and waste disposal packages.

Today, the concept has been largely abandoned for purposes of spent fuel management, although some experimental programmes were continued in the USA and in several other countries for possible use in preparing spent fuel for disposal.

RBMK fuel

A notable feature of RBMK fuel is the 10 m long fuel assembly design. For post-reactor management, these RBMK assemblies are cut in half and the separated sections (bundles) of fuel rods are placed in a large basket for subsequent handling either in pools at the site or in dry storage casks or modules for interim storage. At the Ignalina RBMK plant in Lithuania, the rod-bundle baskets are loaded into CASTOR or CONSTOR type storage casks. At Chernobyl, the spent fuel rods are consolidated into bundles with a view to horizontal storage in NUHOMS type modules. However, these techniques are unique to RBMK reactors and fuel design.

3. COST CATEGORIES AND COMPONENTS

There are three basic categories of costs associated with a spent fuel storage facility:

- Capital costs related to facility construction and equipment;
- Operations and maintenance costs (including loading and unloading);
- Decontamination and decommissioning cost at the end of the useful life.

In some cases, the cost of spent fuel transportation to and from the storage site may be a consideration in a total evaluation.

Within each category, there are different components that should be well distinguished in order to make rational cost determinations.

3.1. LIFE CYCLE OF A FACILITY

A project for spent fuel storage involves a series of phases over the life cycle of the facility that can be summarized as shown in Table 4.

The project definition, design and engineering, and regulatory approval stages all precede the construction phase. These activities should be possible to complete within 3–4 years before construction begins, depending on the regulatory environment.

Construction can be expected to take about one to five years, depending on the technology chosen and the conditions in which the project is carried out.

The operational phases (loading, storage and unloading) will have variable time requirements depending on the capacity of the storage facility, the rate at which spent fuel will be available for storage, and the forecast schedule of removal of spent fuel from the storage site.

The decontamination and decommissioning phase will require 1–5 years after the removal of all spent fuel from the storage site, depending on the size (capacity) of the storage facility.

TABLE 4. COST CATEGORIES AND COMPONENTS

Category of costs	Project phase	Remark
CAPITAL	Project Definitions	Alternatives are evaluated to select the best option. A plan for project implementation is established.
	Design Engineering	The facility is designed. The investment plan established.
	Regulatory Approval	Safety analysis documents are prepared. Licences are issued by authority for the facility.
	Construction	The storage facility is built.
O&M	Spent Fuel Loading	Spent fuel is placed in storage in the facility. Dry storage casks/modules are procured.
	Storage Only	Monitoring is carried out and protection of the stored spent fuel is provided.
	Unloading	Spent fuel is removed from storage. Spent fuel is transferred to a transportation cask (if applicable). Spent fuel is shipped to off-site destination.
D&D	Decontamination and Decommissioning	The fuel storage facility is decontaminated and dismantled. Site is restored to its original condition.

3.2. COST CATEGORIES AND COMPONENTS

3.2.1. Preparatory costs

Preparatory activities include, but are not limited to project management, design and engineering, and licensing. This is the time when key assumptions and technical specifications for the spent fuel storage project must be defined, i.e. the nature of the technology to be used, the timetable for various actions, the type and amount of spent fuel to be stored, and the likelihood of potential changes, either in the licensing procedures or related to societal or political factors.

The licensing process for spent fuel storage facilities usually follows regulatory requirements of the local competent authority for nuclear safety as well as a country's environmental requirements. In particular, the environmental assessment, a critical path item in the approval process, generally allows public consultation and can take considerable time. It is in the interest of the project's proponent to initiate its own programme of public consultation and dialogue early (see Section 4.6 on Risks and Uncertainties).

3.2.2. Capital related costs

The individual items of capital cost will vary depending on the storage technology. Generally, however, the capital cost of the basic facility (infrastructure) can be assumed to occur prior to any actual storage taking place.

3.2.2.1. Pool storage

In the case of pool storage, the capital cost includes the pool, the building that houses the pool, spent fuel handling systems, pool water cleanup and monitoring systems, air filtration and monitoring systems and security systems.

3.2.2.2. Storage in casks

In the case of the use of dry storage modules or casks, the capital cost of the basic storage facility includes the pad and land on which the dry storage casks or modules are to be stored, plus the security and monitoring equipment and facilities that are needed to protect the stored spent fuel and to provide assurance [to ensure?] that the radioactive content of the spent fuel is appropriately isolated from the biosphere. In some Member States, a cask storage building may be required, significantly changing the capital cost and design cost for this option.

The cost of the auxiliary equipment necessary to handle storage cask/modules, and canisters or baskets, and place them into storage can be assumed to be a capital cost that is incurred upfront – prior to actual storage taking place. (Note: The cost of the auxiliary equipment needed solely to **remove** spent fuel from storage and load it into a transport cask for off-site shipment, if different, can be assumed to be a cost that can be delayed to the time of first removal of spent fuel from storage. Transport cask impact limiters may be an example of this.)

The cost of the actual casks/modules and associated canisters or baskets can be assumed to be incurred in the year immediately preceding their actual use.

3.2.2.3. Vault storage

In the case of vault storage, the capital cost includes the vault, the building that houses the vault(s), spent fuel handling systems, air filtration and monitoring systems, and security systems. As in the case of a pool, all of these costs are generally incurred prior to the commencement of storage. However, it is possible to modularize the vault design to some extent so that storage can be added in increments. In this case, some capital expenditure can be delayed until needed.

The capital cost components for the different technologies are summarized in Table 5.

In all cases, there are other upfront costs associated with project management, design and engineering, and licensing. Costs for these preparatory activities may represent up to 20% of the total capital costs.

TABLE 5. CAPITAL RELATED COSTS

Option	Pool	Cask	Canister/Basket	Vault
Infrastructure (if needed)	Land			
	Site preparation			
	Bridges, roadways, site access			
Systems	Pool building	Storage cask	Canister or basket	Vault building
	Pool structure	Cask handling	Canister handling	Storage vault
	Water cooling	Cask loading and unloading	Canister loading and unloading	Canister handling
	Water purification	Cask sealing	Canister welding	Canister welding
	Air filtering	Cask operating	Canister operating	Air filtering
Transfer equipment	Fuel (basket) handling	Transfer cask		
		Transfer cask handling		
		Transfer cask loading and unloading		
Transport equipment	Transport cask			
	Transport cask handling			
	Transport cask loading (and unloading)			
Decontamination	Decontamination			
Common facilities	Airborne particulate monitors			
	Radiation monitor			
	Security fencing			
	Intrusion alarm system			
	Access control system			
	CCTV monitoring system			
	Guard house/stations			

TABLE 6. ELEMENTS OF OPERATING COSTS FOR SPENT FUEL STORAGE

- Staff costs (i.e. salaries, wages, benefits, etc.)
- Materials and supplies
- Utilities (including water, electricity and fuel)
- Annual licence charges
- Overhead (including property taxes, insurance)
- General and administrative expenses

3.2.3. Operation and maintenance costs

Operating costs for a spent fuel storage facility will vary widely depending on whether the storage technology used is passive or active. For example, water pool storage generally requires the operation of cooling and cleanup systems for the pool water. Experience has shown that this involves higher operating costs than for a vault or a cask that is cooled by natural convection. Nevertheless, the same basic elements of costs are applicable. An example listing the elements of operating costs for the storage of spent fuel is shown in Table 6.

These costs must be estimated on an annual basis for all operational aspects of the spent fuel storage operation, including:

- Emplacement and removal of spent fuel into or from storage;
- Seal welding and opening of canisters of spent fuel;
- Waste conditioning and disposal;
- Maintenance;
- Environmental monitoring;
- Physical protection;
- Safeguards.

Alternatively, operating costs can be estimated on a unit basis and the total annual operating costs determined by applying the unit cost times the number of units for each year. For example, for each unit, separate costs can be established and applied to the number of units to be loaded and emplaced in storage, or removed from storage and unloaded during each year. These costs are for:

- loading a cask or other storage module;
- cask sealing and decontamination;
- transfer of the cask to the storage location and emplacement in storage;
- removal of the cask from storage and transfer to an unloading facility;
- transferring the fuel from the storage cask to the transport cask;
- decontamination and monitoring of the loaded transport cask;

In this case, the annual cost of operating the storage site (e.g. monitoring, periodic inspection and physical protection) must be added in order to obtain the total annual operating costs.

In this way, the costs for these unit operations can be estimated well ahead of the time they are used to estimate total operating costs, and subsequently can be applied to the number of casks being emplaced and/or removed from storage during the year.

This process can also be used to estimate the operating costs for storage pools and vaults — only the unit operations involved are different.

3.2.4. Decommissioning costs

The cost of decontamination and decommissioning (D&D) of spent fuel storage facilities at the end of their useful life must be estimated. These costs may be expected to vary widely for the various types of storage, with water pools (and to a lesser extent vaults) having the highest D&D expenditures.

The design features of a dry storage system generally provide for the inherent ease and simplicity of decommissioning the spent fuel storage facility:

- Spent fuel assemblies are contained within the canister, which is sealed by welding at the originating reactor. Measures to ensure that the canister external surfaces are maintained in a clean condition are implemented during the canister loading operations at the originating reactor, which prevent contaminated fuel pool water from contacting the external surfaces of the canister. Following fuel loading operations, a swipe survey is performed on the canister lid and on the transfer cask internals (representative of removable contamination levels on outside of the canister). The canister is normally not permitted to be transported to the storage facility if contamination levels exceed defined limits. Therefore, it is expected that canisters arriving at the storage facility will have minimal, if any, contamination of external surfaces.
- Under normal conditions of canister transfer and storage operations, the potential does not exist for external contamination of the storage casks.
- The design of the storage cask surface must be such to facilitate its decontamination, if necessary, so that bare concrete (which is porous and relatively difficult to decontaminate) is not exposed to contamination. The cavities of most storage casks are completely lined with steel, including the cylindrical walls, a pedestal

that supports the canister, and lid, making them relatively easy to decontaminate. Casks have layers of gamma (lead) and neutron shield materials sandwiched between steel. The inner and outer liners both consist of carbon steel, which is relatively easy to decontaminate. The sliding doors at the bottom of the transfer casks are also steel or steel lined.

— The neutron flux originating from a canister containing spent fuel assemblies is approximately 10 orders of magnitude lower than neutron flux levels at an operating nuclear power plant (10^3 versus 10^{13} n/sec-cm^2) and consists of fast neutrons with energies around 1 MeV. The cask materials and pad concrete will be only very slightly activated (less than 5 μR per hour above background) as a result of their long term exposure to the relatively small neutron flux emanating from the spent fuel, which will allow the general release of the casks as non-controlled material. Hence, any tasks necessary to decommission storage casks are expected to involve only surface decontamination, if necessary, and not removal of activation products at depths below the surface.

— Canister decommissioning after service life will also require most likely just decontamination.

— If there is a canister transfer building at the spent fuel storage facility, the concrete floor as well as the interior surfaces of the concrete walls in the transfer cells may have a coating of special paint or epoxy applied, which is non-porous and easily decontaminated. This provision will help to assure that decontamination can be performed by wiping down surfaces or stripping the coating, without the need to use more aggressive methods (e. g. abrasive blasting, scrabbling) that require removal of surface concrete.

The basic elements of cost involved in D&D are shown in Table 7.

These costs must be estimated for all operational aspects of D&D, including

— D&D planning and licensing;
— Surveillance and maintenance;
— Decontamination of structures and equipment;
— Removal of structures and equipment;
— Disposal of structures (including casks);
— Disposal of equipment;
— Site restoration and monitoring.

It may be difficult to impossible to determine costs that could occur 50–100 years in the future. Changes in technology, regulation, public policy, etc. could all have a profound affect on the actual cost at time of need. The major purpose of including D&D costs in spent fuel project evaluations is to try to discern differences between the alternate technologies. Of course, this must be based on best estimates of the **current** decommissioning strategies and cost. In reality, if the spent fuel facility is anticipated to operate for 50–100 years, the D&D costs will be heavily discounted (see Section 5) in any evaluation, and the discernable differences between technologies will be negligible.

TABLE 7. ELEMENTS OF COSTS FOR D&D OF SPENT FUEL STORAGE FACILITIES

- Rental of D&D equipment
- Staff costs (salaries, wages, benefits, etc.)
- Materials and supplies
- Utilities
- Subcontractor charges (for expert advice, special services, independent audits and measurements, etc.)
- Waste transport and disposal charges
- Licensing expenses
- Overhead
- General and administrative expenses

In any case, after the project is under way, most regulatory authorities will require a periodic update (e.g. 3–5 years) of the decommissioning plan and cost to ensure that adequate financial reserves are available for this purpose.

3.2.5. Off-site transportation costs

Since spent fuel storage facilities are intended to be temporary (even if long term), it will be necessary to remove the fuel from the facility to a reprocessing plant or a final waste repository (unless the storage is at these facilities). In some scenarios, it may be necessary to transport fuel from the reactor to site to the storage site. Therefore, depending on the specific situation, the cost of off-site transportation can impact the method of storage.

For example, a metal transportable/storage (dual purpose) cask does not involve the unloading of a storage cask and the loading of spent fuel into a specialized transport cask, as is the case when the spent fuel is stored in a storage-only cask or a pool or a vault. Moreover, there is virtually no turnaround time for the transport cask at a dual purpose cask storage site, because there is no need for a transport cask or transport overpack. A dual purpose cask does, however, require impact limiters in the transport mode, but they are re-usable for repeat shipments.

Another technology that is receiving considerable support in the current market (and which is an evolution of the metal dual purpose cask) is the ‘flexible’ transportable/storage (dual purpose) casks. In this concept, the spent fuel is placed into a metal canister that becomes the spent fuel package for all future activities. This canister is first placed in a concrete overpack for long term storage. When it comes time to remove the spent fuel, the canister is transferred to a reusable (metal) transport overpack for off-site shipment. Relative to the metal dual purpose cask, the flexible dual purpose casks significantly reduces the amount of metal in the system and all related costs. On the other hand, it requires a transfer system with transfer operations and equipment that is not needed with the metal dual purpose cask design.

For pools, vaults or any other storage-only concept, single purpose transport casks will be needed to perform off-site transportation. Such casks are generally available (for purchase or lease) in the international market. However, the facility will have to provide some means of transferring the spent fuel safely to the transport casks. The capacity of commercially available transport casks (i.e. the number of metric tonnes per loaded cask) can therefore impact operating and handling costs.

Some elements of capital and operating costs required for the off-site transport of spent fuel to or from storage facility are shown in Tables 8 and 9.

It may be difficult to provide reliable estimates if the transport is envisioned late in the operating lifetime of the facility. In this case, it may be necessary to use current best estimates for quantifying the cost of **differences** between technologies (as is the case with D&D costs).

Finally, the prospective cost for construction or improvements in off-site infrastructure to and from the storage site (e.g. railroads, roads, bridge, barge shipping facilities, etc.) should be considered to determine the general site adequacy and any meaningful differences resulting from the type of storage facility selected.

TABLE 8. ELEMENTS OF CAPITAL COSTS FOR SPENT FUEL TRANSPORTATION

- Transport cask and impact limiters
- Trailer (for truck shipments)
- Rail car (for rail shipments)
- Personnel car (for rail shipments)
- Buffer car (for rail shipments)
- Security equipment (including escort vehicle for truck shipments)

TABLE 9. ELEMENTS OF OPERATING COSTS FOR SPENT FUEL TRANSPORTATION

Rail shipments	Truck shipments
Freight costs (round trip) • Cask and rail car (loaded) • Cask and rail car (empty) • Buffer and personnel car (cask loaded) • Buffer and personnel car (cask empty) • Heavy haul/barge costs	**Freight costs (round trip)** • Cask (loaded) • Cask (empty) • Demurrage
Maintenance costs • Cask • Rail car • Buffer car • Personnel car	**Maintenance costs** • Cask • Trailer
Traffic management	Traffic management
Security costs • Guard salaries and benefits • Rail travel costs • Subsistence • Air fare	**Security costs** • Guard salaries and benefits • Subsistence • Escort vehicle costs • Police escort costs

3.2.6. Operational contingencies

New storage facility design and capacity specifications should be made according to projections of spent fuel arisings less any capacity to accommodate it through other alternatives. In this determination, it is good operating procedure to allow (empty) space in the reactor pools for removal of one full core of reactor fuel in case of emergencies (referred to as full core discharge) or operational contingencies.

Schedule and capacity allowances to deal with potential project delays in planning the AFR storage, regulatory changes and security or for advances in fuel cycle technology such as high burnup and MOX should also be considered. If these factors have a large uncertainty, a modular approach may be more appropriate to satisfy immediate needs (i.e. several years of storage) while enabling flexibility for future extensions. Future expansion could be anticipated in the initial stage and refined over time as expansion of the AFR storage system is implemented.

The refurbishments and/or modifications of a spent fuel storage facility can range from relatively simple replacement of equipment to major reconfiguration and reconstruction in response to new operational or regulatory norms. Examples of such modifications include re-racking and seismic upgrades for spent fuel storage pools.

The cost implications of these works can be relevant to investment in construction or decommissioning as appropriate. However, the actual estimation of these costs is subject to large uncertainties due to difficulties in predicting the extent of work or the time frame of the refurbishments or modifications. The means of dealing with uncertainties and associated contingencies can vary between alternate technologies and may impact the choice. Therefore, contingency planning for estimation purposes should be included in the cost estimate and decision bases, especially in cases where there is no clear idea of such a prospect.

4. FACTORS AFFECTING COSTS AND ECONOMICS

All of the available storage technologies have specific advantages and disadvantages that can prevail depending on the situation. It is absolutely necessary, therefore, to set forth the detailed requirements and criteria for the required facilities at the outset of a spent fuel storage project. These requirements or specifications will have a very important effect on the technology choice and the costs of the facility to be built.

For example, in terms of initial capital costs, pools are always more expensive. But the storage temperatures are considerably lower than those encountered in dry storage casks and pools. Pools provide a large margin for storage of high burnup and high enrichment fuels, including MOX if that is an issue, relative to cask storage systems. Pool storage is also relatively convenient in assuring safeguards and carrying out fuel inspection during storage.

On the other hand, dry storage casks tend to have lower initial capital costs, better modularity and passivity (i.e. independence from the need of active cooling systems as for a pool). Casks designed for both storage and transport also limit direct handling of the fuel. The economic significance of these different features can only be determined by rigorous evaluation of the options using relevant site specific requirements and specifications.

4.1. TECHNICAL FACTORS

The key technical parameters to be considered in the safety of spent fuel storage include:

- Thermal load of spent fuel;
- Burnup of the stored spent fuel (burnup credit can be used for demonstrating real safety margins);
- Criticality calculation (loading pattern of reactor pool);
- Radionuclide inventory of spent fuel (currently at least safeguards relevant radionuclides are calculated in terms of mass and activity);
- Physical integrity of the spent fuel.[4]

These parameters have the most significant implication in the design and operation of storage in facilities in terms of costs of storage.

4.1.1. Characteristics of spent fuel

The characteristics that must be considered are: fuel type(s) (geometry, weight and enrichment), burnup (minimum to maximum range), cooling time from discharge from the reactor (decay heat), radionuclide inventory and the physical condition of the clad (clad failure and external contamination).

4.1.1.1. Types of nuclear fuel

The applications 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 used.

Although the preponderant fuel type used in commercial nuclear reactors today is LWR fuel, there are several other fuel types such as PHWR, GCR and RBMK that might require spent fuel management. The main characteristics of these fuel types and associated fuel cycle backend are summarized in Table 10.

Post-irradiation characteristics of spent fuel and data needed for design and operation of storage facility are determined by irradiation history during reactor operation and time of cooling after discharge.

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

TABLE 10. TYPES OF NUCLEAR FUEL IN COMMERCIAL USE

Type	Design	Physical spec.	Remark
LWR	PWR BWR WWER	Square/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, 1 m long assembly	Need to reprocess Dry storage possible
OTHER	RBMK	8 cm dia × 10 m long assembly (fuel rods in two sections)	Need to cut to size No reprocessing
	PBMR	6 cm dia spherical form fuel element	Canning Possible to reprocess

4.1.2. Spent fuel burnup

In particular, spent fuel burnup is a crucial parameter to be taken into account in the design of spent fuel management facilities.

4.1.2.1. Burnup credit

Historically, fresh fuel assumptions have been used by many Member States as the regulatory baseline for safety in spent fuel storage and transportation systems. This assumption is very conservative, since it overestimates the available reactivity in the stored fuel, which leads to complicated criticality designs and/or reduced payload. In turn, this creates more storage and transport activity, and higher cost.

More recently, regulators have considered that the reactivity reduction associated with the actual (or some percentage of the actual) burnup of the spent fuel can be applied without compromising criticality safety margins. The effect of burnup credit in safety criticality applications is to increase payload of a given facility or component. While this improves overall economics, it also contributes to public health and safety (and resources conservation) by reducing the amount of operations required for managing spent fuel. Currently, burnup credit applications are being used or considered by a number of countries.

4.1.2.2. High burnup

The trends toward higher burnup for uranium fuel and the use of MOX fuel have already had important impacts in the development, design and operation of spent fuel storage systems. In the USA, for example, the NRC has provided guidance that storage systems for high burnup fuel must provide performance conditions such that the cladding will not degrade to a gross failure and create technical problems with respect to redistribution of hazardous materials during storage or subsequent transportation and handling. High burnup fuel that does not satisfy the pre-conditions must be enclosed in approved ‘failed fuel’ baskets.

The acceptance criteria for high burnup (zircaloy-clad) fuel storage in dry casks can be summarized as following for defect fuel.

4.1.2.3. Classification of spent fuel

Detailed information on the physical integrity of spent fuel is very important for the design of storage facilities. In particular, defective fuel may require a special method of handling (e.g. canning) prior to storage in an AFR (if it is not done already at the reactor pools). Similarly, operational objectives and safety approach for defective fuel may differ at the AFR storage. What may be considered generally acceptable for AR storage may not be suitable for AFR storage due to potential for contamination during transportation, handling or long term storage. Defective fuel may require special-sized containers for storage as well as transportation if they do not fit into standard containers. An agreed on set of conditions or criteria (usually based on sipping procedures) would be required to identify and manage defective fuel.

In addition, it is necessary to avoid failure of cladding that might be caused by the conditions of storage, i.e. temperature effects on cladding and fuel material, particularly during the early period of spent fuel storage and particularly in passively cooled systems such as casks. Since creep rupture is considered the dominant cladding failure mechanism under normal operations of dry cask storage, cladding temperature limits are predetermined, monitored and controlled to maintain the spent fuel cladding integrity over the entire facility licence period.

At the AFR storage site, specific detection systems may be needed to confirm reactor data on the spent fuel that are received, while careful monitoring of fuel integrity parameters during storage is used to confirm fuel integrity at the time of fuel retrieval.

4.1.2.4. Age (decay)

The natural radioactive decay of nuclides is another parameter that will reduce heat load and radioactivity over time, and thus will influence the technical requirements of the spent fuel facility.

Spent fuel assemblies that are newly discharged from reactor have a high residual heat due to radioactive decay and are usually required to be cooled for 3–10 years in water before being able to be moved to a passive dry storage system. The actual cooling time is a function of the spent fuel burnup achieved (heat source) and the design features of the spent fuel storage system (heat discharge) to be used. Longer cooling times simplify the AFR storage facility design, but they require greater AR pool capacity to handle the accumulated inventory.

As the discharge burnup of spent fuel increases, so do the residual heat and the time needed for cooling in the pool in order to meet the initial conditions of the storage equipment. This could increase the demand for AR pool capacity and must be taken into account when planning. Alternatively, the AFR equipment could be re-designed and re-licensed for the new conditions. This might include increased shielding on a cask to meet surface dose limits, for example. However, since a cask is usually constrained by the total allowable weight of the loaded cask and/or its physical dimensions, such changes could reduce the payload (capacity) of the cask.

Heat removal capacity of a specific cask design may also limit the payload of high burnup fuel without adequate post-irradiation cooling time. Mixed loading of hotter and colder spent fuel assemblies or ‘fins’ to dissipate more heat are sometimes required due to thermal loading limits. In any case, there are important ‘trade offs’ to evaluate between post-irradiation cooling time and burnup, on the one hand, and cask design and payload, on the other. These should be considered when planning the new facility and selecting a technology.

4.1.3. Functional factors

4.1.3.1. Economies of scale

As a common rule, the scale of operation has an effect on the costs. In simple terms, spreading the fixed cost portion of the project over a larger number of units produces a lower unit cost. Recurring costs, associated with each unit, are not affected.

The magnitude of economic scaling benefit is dependent on the characteristics of the system. As a general rule, the largest scaling benefit occurs with higher fixed capital cost systems.

The relationship between storage capacity and capital costs of a facility can be represented as following (see Fig. 3):

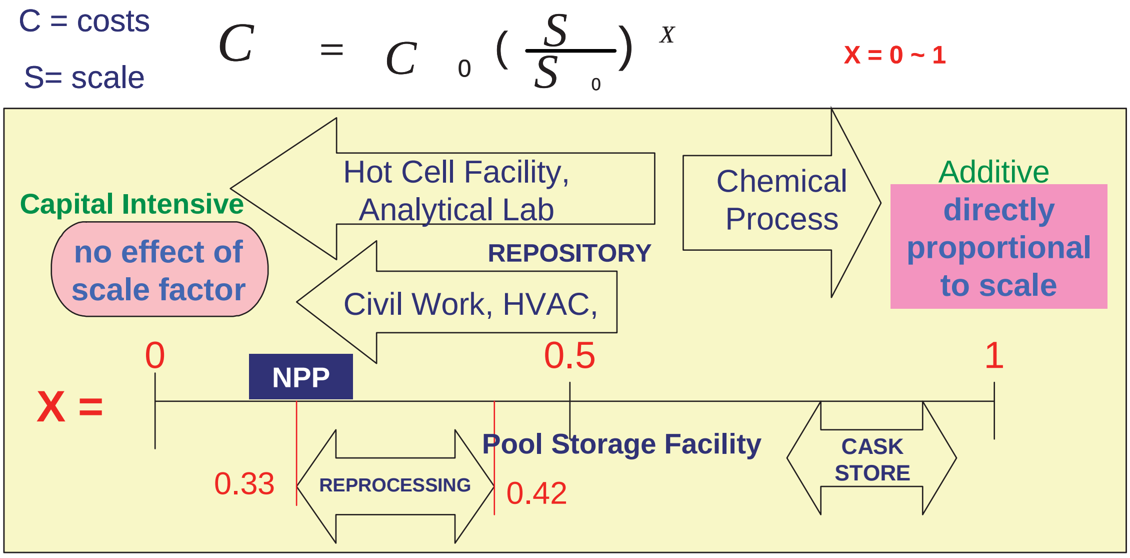


FIG. 3. Capacity factors of various nuclear facilities.

The ‘scalable’ considerations associated with spent fuel storage facilities include the following:

(1) The total storage capacity (in terms of numbers of PWR and/or BWR assemblies, and the associated MTU);
(2) The maximum annual capacity for loading spent fuel assemblies into storage and the removal therefrom;
(3) The estimated schedule for placement of spent fuel in storage, for storage, for removal (including the length of time the storage facilities are expected to be operated after the final shutdown of the nuclear power plant), and for decontamination and decommissioning;
(4) The extent to which the storage facility is to be located at a site that has infrastructure for security, emergency response, environmental safety and health monitoring, surveillance, change rooms and site management;
(5) Land area limitations;
(6) Applicable regulatory requirements for safety, safeguards, physical protection, and so on;
(7) Applicable dimensional constraints on casks and associated equipment;
(8) Load limitations on roadways and rail track within the site and external to it;
(9) Acceptable storage technologies from operational and public acceptance standpoints;
(10) Requirements for any building to house storage activities.

In addition, some equipment needed for the realization of spent fuel storage activities might be included. Activities involved in alternative operational scenarios might include the following:

- Loading a metal storage or transfer cask in a water pool;
- Placing the spent fuel assemblies into canisters prior to storage, or storage of bare fuel assemblies;
- Storage in metal casks or in concrete casks/modules;
- Transferring stored spent fuel to transport casks in a water pool or vault, or otherwise transferring them in the absence of availability of a pool;
- Opening of canisters prior to shipment of contained spent fuel, or shipment of the unopened canisters.

It is clear that fixed capital costs can be significant for some systems (e.g. pools and vaults). In such cases, large capacity of the spent fuel storage facility will have a favorable impact on the overall economics of the facility. For modular facilities (e.g. cask systems), the economic impact of size is minimal due to the simplicity of the facility infrastructure and low, periodic capital investment, as shown in Fig. 4.

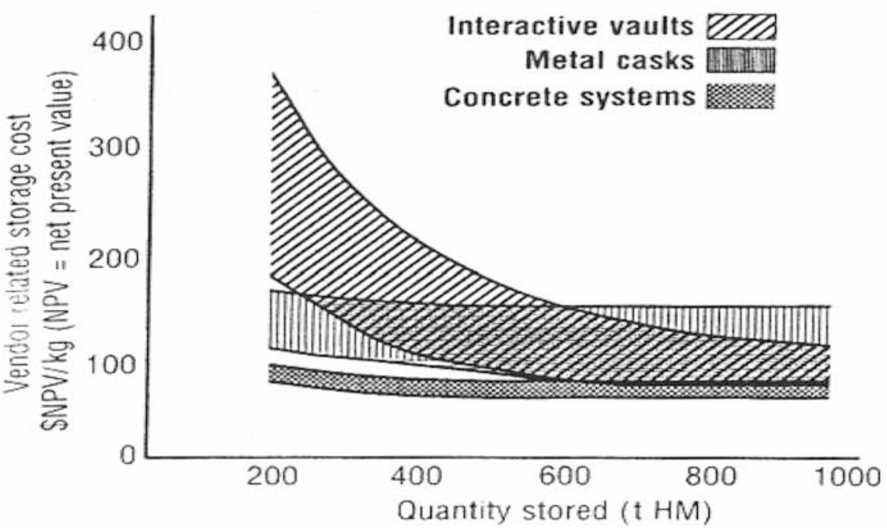


FIG. 4. Economy of scale in storage options.

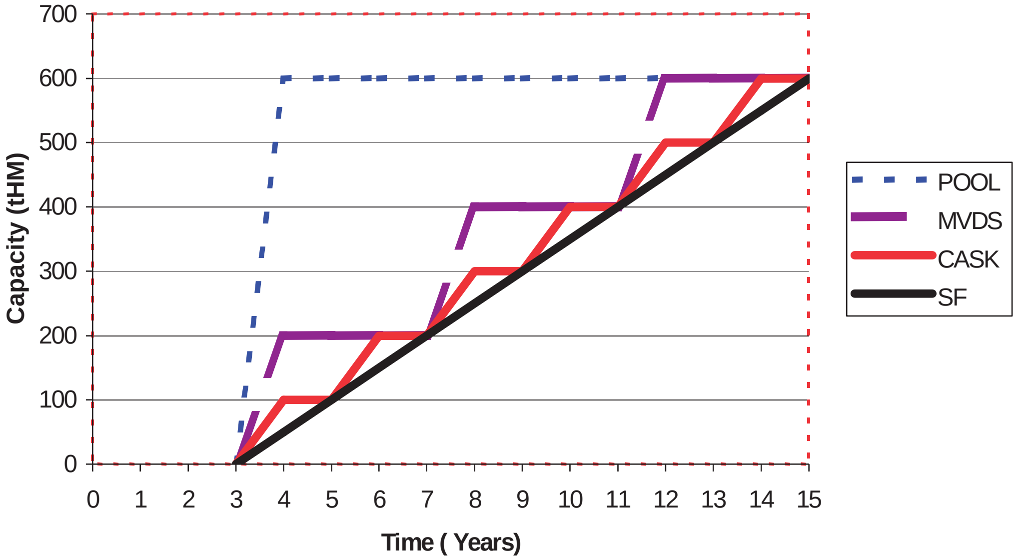


FIG. 5. Modularity effect on costs of spent fuel storage options.

In the absence of other technical constraints, pools and vaults generally require large storage volumes for economic justification (e.g. >600 t HM). Such volumes normally would require use by several reactors at a multi-unit site or at some central storage system, such as CLAB (Sweden) or ZWILAG (Switzerland). (Note: A typical LWR discharges about 20 t HM/GW·a.)

4.1.3.2. Modularity factor

Another important economic consideration in selecting a spent fuel storage system is the degree of modularity. The relative ability (or inability) of various options for tracking the actual spent fuel storage needs can convert into significant economic differences. This can be illustrated by Fig. 5.

The open area between the curves in Fig. 5 is proportional to the carrying cost of capital expensed before the storage need actually occurs. The larger the area (between options), the greater the associated carrying cost. As indicated, the high degree of modularity available with dry storage casks is particularly propitious for long term storage and can be a crucial for those cases where cash flow is limited. Modularity also can provide future flexibility with indirect economic benefits to be discussed later.

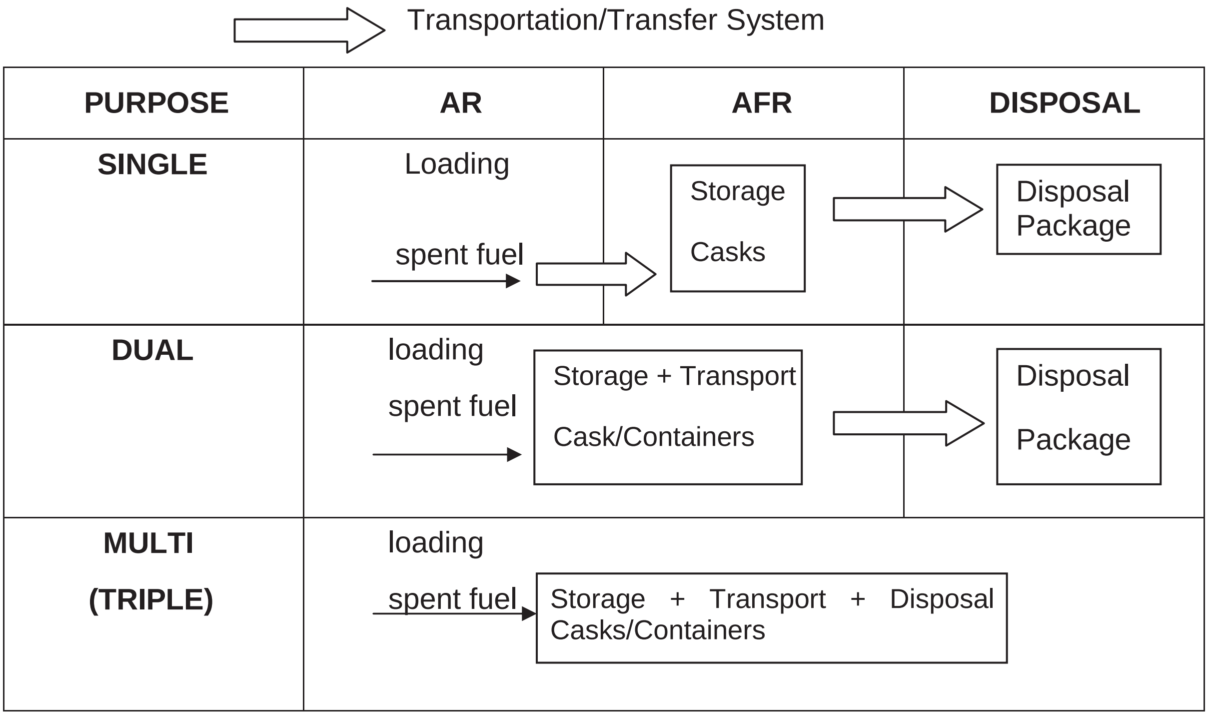


FIG. 6. Functional purposes of containers in the back end of the fuel cycle.

4.1.3.3. Multifunctional systems

Another technical feature, which was mentioned above, is the mobility (or transportability) of the storage system. Functional purposes of containers in the backend fuel cycle are shown in Fig. 6.

The main advantages of dual or multipurpose technologies include:

- Reducing the need for handling bare fuel assemblies and thus associated dose and possibility of human error;
- Minimizing the need for transfer facilities and associated safety risk and costs;
- Reducing the interfaces between different steps of the spent fuel management system, including safeguards inspection.

On the other hand, dual and multipurpose casks are more difficult to design and license, and generally cost more than storage-only casks. In addition, given the large uncertainties involved in long term issues associated with transport or disposal, repacking might be required in any case, the currently perceived advantages lost and the extra cost wasted.

4.1.4. Conditional factors (e.g. site infrastructure, environment)

For sites available within the selected area, the following requirements and conditions should be assessed:

- Price of land;
- Site preparations and development, including consideration on future expansion;
- Environmental impacts (restriction, standards, guidelines);
- Ecological conditions (soil, site hazards, climate, seismic activity, etc.);
- Access infrastructure surrounding the site;
- Security implications.

4.1.4.1. Site

System comparisons need to take account of differing cost impacts of site preparations for various solutions. An important consideration concerns the availability of appropriate rail track and/or the nature and conditions of roads and bridges accessing the storage site. A further site consideration concerns the space available for a storage installation. A system requiring a comparatively large ‘footprint’ may require modifications to the controlled site area. Such extensions may only be temporary to provide space for site construction offices, material storage and assembly, etc.

In particular, space may be limited at some reactor sites, which could influence the selection of storage technology.

Finally, the possibility of the storage facility lasting longer than the reactor operations should be considered (Sections 4.8 and 4.9).

4.1.4.2. New versus existing sites

The infrastructure requirements may differ vastly between storage facilities at-reactors (or reprocessing centres) and those located at an independent site. At an existing site, the pool is probably available for use in loading storage or transfer casks, and the welding of canisters generally can be performed in buildings and facilities at the plant. Also, the supply of utilities, maintenance, security, and support services should be available at incremental cost.

In contrast, storage facilities at an independent site must have a stand-alone capability to unload and load transport casks (cranes, hot cell, etc.), and to provide utilities and services that are only minimally incremental to at an existing site including, but not limited to, the following:

(1) Operations personnel and supervision;
(2) Administrative personnel;
(3) Health physics personnel;
(4) Maintenance shop and personnel;
(5) Security personnel;
(6) Radiation and air monitoring control station;
(7) Off-site security alarm station;
(8) Administration and services building (including change rooms);
(9) Emergency response capability;
(10) Security response capability.

An independent cask or silo storage facility may also require specialized cask handling equipment, fuel handling equipment, decontamination equipment, radiation protection and leak tightness monitoring equipment.

The net result is that a storage facility can share the existing infrastructure of an existing site, in whole or in part, whereas an independent facility must have its own infrastructure, i.e. stand-alone operations.

Unless co-located at the reactor or at a future disposition site, storing spent fuel at an independent special-purpose site will require two shipments instead of one, and the spent fuel management cost would increase. The total shipping distance may also increase.

On the other hand, there may be some advantages of an independent (centralized) storage facility:

- It consolidates the national and international physical protection and safeguarding of large quantities of spent fuel during storage, minimizing such activities at individual sites,
- It minimizes the amount of spent fuel located at reactor sites so that the reactor operators can focus their attention on the safe and efficient operation of the nuclear power plants.
- It minimizes investment in multiple projects, even though each might cost less.
- It minimizes interference with decontamination and decommissioning activities at the end of reactor life.

4.1.4.3. Environment

As part of an application for a spent fuel storage facility, an environmental impact study (EIS) is usually required in which the environmental impacts associated with constructing and operating the facility are analysed, possible alternatives are evaluated and a cost-benefit analysis of the project is performed. Regulations usually require that the public be allowed to comment on this EIS.

The EIS considers the following issues:

- How the spent fuel storage facility will interface with ecology, geography and land use of the area; the socioeconomics of the area; noise and traffic; and historic, scenic, cultural and natural features;
- The external appearance of the spent fuel storage facility;
- The environmental effects of construction and operation of the facility, including decommissioning the site and returning it to its original condition;
- Environmental effects of credible accidents at the site or during transportation;
- Environmental measurement and monitoring programmes;
- The economic and social effects of the facility during construction and operation;
- Facility siting and design alternatives.

For example, in the case of the proposed private fuel storage facility (USA), the Nuclear Regulatory Commission evaluated compliance of the proposed facility plan with all applicable environmental laws and regulations, and issued a final EIS in January 2002. The EIS found that the proposed facility would have small to moderate environmental impacts, and that the overall benefits of the facility would outweigh the disadvantages and costs based on consideration of:

- The need for an alternative to AR spent fuel storage that provides consolidated and economical storage capacity;
- The minimal radiological impacts and risks from transporting, transferring and storing spent fuel in casks;
- The economic benefits that would accrue to the local population during the life of the project;
- The absence of significant conflicts with existing land use.

EIS also found that after the facility is no longer needed or its licence expires, the closure and decommissioning plan of the spent fuel storage facility would make the area available for other uses.

4.1.5. Project agenda and time frame

Typically, a project for new spent fuel storage capacity is started when the operator anticipates that declining capacities of AR storage pools (or other available storage facilities) will jeopardize nuclear power plant(s) operation in the foreseeable future.

The planning horizon must include not only the facility construction time, but also lead time for legal and regulatory applications and approvals prior to the start of construction (i.e. environmental impact assessment, preliminary safety assessment etc.). These will vary from country to country depending on the status of nuclear programme and regulatory infrastructure. In many cases, construction of the spent fuel storage facility may take less time than the licensing process. Moreover, the cost of licensing activities can be significant and the budget for these activities must be secured in advance. All these factors must be taken into account in order to place the project agenda within a certain expected time frame and preferably, with some margin for delay. An interruption in reactor operations due to insufficient storage capacity can be economically disastrous.

4.2. TECHNICAL KNOWLEDGE AND THE LEARNING CURVE

As in any industrial activity, project success hinges on the availability of necessary know-how and expertise. Technical knowledge acquired through experience elsewhere could be important for efficient implementation of a project in terms of costs and schedule. A first of a kind facility with little prior experience

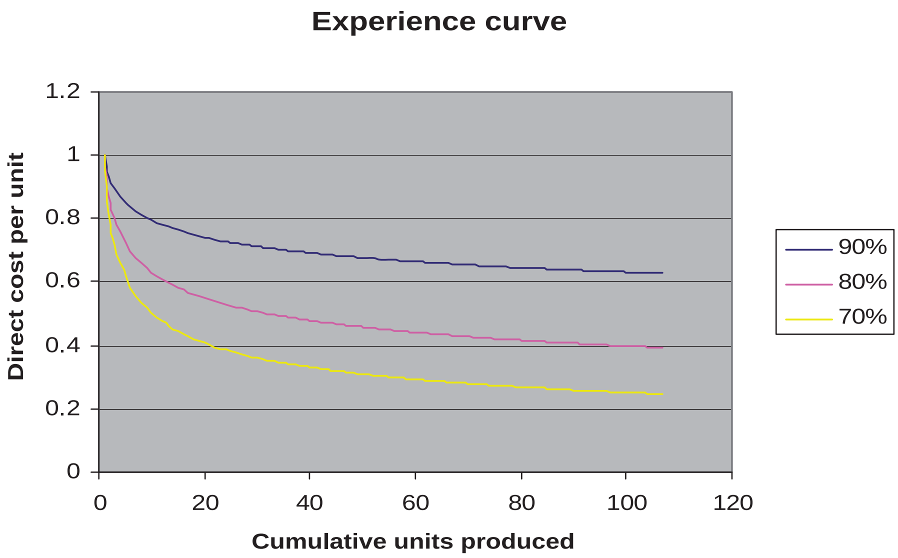


FIG. 7. Example of experience curves: decrease of the direct cost due to experience in production volume.

could be costly, depending on the novelty of the technical concept. On the other hand, project costs tend to decrease given a large number of the same or similar prior projects. The impact on cost can be summarized in the 'Law of Experience':

'The unit cost of a standard product declines by a constant percentage each time cumulative output doubles.' This may be expressed as follows:

$$C_n = C_1 n^{-a}$$

where C_n is the cost of the nth unit of production,
C_1 is the cost of the first unit of production,
n is the cumulative volume of production,
a is the elasticity of cost with regards to output.

Figure 7 shows typical experience curves for the various elasticity of cost.

The experience curve shown in Fig. 7, published by the Boston Consulting Group (BCG Perspectives, 1968), has been used occasionally for project cost estimating and strategy analysis. For a variety of reasons, including evolutionary technologies and changing regulations and policies, the cost elasticity tends to be low for spent fuel storage facilities (e.g. top curve in Fig. 7).

4.3. PROCUREMENT AND CONTRACT STRATEGY

Procurement of spent fuel storage equipment and facilities can be divided into two basic phases: procurement of spent fuel storage equipment from the designer/vendor of the equipment (including casks and associated equipment), and procurement of the other storage facility subsystems (including storage pad/building, fencing, security and monitoring systems, etc.) from an architectural and engineering firm. Today, some equipment vendors are in a position to offer both packages (e.g. turnkey projects).

Procurement activities consist of those listed in Table 11.

TABLE 11. PROCUREMENT ACTIVITIES ASSOCIATED WITH ACQUISITION OF SPENT FUEL STORAGE EQUIPMENT AND FACILITIES

Activity	Spent fuel storage equipment	Other storage facility subsystems
Development of requests for proposals and specifications	X	X
Evaluation of proposals	X	X
Selection of contractor/vendor	X	X
Approval of engineering and designs	X[a]	X
Approval of storage technical safety analyses	X[a]	
Regulatory approvals on facilities		X
Oversight of equipment fabrication	X	
Oversight of construction		X
Performance of QA audits	X	X
Acceptance of delivered equipment, systems and services	X	
Acceptance of construction		X

[a] Only to the extent that modifications to standard designs of spent fuel storage casks/modules are required.

In addition to cost, the evaluation of proposals of prospective suppliers should consider an evaluation of each vendor’s basic technology including;

- The operational complexity and impacts on other site activities;
- The potential for operational complications or off-normal operations;
- The perceived public acceptance of the technology;
- The resources, reputation and capabilities of the supplier and its subcontractors.

In the negotiation of contracts, effort should be made to adhere to the terms and conditions set forth in the request for proposal (specification) and determine that the received proposals match the terms as closely as possible. Any exceptions should be quantified to the extent possible and added to the evaluation in order to normalize the offers of all bidders.

The items described in the following sections set forth some strategies that might be considered in contracting for spent fuel storage modules and associated equipment.

4.3.1. Contractual scope and conditions

4.3.1.1. Scope of work

A scope of work should be established, together with specifications that clearly define what is to be provided, including:

(a) Storage and associated equipment;
(b) Licensing support services (including required documentation);
(c) Training services (including training manuals);
(d) Operational assistance (including standard operating procedures).

To the extent possible, procurement should be arranged for the equipment and suppliers that are pre-approved by regulatory authorities. If a new or modified design is involved, efforts should be made to have the supplier guarantee that it can obtain the necessary regulatory approvals within a specified time period. Alternatively, the supplier should provide guarantees and the necessary technical resources to support obtaining timely regulatory approvals, on a fixed price basis.

4.3.1.2. Delivery schedule

A clearly defined schedule of deliveries should be established, including specific milestones. In the event of failure to meet this schedule, agreed penalties should be assessed with the supplier (generally through a reduction in the amounts to be paid to the supplier for the equipment).

4.3.1.3. Price conditions

Fixed prices should be obtained for casks/modules, canisters, transfer casks and associated equipment items. These may be subject to escalation or de-escalation as a result of changes in established (and agreed) cost/price indices.

4.3.1.4. Delivery condition

An attempt should be made to require payments for equipment to be made after delivery and acceptance of equipment items and/or systems, but realistically, progress payments (pro-rated) will probably be required. In the latter instance, the progress payments should be tied to a measurable milestone (e. g. start of fabrication, completion of specific components, completion of fabrication and assembly, shipment, receipt and acceptance, etc.).

4.3.1.5. Warranties

Warranties (possibly in the form of withholding of final payment) should be sought from suppliers ensuring that:

- Delivery of equipment and services meet the contract specifications;
- The equipment and services provided by the supplier constitutes an appropriate system for storage of the purchaser's (or purchasers' clients) spent fuel in the latter's facility in full accordance with applicable regulations;
- Delivery shall be made in full accordance with the project schedule.

4.3.2. Payment schedule

Payment terms should be negotiated for each item of equipment or service purchased in connection with spent fuel storage systems. An example of some terms is set forth in Tables 12 and 13.

TABLE 12. EXAMPLE PROGRESS PAYMENT SCHEDULE FOR STORAGE CASKS AND CANISTERS (% OF CONTRACT PRICE)

Payment made upon	Storage cask/module and canisters (%)
Release for fabrication	10
Start of fabrication	20
Completion of fabrication	45
Delivery to storage site	15
Acceptance by buyer	10

TABLE 13. EXAMPLE PROGRESS PAYMENT SCHEDULE FOR CONSTRUCTION ACTIVITIES (% OF CONTRACT PRICE)

Payment made upon	Storage module[a] (%)	Building and infrastructure for modular storage[a] (%)	Plant and infrastructure for cask storage (%)
Signature of contract	10	10	10
Start of construction	20	30	20
Monthly against progress payments	50	40	50
Completion of construction	10	10	10
Acceptance by buyer	10	10	10

[a] Vault or pool

Vendors proposals should be thorough in response and evaluated strictly under criteria and factors contained in the Request for Proposal (RFP).

4.4. SOCIAL AND POLITICAL FACTORS

Public resistance to spent fuel storage projects has often been expressed mostly by groups of activists. In several cases, this has resulted in public demonstrations and even civil disobedience against spent fuel storage projects and the associated transportation of spent fuel. To improve acceptance, some countries provide for extensive public participation in regulatory proceedings, thus providing opponents of a spent fuel storage facility the opportunity to express their views.

4.5. LONG TERM ISSUES

There are several institutional issues to be considered in conjunction with long term interim storage of spent nuclear fuel as follows:

Long-term interim storage must ensure by design, operation and institutional arrangements, the retrievability of spent fuel at the end of the storage period. Maintenance of physical integrity throughout the duration of storage is a corollary requirement in this regard, and institutional arrangements must be developed for appropriate record keeping and mechanisms to ensure that this information is transferred to future generations.

Long term storage implies a commitment to active management for long period of time at the risk of an unforeseeable future including possible loss of social stability and control. While economists have developed reasonably good estimates of social discount rates at the national level and applicable to periods of a few decades, the relevant discount rate for the world as a whole and adopted to very long term effects is less easy to determine. For long term decisions, discounting requires at least some adaptation, but there is no consensus on the value or the theoretical foundation of an approach.

4.6. RISKS AND UNCERTAINTIES

Spent fuel storage projects are subject to the same type of risks and uncertainties to which other nuclear projects are exposed. These include:

- External factors
  (a) Regulatory actions;
  (b) Litigation;

   - (c) Political action;
   - (d) Public (activist) opposition.

- Internal factors
   - (a) Cost;
   - (b) Schedule.

The external factors impact cost and schedule, and must be mitigated promptly and to the extent reasonably work possible. However, the aforementioned internal factors are otherwise basically under the control of the owner of the spent fuel storage project. Thus, cost estimates should contain sufficient realistic contingency, schedules should be comfortably achievable with reasonable diligence, the satisfactory reliability of the supplier of the storage technology should be established and its performance subject to contractual assurances, and diligence should be maintained in oversight of quality assurance activities. If these are not accomplished so that timely adjustment in activities is possible, the project can be exposed to unacceptable cost overruns and delays.

4.7. ABILITY TO MANUFACTURE STORAGE COMPONENTS

Another factor that could influence the spent fuel technology selection is the ability to perform the construction work and/or manufacture components within the country or region. While quality and design performance must be ensured, probably by way of technology transfer and licences, the manufacture of components for some spent fuel storage systems is relatively easy. Dry storage cask components, for example, can be manufactured in many qualified metal forming shops. In addition, the repetitive nature of the business makes it easy to rationalize operations over many years in case some investment is required. Pools and vaults may be less amenable to localization in this regard.

In any case, providing maximum content from within a country (or a region) provides jobs, minimizes currency exchange and fluctuations and may reduce susceptibility to supply interruption depending upon the extent of local manufacture. In some instances, it may be possible to negotiate with the design vendor to serve a broader region or customer base.

4.8. FUTURE INFLATION, CURRENCY EXCHANGE/VALUATION

While in theory it is economically good to delay costs to just before they are needed (Section 5), there are some long term risks that are difficult to foresee and which might make postponement an unwise strategy. With wet pools, and to a lesser extent vaults, the project commitment and cost are fixed up front and then fixed for a relatively long period. In this scenario, future financial events are marginalized.

But generally, fixed commitments for cask equipment and services are **not** made up front, at least not consistent with the project plan, so future financial events can be more severe.

The following are some considerations in this regard:

- Current prices, used for evaluation purposes, probably can be obtained under strong international competition. If the competition disappears over time, prices may rise. A reduction in qualified competition could result from market share considerations, or changing interests on the part of suppliers, beyond the control of the buyer.
- Runaway inflation (inflation that exceeds rates of return), even for a short period of time, can reduce the available ‘funds’ anticipated for procurement of subsequent equipment and services.
- If equipment is provided from outside the country, or common currency region, the anticipated project cost may change in terms of local currencies due to currency revaluations and exchange rates. This could be positive, negative, or both over a long period of time.
- Depending on the circumstances, transportation logistics, politics or other international disruptions could affect delivery and cost of the needed services.

In some ways, a large fixed project from the start provides greater security and cost certainty, even if it is initially more expensive.

Of course, unforeseeable events are unforeseeable. However, in any complete evaluation, such considerations should be subjected to a probability versus consequences risk analysis.

4.9. THE ‘END GAME’ FINAL DISPOSAL STRATEGY AND TIMING

Spent fuel storage in this report is considered to be interim, even if long term. In all cases, a final management (disposal/reprocess/other) solution will be needed.

In countries where a disposal plan is in place, spent fuel management facilities should take into account the timing and nature of the disposal plan in choosing a facility. This might include spent fuel receipt and packaging plans (if known), transportation requirements and distances, and probable availability dates.

If there is no disposal plan, one should anticipate the need to eventually manage the entire lifetime production of spent fuel for a very long time, since final repositories will inevitably take a long time to develop. A related aspect of this situation is that the spent fuel facility may operate longer than the reactor, which raises issues about long term support and security systems.

4.10. SECURITY ASPECTS

The world has become more vulnerable to motivated and relatively sophisticated terrorist activity, and the use of nuclear power bears such concern. In particular, spent fuel contains highly radioactive materials that can cause harm if released to the environment. A spent fuel storage facility evaluation needs to consider security issues (and cost) over its lifetime for each option considered. Some technologies such as wet pools, and to a lesser extent vaults, will require active systems and human attention for normal operation as well as security. This can be very costly and potentially inadequate for very long time periods. Casks have other vulnerabilities and structural concerns (if exposed to the environment) over very long time periods. In any case, continuity of security, maintenance and control must be evaluated.

5. COST ESTIMATION AND ANALYSIS

In order to make proper decisions, the cost categories and issues discussed in the preceding sections must be brought into a consistent time frame, using relevant financial terms, for each plausible spent fuel storage option.

A common basis for comparison must necessarily include:

- Comprehensiveness of costs (e.g. total life cycle cost considerations);
- Equal inventory value (all relevant costs for a specific amount of spent fuel to be managed).

The cost estimates for each storage option must follow the same format and content, including the following:

(i) Project background;
(ii) Cost estimating assumptions;
(iii) Work breakdown structure;
(iv) Work element definition;
(v) Cost categories;
(vi) Estimating methodology;

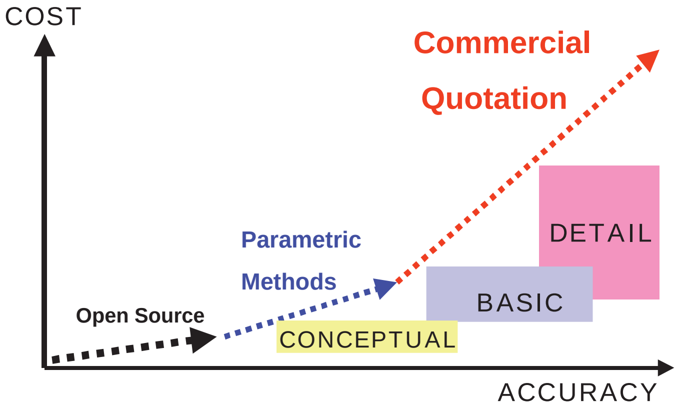


FIG. 8. Cost of the cost estimate versus accuracy of the estimate.

(vii) Schedule and cash flow;
(viii) Present value analysis;
(ix) Labour rates;
(x) Other project requirements.

5.1. COST ESTIMATION

Usually, a project evaluation is progressive, with improved accuracy at each ensuing stage of the process. Also, better information and improved accuracy usually come at a greater expense. The relationship between the cost of the estimate and the accuracy of information can be represented as Figure 8.

As indicated, the stages in the evolution of a spent fuel storage project can be characterized by the level of detail as follows:

- Conceptual design;
- Basic system/process design;
- Detailed design.

For each of these levels of study, appropriate methods have been developed and applied.

5.1.1. Preliminary estimates

The simplest technique, the ‘rule of thumb’ technique, is often used at an early stage of the project for screening various options. With this technique, the probable range of costs can be determined by extrapolation of known historical data for similar projects.

First, the basic functional requirements for the new facility must be reasonably defined. Next, reference projects having similar characteristics and for which cost values are available must be identified. Consultants who work in the spent fuel business or utilities with recent experiences may be useful sources for such information. At this point, the new costs can be deduced from the reference cases using correlation techniques and simple linear relationships with respect to some engineering parameters such as size and power. One useful technique in this regard is the exponential rule for extrapolation of costs as a function of facility size or capacity, as discussed in Section 4.1.3.1.

5.1.2. Definitive estimation

During preliminary screening, as discussed in Section 5.1.1, several options can likely be eliminated and the most appropriate design (or designs) can be carried forward for more detailed analysis. In this phase, higher accuracy estimation is usually required for final decisions and budgeting. Whereas the preliminary screening and budget estimates can be completed inexpensively and in a short time, these more definitive estimates may require months to complete and, for larger projects, can require thousands of technical person-hours.

There are basically two approaches to the definitive estimates.

5.1.2.1. In-house estimate

The ‘in-house’ estimate is used mainly by organizations that have some prior detailed and recent experience with the type of project being considered. In this approach, estimates are developed from historical cost data with details modified or updated to the extent necessary to reflect the new project conditions. This approach is a more sophisticated, experience-based extension of the parametric estimating approach discussed above. Experience indicates that no more than 20% of the new project basis should differ in order for this technique to be reliable and valid. (Of course, this is at the judgment (and risk) of the evaluator.)

5.1.2.2. Design quotations

The second type of definitive estimate is much more detailed and is most often used for spent fuel storage projects today. Here, each item for the specific project is developed in sufficient detail in terms of engineering to allow a customized price quotation to be made. Vendors qualified to supply these items are asked to provide estimates or, better yet, a price for this work.

To be most useful, the detailed bid approach requires much effort by the owner during the preparation of the RFP and the vendors in preparing their quotations. But while this RFP approach is costly, it is more accurate and can minimize technical problems and cost overruns later.

5.2. EVALUATIONS AND COMPARISON OF COSTS

Once the cost components have been determined with sufficient accuracy, an ‘evaluation’, or comprehensive economic analysis, of the options can begin. There are several ways to evaluate and compare the economic merit of options (i.e. ‘figures of merit’). Some examples of spent fuel storage costs are given in Annex I.

5.2.1. Overnight costs

‘Overnight’ capital costs are a summation of all project costs without regard for timing of the expenditure, i.e, they assume the plant is built ‘overnight’ and thus do not include escalation, interest charges or financing costs. It is a measure of the direct costs of a system or project only.

While this may be useful for comparing equipment, a thorough evaluation should also include related indirect costs such as project financing, future cost adjustments and contingencies. The most often used technique for this is net present value (NPV) analysis.

5.2.2. Net present value

The basis of the net present value approach is that a series of future costs will be covered by a sum of money which, if invested at an appropriate reference point in time (e.g. now), would, together with the interest earned, meet those future costs as they arise, with no surplus remaining. The amount to be invested is determined by ‘discounting’ the various costs (at assumed financial rates) from their actual time of occurrence to the reference point and forming the total. The present value cost [P(LCC)] correlation to life cycle costs (LCC) is shown in Fig. 9.

The effect of ‘discounting’ is that a lesser amount of money can be set aside today (to pay a future cost) because the funds set aside will earn a return until the time the cost actually becomes payable. A cost incurred immediately would not have an opportunity to earn a return.

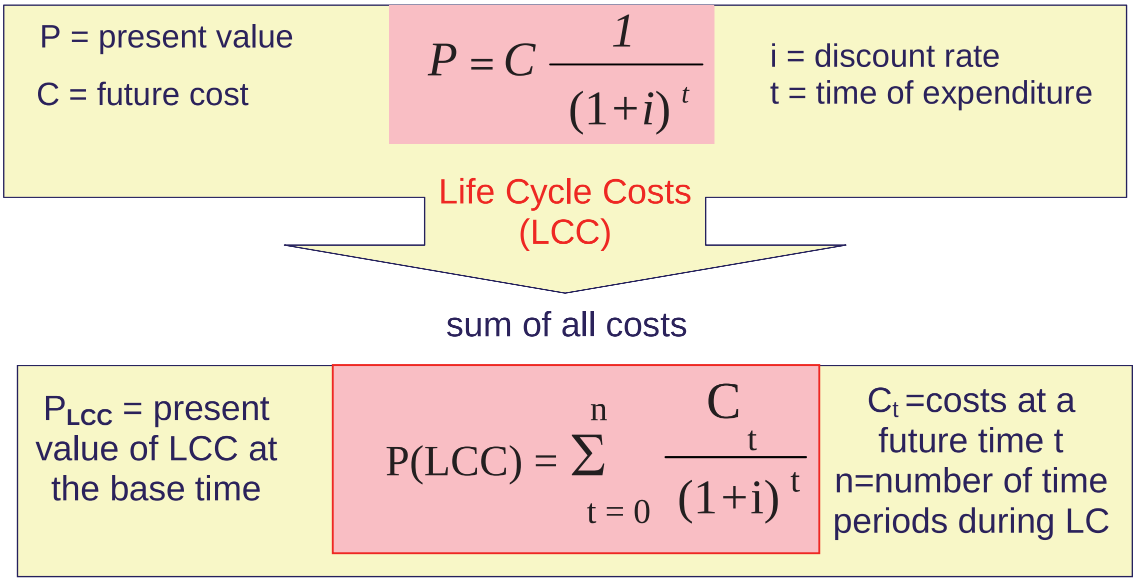


FIG. 9. Correlation of present value costs to the life cycle costs.

For example, if expending € 1 million could be delayed five years and the value of money is 5%/year, a present value savings of € 216 000 (approximately 22%) could be realized. This is obtained by discounting the € 1 million by 5%/year over the five-year period with the result being € 784 000. It is the same as investing € 784 000 in the initial year (reference year) at a 5% per year return, to yield € 1 million at the end of five years when the expenditure has to be made.

The use of discounting to a common reference year allows comparison of costs of alternative methods of storage where different quantities, schedules and spending patterns are involved.

(1) As a first step, the relevant project items for each viable option are identified for each year of the projected life of the project.
(2) Next, the cost of these items is identified by quotations or estimates for the applicable year. These direct costs form the basis for the subsequent financial calculation; their total is a figure that is useful in communication (‘market price’ or ‘overnight cost’). If costs are not quoted for future years, a projected annual escalation rate can be used (in %/year) to estimate each cost item for the year when payment is due.
(3) Finally, the NPV of the cost items is determined by discounting each of them to a common reference year (e.g. the year the cost evaluation is being made, or the year construction is to start, or the first year of operation, etc.). The sum of all the individual elements produces the NPV of the total LCCs of the fuel storage project.

If a common amount of spent fuel is to be managed for all options and if all relevant factors have been included, the lower NPV value will represent the most economic choice from among the options considered and can be used as a basis for decision.

5.2.2.1. Difference in discount rate

Discounting, as described above, requires the selection of an appropriate discount rate, which, in turn, requires the determination of the ‘real’ value of money invested. In fact, the value of money invested may vary significantly depending on the nature of the organization that owns the spent fuel storage project.

- For government and other non-profit organizations, the ‘money value’ is the interest rate on funds borrowed by the organization (bonds).

— For a profit-making commercial organization, where it assumes the risk of the project, the value of money is the before-tax rate of return that the organization normally expects to realize from its industrial endeavours of similar risk exposure.

— For a regulated utility with a franchised monopoly that limits its unrecoverable risk, the value of money is the composite cost of capital (i.e. the applicable mix of the return on equity allowed by regulatory authorities and the debt rate).

Thus, the ‘money value’ can vary nominally between 5 and 20%, depending on the sponsor of the project. This wide spread can sometimes produce differences in the technology choice between organizations, even for a seemingly similar set of conditions. Obviously, a private organization with a high money value will have a greater incentive to delay expenditures and may come to a different conclusion than a government organization, for example.

In any case, if expenditures are spread out over time, the effect of escalation should also be taken into account. This can be accomplished by discounting future costs by the ‘real value of money’ (i), which results from dividing one plus the ‘money value’ (r) by one plus the annual escalation rate (e), as follows:

$$\text{real value of money} = i = \frac{1+r}{1+e} \simeq [1+(r-e)]$$

The approximate function noted above simplifies the analysis and has the advantage that the analyst need only speculate about the **relationship** between the future values of money and the escalation rates, rather than the absolute values. Experience has shown that this differential rate relationship is considerably more stable over time than the absolute values of the rates. Also, the inaccuracy is meaningless over a broad range, especially taking into account the bigger uncertainty in the absolute values. An example is shown in Table 14.

In either case, the use of real money values has the effect of increasing future costs by the escalation rate (e.g. numerator), and then discounting them by the value of money (e.g. denominator). This ‘real value of money’ is also sometimes referred to as the ‘effective discount rate’.

In all cases, use of ‘discounting’ improves the economic attractiveness of spent fuel storage alternatives that involve delayed expenditures as compared with those that have high initial expenditures requirements. Also, the effect is greater with higher ‘real value of money’ rates.

5.2.3. Levelized unit costs

Generally it is not the case with spent fuel arisings, but **if** the alternate spent fuel management options (or related technical requirements) produce different rates of storage, then it may be necessary to use levelized unit cost (LUC) as the figure of merit. The LUC calculation method is shown in Fig. 10.

TABLE 14. EXAMPLE OF DIFFERENCES IN COST RATES

r	e	i Actual	i Approximate
.06	.02	.039	.04
.09	.04	.048	.05
.12	.06	.057	.06

$$\mathbf{LUC} = \frac{\displaystyle\sum_{t=0}^{n}\frac{C_t}{(1+i)^t}\qquad\text{(Total costs for } n \text{ periods)}}{\displaystyle\sum_{t=0}^{m}\frac{Q_t}{(1+i)^t}\qquad\text{(Total quantity for } m \text{ periods)}}$$

FIG. 10. Calculation of LUCs.

The LUC is based on the hypothesis that the NPV of all expenditures must equal the NPV of all benefits. In the case of spent fuel management, the benefit realized in any year is the product of the quantity of spent fuel delivered for storage and the applicable LUC escalated to the year of delivery. Thus, the LUC can be determined as follows:

Total NPV of costs = Total NPV of benefits

Benefits = (quantities) × (LUC)

Total NPV of costs = Total NPV of (quantities) × (LUC)

The numerator in this equation is the NPV discussed above.

An illustration of the NPV calculation and LUC is provided in Table 15.

Here, the initial capital cost of 100 units of money is assumed to occur in the reference year with 5 units incurred every year thereafter for ten years (while spent fuel is being placed in storage), 7 units incurred in each of the subsequent two years (while spent fuel is being removed from storage), and 10 units incurred (for decommissioning) in each of the subsequent two years (all in 2003 unit of money values). Meanwhile, 10 units of spent fuel are placed in storage each year for a period of ten years. (Note: The values used are for demonstration of principles only and do not represent actual spent fuel storage costs.)

The annual costs and benefits are shown by columns 2 and 4. The ‘overnight’ cost and benefits are the summation at the bottom of these columns. The NPV of each annual cost and benefit are shown by columns 3 and 5 and the total NPVs of each are the summation at the bottom of these columns. To determine LUCs, the NPV of the total costs (summation of column 3) is set equal to the NPV of the total quantities stored (summation of column 5). Solving for C, in this example, the LUC is 159.00/77.57 = 2.050/unit stored.

According to the assumptions, this LUC, when applied to the specific quantities to be stored, will provide sufficient funds to pay all costs incurred including direct costs, escalation and imputed interest for the time between when the costs are incurred and the benefits realized.

5.3. COMPARISON OF COSTS

5.3.1. Comparative values between different options

For a new project, it is generally best to evaluate alternative methods of storage on the basis of the total discounted life cycle costs. However, if the options being compared do not involve the identical quantities of

TABLE 15. EXAMPLE CALCULATION OF NPV AND LUC FOR STORAGE[a] (APPLIES TO ANY UNIT OF CURRENCY)

Year	Costs incurred		Value of service to break even[b]	
	Annual costs	NPV of annual costs (Costs discounted @ 4.9%/year)	Annual needs[c] C	NPV of annual needs (Costs discounted @ 4.9%/year) C
2003	100	100.00		
2004	5	4.77	10	9.53
2005	5	4.55	10	9.08
2006	5	4.34	10	8.66
2007	5	4.14	10	8.26
2008	5	3.95	10	7.87
2009	5	3.77	10	7.50
2010	5	3.59	10	7.15
2011	5	3.42	10	6.82
2012	5	3.26	10	6.50
2013	5	3.11	10	6.20
2014	2	1.19		
2015	2	1.13		
2016	2	1.08		
2017	2	1.03		
2018	2	0.98		
2019	7	3.27		
2020	7	3.12		
2021	10	4.25		
2022	10	4.05		
Totals	194	159.00	100C	77.57C

[a] Reference year is 2003.
[b] C is the levelized one-time unit cost.
[c] Number of units times the LUCs.

spent fuel being stored on the identical schedule of emplacement and/or removal from storage, then the use of LUCs is the more appropriate figure of merit.

An example of a comparative study on the economics of different options as presented in the literature is shown in Fig. 11.

5.3.2. Expenditure profile

One of the first analytical requirements is to determine the expenditure profiles for each option based on the project implementation scenario. As discussed in preceding sections, the expenditure profile represents the time series of costs associated with an option without consideration of the value of money. These profiles then become input into NPV calculations for comparison between options as discussed in Section 5.2.3.

Figure 12 shows a few examples of facility expenditure profiles.

5.4. SENSITIVITY ANALYSIS

Unfortunately, evaluations of long term projects (20 years or more) have the associated difficulty of predicting the future. Also, the choice between options depends less on the ranking order of the NPV than on the associated uncertainty. In some cases, it might be preferable to choose an option with a higher NPV and a low uncertainty, rather than one with a lower NPV but with a higher uncertainty.

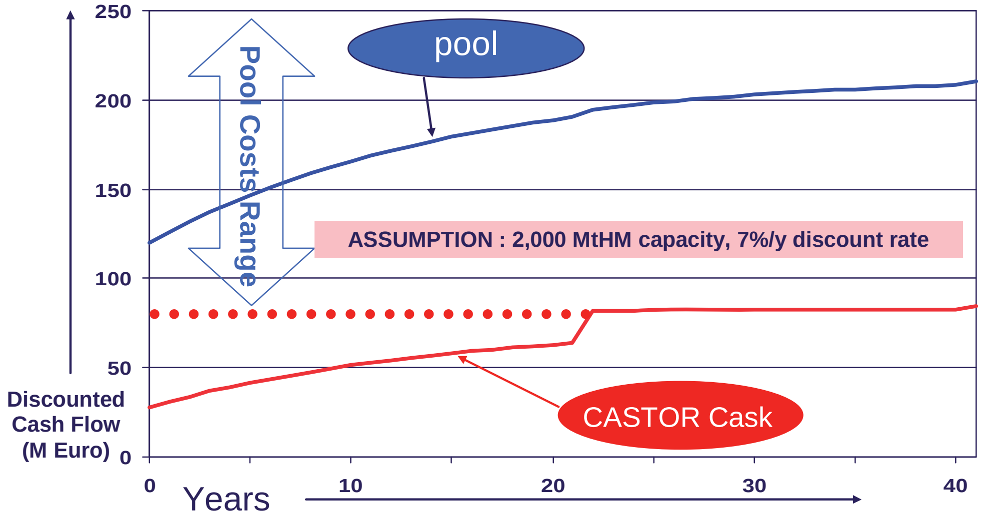


FIG. 11. Comparison: pool versus metal casks (Fluege, IAEA-CN-102/73, 2003).

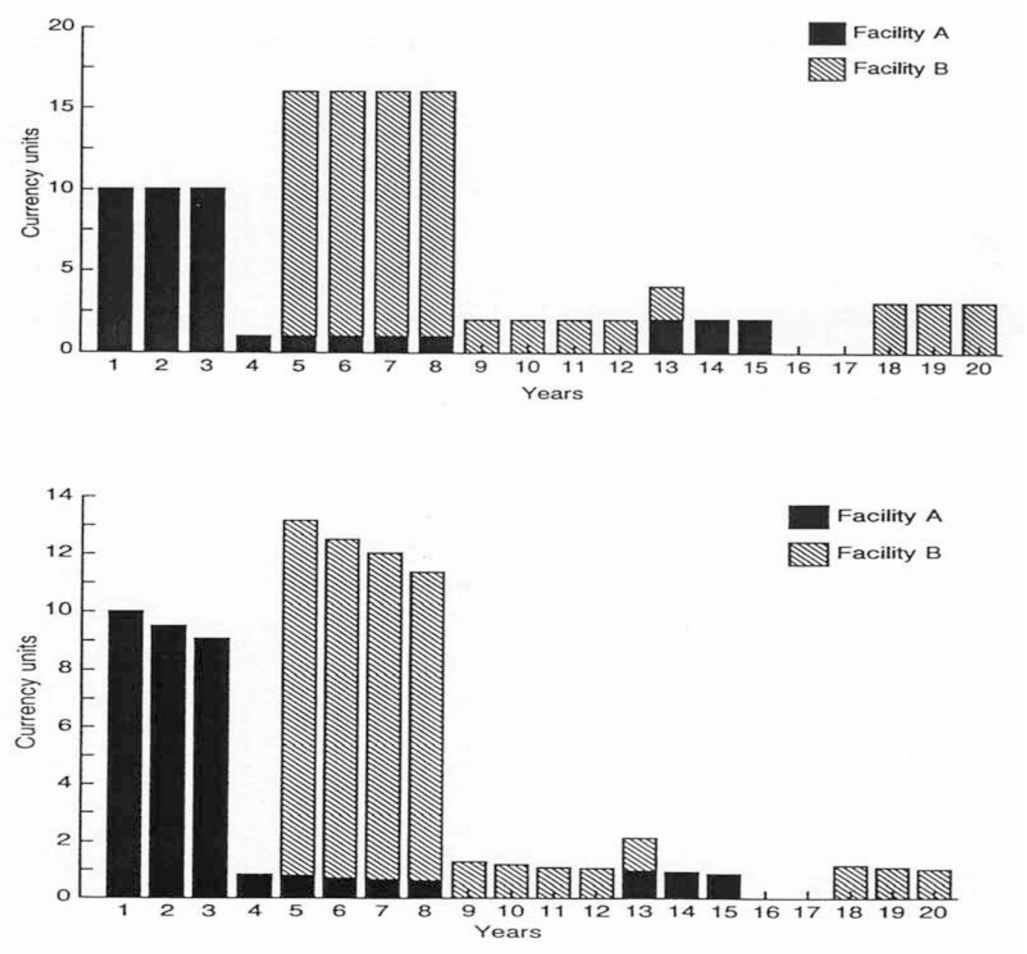


FIG. 12. Examples of spent fuel expenditure profiles.

For this reason, it is prudent to evaluate the sensitivity of the NPV of the options to changes in assumptions, particularly for those parameters that, by inspection, are likely to have a dominant effect on the NPV. This can be done by arbitrarily changing the value of a parameter, say by ±10%, and calculating the change in the NPV. The sensitivity is then simply expressed as the ratio of the resulting change in the NPV to the change in the parameter value (e.g. NPV difference per percent parameter change). Sensitivities may also be expressed in terms of the LUC difference per percent parameter change in a similar manner.

The parameters that might be subjected to a sensitivity analysis include: discount rate, to reflect uncertainties in the macroeconomic environment; currency exchange rates, which have an effect on the prices of imported materials or services; filling rate of storage facilities; lifetime of facilities; and operating lifetime of facilities and long term cost assumptions, say, for transport and decommissioning. In effect, any parameter considered by the evaluator to be too futuristic to be determinable should be subjected to sensitivity analysis.

The sensitivity values thus determined should be compared for each option under consideration to ascertain if this might change the conclusions. In more sophisticated analyses, the various parameter sensitivities can be weighted in terms of importance or probability of occurring. The summation can be another figure of merit for the owner's decision making process.

5.5. USE OF CALCULATION TOOLS

There are a number of computer programs available commercially and from various governmental organizations that can perform discounted LCC calculations (and LUC determinations). Many of these programs determine cash flows as well as return on investment and the time required to recover the investment for more sophisticated or complex projects.

Several software tools which are applicable to spent fuel storage cases were identified and introduced in the Annex II and a few sample calculations are attached for information in Annex III.

Alternatively, the determination of total discounted LCCs, or LUCs, can be made using available computer spreadsheets (e.g. Excel).

After reviewing available evaluation methodologies, the net conclusion was that most financial programs are much more sophisticated than that needed for spent fuel storage evaluations, and that the evaluator of a spent fuel storage project would be better served to use a simple spreadsheet specifically tailored to such evaluation

6. FINANCING AND BUSINESS ASPECTS

This section looks at some related business aspects of funding spent fuel storage (i.e. institutional arrangements, commercial aspects and aspects of international services) that might be considerations in planning a spent fuel storage project or determining the most suitable option.

6.1. NUCLEAR POWER AND FUEL CYCLE COSTS

The revenue and expense of nuclear power as a business system is represented in Fig. 13.

As indicated, spent fuel storage is a cost element, among other fuel cycle costs, that occurs after energy has been created and sold (for revenue). For this reason, some mechanism is required for generating revenue while the fuel is in use. Generally, a levy on electricity rates are used to collect the resources needed for this activity. Often, levies are applied only to the amounts of electricity generated by the nuclear power plants.

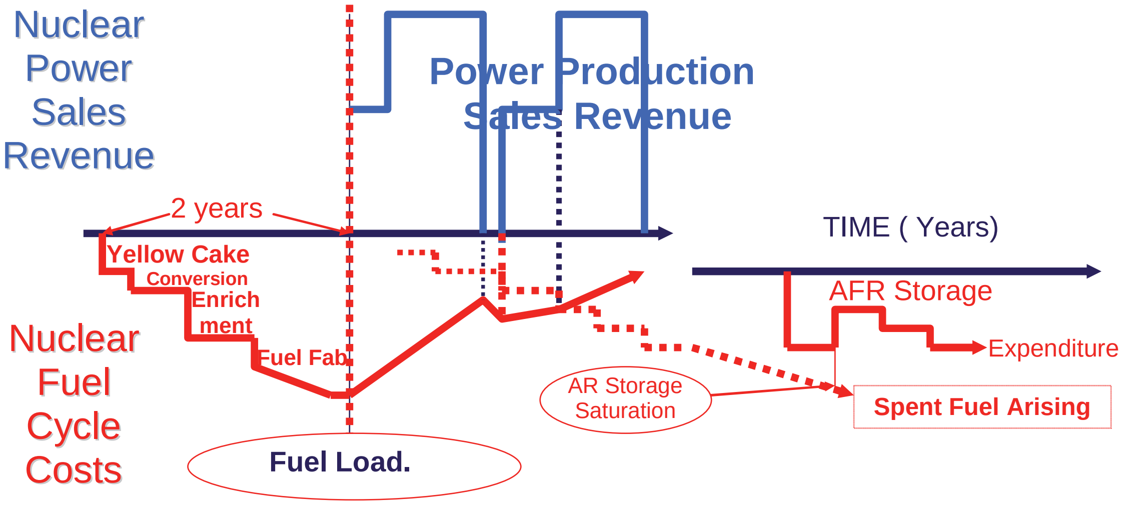


FIG. 13. The revenue and expense of nuclear power.

6.2. METHODS FOR SPENT FUEL STORAGE FINANCING

6.2.1. Utility financing

Even though the aforementioned funds are designed to recover all spent fuel management costs over a period of time, it is necessary to apply this levy uniformly so as not to penalize near term energy consumers (while the facility is being built) for the benefit of later users (when the facility is merely operating). The 'levelized unit cost', as discussed in some detail in Section 5, is the most often used levy formula. But an essential and practical aspect of this process is the need to finance the actual construction and start-up of the facility.

Traditionally, a utility makes expenditures in plant and equipment mostly from capital raised in the form of equity and debt, although some may come from current capital budgets (e.g. casks). It amortizes these financial obligations via depreciation, payment of interest on debt and return on equity. However, in some rare instances, it may be possible and advantageous for a utility to lease the storage casks or modules. Generally, leased equipment may be useful for management of spent fuel for short periods of time (temporary storage) and/or in instances where the equipment may have repetitive use (e.g. transport casks for transhipment to another pool). Such leases can be structured in the same way as those involved in the leasing of aircraft or railroad cars, etc.

If more than one utility is involved, the shared facility may include equity contributions from each utility pursuant to 'subscription agreements' through which the customers will commit to store spent fuel at the facility and pay an annual storage fee. The consortium may also retain the option of obtaining a portion of the facility construction costs through the sale of debt securities secured by the service agreements.

The proposed Private Fuel Storage Facility (USA) is an example of how a centralized spent fuel storage facility might be funded:

(1) The filing of a license application (licensing proceedings, detailed design, preparation of bids specifications, etc.) was funded by direct payments from member utilities pursuant to subscription agreements.

(2) If the project proceeds to the construction phase, construction may be funded either through direct equity contributions from utility members pursuant to Subscription Agreements and/or through Service Agreements with storage site users (including possibly non-members). In either case, no construction will take place without the commitment for a significant quantity of spent fuel storage, so that there is reasonable assurance of adequate funding. The Service Agreements will provide assurance for the continued payment of these costs by requiring the customers to provide annual financial information, meet creditworthiness requirements, and, if necessary, provide additional financial assurances such as an advance payment, irrevocable letter of credit, third-party guarantee, or a payment and performance bond.

(3) The operations and maintenance cost for spent fuel in storage will be paid by the customer on an annual basis pursuant to the Service Agreements.

(4) Funding for decommissioning activities consists of two components: storage cask decommissioning and decommissioning for the remainder of the facility. The costs for decommissioning each storage cask would be prepaid into an escrow account under the Service Agreement with each customer, prior to shipment to the storage facility.

The costs of decommissioning the remainder of the facility and site may be funded through a letter of credit together with an external sinking fund. As the actual costs of decontamination and decommissioning are paid into the external sinking fund, the letter of credit would be reduced by an equivalent amount. Customers would be required under the Service Agreements to pay in proportion to the maximum amount of the total facility capacity that they use (or commit to use) during operation.

The per cask fee and the amounts of the escrow account, external sinking fund and letter of credit would be reviewed and adjusted annually to account for inflation and any changes in the scope or cost of decommissioning.

6.2.2. Government

A government organization can finance facilities, such as spent fuel storage facilities, from funds appropriated by the government authorities. If provisions for collection of annual payments from electric generator organizations have **not** been made, the government can finance the required facilities with appropriated funds from tax revenues to recover the cost, with interest, over the lifetime of the storage project.

6.2.3. Commercial

A non-utility commercial organization can finance spent fuel storage facilities from its own treasury or leverage finance for them with a mixture of equity and borrowed funds. However, a commercial organization would not be willing to do this unless its utility customers contractually commit to store specific quantities of spent fuel on a specific schedule. In fact, the commercial organization would probably require one of the following guarantees to protect their investment:

- A guarantee that if the utility did not deliver the specific quantities of spent fuel on the stated schedule, or could not transfer these obligations to third parties, the contracting utility would pay all charges as if they had delivered the fuel; or
- A guarantee to make all capital related payments on a defined schedule, whether or not the storage facilities are even built or operated.

These are referred to as ‘take-or-pay’ contracts, which puts the utility company at risk for all major regulatory changes, legal actions blocking the implementation of storage, changes in laws impacting storage activities, etc., almost to the same extent as if it constructed the facility itself.

Still, there may be some reasons to pursue such arrangements. One would be if the commercial firm had some unique technical know-how or commercial advantage (including financing and/or tax advantage) in providing the service. Another reason may be if several utilities see some collective improvement in cost and/or operations from a larger facility.

6.3. COMMERCIAL ANALYSIS OF STORAGE SERVICES

It is not often easy to determine the best institutional arrangement for the spent fuel storage and disposal, due to the uncertainty in public acceptability, among other factors. The best balance between governmental and private sectors in managing spent fuel will be determined case-by-case on the basis of specific circumstances that can change with time.

6.3.1. Profit from commercial service

In most countries, a utility is legally responsible for generating sufficient revenues to fund the **interim** management of the spent fuel. The funds must be conservatively invested and the owner is not entitled to profit from this dedicated pool of money. The utility may 'profit', however, to the extent it can sell its electricity in the market at prices that exceed all costs including the spent fuel management cost. Thus, the owner has an incentive to keep the cost of spent fuel management low, which is a part of the cost base.

In some countries, a public body is established with the mission to "take title" of the spent fuel and for downstream management, including final disposal or reprocessing. In this case, the overall responsibility of spent fuel storage is not subjected to commercial conditions, although the facilities and equipment provided by commercial vendors may be.

6.3.2. Financial analysis for storage business

It has not yet been customary, in any of the existing institutional arrangements, to see the 'ownership' of spent fuel transferred to a private business. But the possibility of privatizing the business of spent fuel storage for the interim term (until turnover to the end point) is feasible. For example, storage of spent fuel in existing reprocessing facilities has already been offered by some reprocessing companies. Normally, this is offered in conjunction with subsequent intent to reprocess the spent fuel, but in principle, it could be returned without reprocessing at an agreed service charge. Similarly, an independent central store could be set up for this purpose (PFS discussed above is a potential example).

Should the opportunity open to industry for spent fuel storage as normal business, the key economic factor will be profitability for the interested entrepreneurs. For such business, financial analysis tools such as COMFAR would provide the results of profitability analysis. Samples of such analysis by COMFAR for several cases are given in Annex II.

6.3.3. International services

Some international management concepts for spent fuel date back to 1946 (Baruch Plan). The International Monitored Retrievable Storage System (IMRSS) developed in the mid-1990s is another international example where spent fuel could be stored for an extended period and retrieved at any time for peaceful use or disposal.

In 1994, the Marshall Islands supported a project for an international repository for spent fuel. Concurrently with that proposal, the US Fuel and Security Group proposed to establish a repository on an uninhabited Pacific Island, the Palmyra Atoll. At the same time, the South African Atomic Energy Corporation outlined a concept for complete back-end services including international storage and permanent disposal with full ownership and liability to the host state when the material was shipped (see IAEA-TECDOC-990 and IAEA-TECDOC-1089).

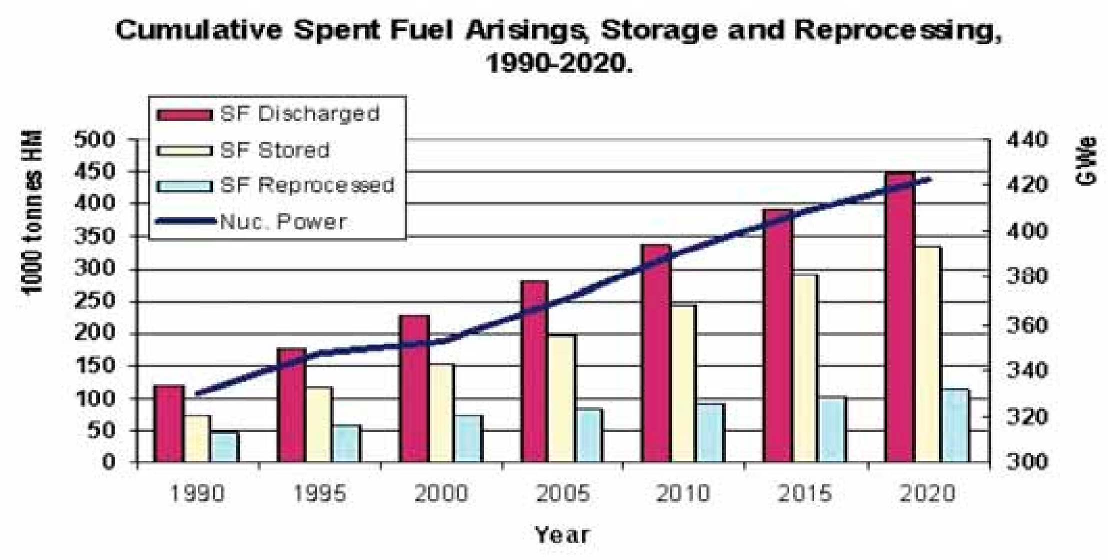
In 1998, a plan by a commercial consortium, Pangea, explored the feasibility of an international repository concept. Finally, in 2000, the Non-Proliferation Trust concept called for establishing a dry cask storage facility in the Russian Federation that would accept 10 000 t HM of spent fuel from other countries on a commercial basis, at a projected price of $1500/kg HM. None of these concepts matured for a variety of economic, technical and political reasons.

Another more recent development is the 'cradle to grave' (or comprehensive fuel service) concept. Typically, this concept uses a fuel lease, or energy price, contract form, rather than a facility purchase contract discussed herein. In this concept, the fresh fuel is delivered to the utilities for use in reactor and then returned to the supplier after use. The utility pays a lease fee or an energy fee that includes all fuel cycle services, including spent fuel management.

This concept was used routinely in the former USSR and in some early commercial reprocessing contracts in the West. However, it must be noted that such arrangements have political complications, especially with respect to the backend responsibilities. Also, the concept could apply only to new fuel, not for management of spent fuel that is already stored in pools or in dry stores around the world.

Appendix I

CUMULATIVE WORLD INVENTORIES OF SPENT FUEL



Appendix II

COMMERCIAL CASKS FOR SPENT FUEL STORAGE (AND SOME ALSO FOR TRANSPORTATION)

(P=PWR, B=BWR, C=CANDU, W=WWER (440/1000), R=RBMK, H=HTR)
(Listed by alphabetical order of supplier/owner names), as of 2005

Supplier/Owner	Casks/Canister		Technical Requirements		
	Product Model	Number of Fuel Elements	Maximum Burnup (GW·d/t·HM)	Maximum Heat Load (KW)	Total Wt (MT)
AECL	Concrete Silo	360C	9	1.8	
		342C	9	1.71	
		486C	9	2.4	
		540C	9	2.7	
BNFL Fuel	TS-125	21P/64B		22	139
Solutions	VSC-24	24P	51.8/45	24	144
metal cask and	W-150	21P/64B		24.8/25.1	160
concrete cask	W-21 (Canister)	21P	15~60	22/25.1	
	W-74 (Canister)	64B	15~40	17.6/24.8	
ENSA	DPT	21P	40	27.3	113/114
GNS	CASTOR 1C	16B	35	14,4	81.1
	CASTOR-V/19	19P	65	39	125.6
CASTOR family	CASTOR-V52	52B	65	40	123.4
metal cask	CASTOR-V/21A	24P	60	34	119
	CASTOR Va	21P	75	40	126.2
	CASTOR Vb	24P	75	34	110.4
	CASTOR X28	28P	37.5	17.2	133
	CASTOR V21 (Surry)	32B	60	32	107.9
and	CASTOR X33F	33P	60	16.6	107.3
	CASTOR-440/84	84W440	42	21	116
	CASTOR RBMK	102	29	12.5	117
	CASTOR THTR/	ca. 2,100H	114	Ca.0.2	32
	CASTOR AVR	ca.1,900	115	Ca.0.2	30
CONSTOR family	CONSTOR-440/84	84W440	41	20	120
concrete cask	CONSTOR-1000/19	19W1000	49	21	125
	CONSTORRBMK	102R	30	7	84.4
H-Z	Metal cask for storage	61B	50	17	118
Holtec	HI-STORM-24	24P	68.2	27.8	163
International	HI-STORM-32	32P	68.2	28.7	163
metal cask and	HI-STORM-68	68B	65	28.2	163
concrete cask	HI-STAR -24	24P	42.1	19	114
	HI-STAR-68	68B	37.6	18.5	114
KSL	TN-24	32B/37B	33	28/20	113/100
MHI	MSF-21P	21B	60	41	121
MSF family metal	MSF-57B	57B	63	49	123
cask	MSF-69B	69B	40	19	119

Supplier/Owner	Casks/Canister		Technical Requirements		
	Product Model	Number of Fuel Elements	Maximum Burnup (GW·d/t·HM)	Maximum Heat Load (KW)	Total Wt (MT)
NAC International metal cask and concrete cask	NAC-STC	26P (BF)	45	22.1	127
	NAC-C28 S/T	56P (CF)	35	20	
	NAC-S/T	26P / 28P	45	17.4	
	NAC-MPC	36P / 26B	36/43	12.5 / 17.5	89
	NAC-UMS	24P / 56B	50	23	140
	MAGNASTOR	37P //87B	60	35(P)/ 33(B)	161
OAO Izhora	TUK-104/M	57/114 R		5	95/93
	TUK-108/1	72/144 W1000		6.3	39.6
OPG	DSC (CIC)	384 C	9	4.4	70
REA	REA-2023	24P/52B	33	24/20	
ACL (former TN) TN Family Europe (metal casks)	TN-24 DH	28P	55	33	112
	TN-24XLH A/B	24P	55	33	111
	TN-24SH	37P	55	30	96
	TN24E	21P	75	40*	125
	TN-52L	52B	53	40*	112.5
	TN-68	68B	40	21.2	115
	TN-97L	97B	26 (av.)	19	124.5
	TN-24BH	69B	50	40	126
Transnuclear NY TN Family USA NUHOMS Family Canister-based concrete module	TN-32	32P	45	32.7	115.5
	TN-40	85B	45	32.7	113
	TN-68	40	40	21.1	113.8
	NUHOMS-07P	7P/18B		7	48.6
	NUHOMS-24P	24P	45-62	24-40.8	
	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	?

ABBREVIATIONS FOR SUPPLIER/OWNERS:

ACL= Areva Cogema Logistics (former Cogema Logistics, Transnucléaire)
AECL=Atomic Energy of Canada Limited
BNG=British Nuclear Group
GA=General Atomics
GE=General Electric
GNS=Gesellschaft fuer Nukleaire Services
KSL=Kobe Steel Ltd.
MHI= Mitsubishi Heavy Industries, Ltd.
NAC= Nuclear Assurances Corp.
NFT=Nuclear Fuel Transport Co. Ltd.
OCL = OCL Corporation
OPG=Ontario Power Generation
REA=Ridihalgh, Eggers and Associates

Appendix III

COMMERCIAL CASKS FOR SPENT FUEL TRANSPORT

P=PWR, B=BWR, W=WWER(440/1000), M=MOX, H=HTGR, R=RBMK, C=CANDU, M=Magnox, A=AGR

Fuel Type	Casks		Technical requirements			Remark (References.)
	Owner	Model	Capacity (Fuel Assemblies)	Thermal Load (Kw)	Total Wt. (Mt)	
LWR	BNG	NTL-3M	7P	30	54	TRS-240 UK Report (G. Jones)
		NTL-3MA	10B	10	53	
		NTL-9	7B	25	36	
		NTL-11	7P	20	78	
		NTL-14	5P	45	85	
		NTL-15	10B	9	25	
		EXCELLOX-6	6P	20	95	
	GA	GA-4	4P	2.47	27.5	AI-582
		GA-9	9B	2.12	27	
	GE	IF-3000	7P/16B	68-70	60.7	
	GNS	CASTOR-S1	6P/17B	30	79-82	P. Dyck
	Holtec Int.	HI-STAR-24	24P	20	114	USNRC Docket No. 71-9261 Rev 4
		HI-STAR-68	68B	18.5	114	
	H-Z	NH-25	1P/2B	7	29	Yamamoto TRS-240
	Lehrer	LK-80	12P	100	100	
		LK-100	12P/24P	30	72	
	MHI	MSF-1	1P	6.7	45	
	NAC	NAC-LWT	1P/2B	11.5	25.6	Yamamoto
		NLI-1/2	1P/2B	10.6	23.1	
		NLI-10/24	10P/24B	70	97	
	NFT	NFT-10P	10P	25	83	
		NFT-14P	14P	54	115	
		NFT-12B	12B	15	23	
		NFT-22B	22B	25	97	
		NFT-32B	32B	22	106	
		NFT-38B	38B	26	119	
	OCL	HZ-75T	7P/17B	40	82	Yamamoto
	PNTL	EXCELLOX-3				JAI-582 Yamamoto
		EXCELLOX-3A	5P/14B	30	72	
		EXCELLOX-3B	14B	24	74	
		EXCELLOX-4	7P	40	92	
		EXCELLOX-7	17B	20	89	
		EXL-4MOX	8M	8	92	
	TN	TN-8	3P	35.5	38	UK Report (G. Jones)
		TN-9	7B	24.5	39	
		TN-10				
		TN-12	12P/32P	51.6/64	100/105	TRS-240 JAI-582
		TN-12/2 (A/B)	12P	93/70	102/104	
		TN-13	12P/32P	64	105/115	
		TN-17	7P/17B	25 (35)	78	
		TN-17/2	7P	43	81	

Fuel Type	Casks		Technical requirements			Remark (References.)
	Owner	Model	Capacity (Fuel Assemblies)	Thermal Load (Kw)	Total Wt. (Mt)	
WWER	GNS	CASTOR-84				TECDOC-1100
	BIZ	C-30	30/48 W440	9.21	120	F. Takats
	OAO Izhora	TK-6 TK-10B TK-13	30 W440 6 W1000 12 W1000	15 13 20	92 94.4 116	N. Tikhonov TRS-240 TECDOC-1100
		TK-8 TK-11 TK-104 TK-109	9 RBMK 51/102 57/114 72/144	NA 12 5 6.3	NA 105 120 126	IAEA-SM/294-9 CN-102/40 Atomtrans2003 (St.Petersburg)
		TK-11 BN	35 BN600	10.7	90	
CANDU	AECL	NOD-F1	2 C	NA	12	M.Rao (HASL)
	OPG	IFTC DSCTP	192 C 364 C	1.5 3.0	39 100	
	DAE	DAE India	220 C	70	63	
AGR	BNG	Mark A1/A2				TRS-240
		M-1/2	260 Magnox	6.5	49	
HTGR		FSV-1	6H	23-25.		JAI-582

ABBREVIATIONS FOR SUPPLIER/OWNERS

AECL=Atomic Energy of Canada Limited
BIZ= An entity that was involved in the fabrication of the cask in the former East Germany
BNG=British Nuclear Group
DAE= Department of Atomic Energy of India
DAE= Department of Atomic Energy of India
GA=General Atomics
GE=General Electric
GNS=Gesellschaft für Nukleaire Services
MHI=Mitsubishi Heav Industries Ltd.
NAC= Nuclear Assurances Corporation
NFT=Nuclear Fuel Transport Co. Ltd.
OAO Izhora =A holding company involved in cask manufacturing in the Russian Federation
OCL = OCL Corporation
OPG=Ontario Power Generation
PNTL=Pacific Nuclear Transport Limited
TN= Transnucleaire, Inc.

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Annex I

SOME EXAMPLES OF SPENT FUEL STORAGE COSTS

I–1. MONITORED RETRIEVABLE STORAGE (MRS) FACILITY)

In November 1989, the Monitored Retrievable Storage (MRS) Commission published its report to the US Congress on the need for a monitored retrievable spent fuel storage facility as part of the Civilian Radioactive Waste Management System.

Key issues were analysed including the public policy context, equity considerations, economic efficiency and spent fuel management costs, and an analytical methodology was developed with models for MRS and No-MRS alternatives and strategies together with sensitivity analyses. Because DOE's cost studies had traditionally been reported in undiscounted, constant dollars, the MRS Commission used undiscounted dollars to make its studies comparable to DOE's. However, because the spent fuel management and disposal system's benefits and costs are incurred at different points in time under different alternatives and cases, the Commission made cost comparisons based on present value (PV) and on an undiscounted current, or nominal value (NV) basis. Table A-1 compares the costs of the alternatives.

In this example, discounting results in modest increases in the relative cost advantages of the No-MRS alternative over the unlinked MRS system as the repository is delayed. On a nominal value basis, a system without an MRS was estimated to have almost the same total system cost as one with an MRS, if the repository is delayed to 2013 and is slightly less expensive by 2023. On a present value basis, the No-MRS system retained its cost advantage of about 6 % as the repository is delayed in both the 2013 and 2023 cases.

The major cost account increasing the cost of No-MRS cases is the increase attributable to the delay in removing spent fuel from shutdown reactors. In nominal value terms, the annual cost of delaying spent fuel removal from shutdown reactors peaks in 2037 at $145 million, but the present value of the cost in 2037 is only about $22 million.

Compared to a linked MRS system, the cost advantage of the No-MRS alternative remains at about 5%, regardless of whether the comparison is based on the nominal or present value. Recalling the analysis of the uncertainty of the cost estimates, cost differences of this magnitude are small relative to the inherent uncertainty in the cost data from which they were derived.

Discounting the AR storage costs decreases the relative importance of the cost of the AR storage component that is attributable to the removal delay, but the relative importance of the total at-reactor storage category in total system costs remains unchanged. In the linked MRS cases, delaying the repository opening reduces the relative cost of the MRS, because the facility is built later with 'cheaper' discounted dollars, which tends to reduce the cost advantage of the unlinked MRS compared to the linked MRS.

In general, however, it was found that discounting does not significantly change the relationships among the costs of alternatives. No-MRS systems are less expensive if the repository comes on line as scheduled; if the repository is delayed, the cost differences shrink as AR storage costs accumulate.

I–2. CLAB (SWEDEN)

CLAB provides for centralized interim storage in water pools in rock caverns 25 m below the ground. The facility is currently being expanded to a capacity of 8000 t HM of spent fuel. The published data on CLAB is as follows:

- Start of construction: 1980;
- Start of operations: 1985;
- Current storage capacity: 5000 tHM (20 000 BWR fuel assemblies and 2500 PWR fuel assemblies);
- Processing rate: 300 t HM per year;
- Number of employees: 100 full-time staff;
- Number of pools: Four, plus one in reserve;
- Pool temperature: 36°C;

TABLE I-1. COMPARISON OF TOTAL SYSTEM, LIFE CYCLE COSTS[a]: NOMINAL VALUE AND PRESENT VALUE[b] FOR SELECTED CASES

Year Repository Starts	No MRS		Linked MRS[c]		Unlinked MRS[d]	
	PV	NV	PV	NV	PV	NV
			2003			
Total	11.6	24.8	12.5	26.9	12.5	27.0
At-reactor						0.9
[Shutdown Reactors][e]	[0.4]	[1.2]	[0.2]	[0.5]	[0.1]	[0.2]
Development & Evaluation	6.3	9.0	6.6	9.8	6.6	9.8
Transportation	1.0	3.7	1.1	3.7	1.7	3.8
Repository	3.2	9.7	3.2	9.7	3.2	9.7
MRS	—	—	0.9	2.5	1.1	2.8
			2013			
Total	9.2	26.6	9.7	27.9	9.7	26.7
At-reactor	1.8	5.1	1.5	3.7	0.6	1.1
[Shutdown Reactors][e]	[0.6]	[2.7]	[0.4]	[1.3]	[0.1]	[0.3]
Development & Evaluation	4.8	9.0	5.0	9.7	5.1	9.8
Transportation	0.6	3.3	0.6	3.3	0.8	3.3
Repository	2.0	9.2	2.0	9.2	2.0	9.2
MRS	—	—	0.6	2.1	1.2	3.2
			2023			
Total	7.4	28.0	7.8	29.5	7.9	27.2
At-reactor	2.0	6.6	2.0	5.9	0.7	1.4
[Shutdown Reactors][e]	[0.7]	[3.6]	[0.6]	[3.0]	[0.2]	[0.5]
Development & Evaluation	3.8	9.0	3.8	9.6	4.1	9.9
Transportation	0.4	2.9	0.4	2.9	0.5	2.8
Repository	1.3	9.4	1.3	9.4	1.3	9.4
MRS	—	—	0.3	1.7	1.3	3.7

[a&b] Nominal value (NV) is in billions of constant 1989 dollars; present value (PV) is in billions of constant 1989 dollars discounted at an annual rate of 4%.

[c] MRS is to begin operations three years before the repository and be limited to 15 000 MTU per NWPAA

[d] MRS is to begin operation in 2000 and to have no capacity limit.

[e] Cost of delaying the removal of spent fuel from shutdown reactors. This is included as part of AR storage costs.

— Cooling capacity: 8.5 MW;
— Construction cost: SEK 1700 million;
— Operation cost: SEK 100 million/year.

I–3. ZWILAG (SWITZERLAND)

ZWILAG is a joint stock company owned by the four nuclear power plant operators in Switzerland. The company’s share capital is divided in proportion to the thermal output capacity per 1990 of the four plants. The shareholder’s capital is divided as follows:

— BKW-FMB Beteiligungen AG (BKW)	10.7%
— NPP Gösgen-Däniken AG (KKG)	31.2%
— NPP Leibstadt AG. (KKL)	3.8%
— Nordostschweizeische Kraftwerke (NOK)	24.3%

NOK is the managing partner of the company. ZWILAG was financed by the shareholders. Fixed costs and a part of the variable (campaign) costs determined annually are charged to the shareholders in proportion to their respective share. The remaining variable costs are charged directly to the individual operator as and when the campaigns take place.

I–4. MAINE YANKEE ISFSI

Maine Yankee total spent fuel management costs (shown below in 2001 US dollars) for the 64 UMS systems installed (for 1432 spent fuel assemblies in storage) until DOE takes possession of the spent fuel (assumed to begin in the 2018–2023 timeframe) were published in the License Termination Plan of Maine Yankee as follows:

The Independent Spent Fuel Storage Facility (ISFSI) was required by the pre-mature closure and decommissioning of this reactor.

I–5. PRIVATE FUEL STORAGE (PFS)

This section examines the economic costs and benefits of an AFR facility as reviewed by the U.S. Nuclear Regulatory Commission (NRC) in NUREG-1714, for the proposed private fuel storage facility (PFSF). In the following, ‘capacity’ is the amount of spent fuel that could be stored at PFS at any one time and “throughput” is the amount that would be stored over the life of the storage facility. Scenarios are differentiated by: (a) the grouping of reactor sites as sources of spent fuel to be stored at PFS, and (b) the date when a permanent repository is projected to become available, either 2010 or 2015, for both the medium throughput (27 000 MTU), and the maximum throughput (38 000 MTU) scenarios. Fuel shipments were scheduled in a manner that will: (a) limit the amount of additional dry storage that must be added at reactor sites, and (b) reduce the time SNF remains at a reactor site following reactor shutdown for decommissioning. Priority for shipments was provided to: (a) reactors that would require additional SNF storage capacity, and (b) shutdown reactors to ensure that SNF which has cooled for a period no less than five years is removed from such sites on an expedited basis.

Net benefits are calculated by finding the cost avoided by power reactor licensees due to operation of the proposed PFSF, and then subtracting the costs of building and operating the proposed PFSF. The annual costs are calculated for a chosen group of reactors by applying cost assumptions to increments of additional storage requirements for each reactor for each year until all SNF has been shipped off the reactor sites. For each scenario, the cost of a ‘no action’ case (i.e. the case in which the proposed PFSF is not constructed) is calculated in order to establish the baseline cost for the group of reactors without the availability of the proposed PFSF. This cost is then compared to the total costs of the same group of reactors assuming that the proposed PFSF would be available. AR SNF storage costs with the proposed PFSF also available will always be less than AR costs in the no action case, because costs would be reduced by the amount of spent fuel storage at site. All costs and benefits for the alternative scenarios are determined on an annual basis in constant 1999 dollars. These values are then ‘discounted’ to a present value so that they are comparable at a single point in time.

TABLE I-2. TOTAL COSTS OF SPENT FUEL STORAGE AT MAINE YANKEE ISFSI (US$ million as of 2001)

ISFSI Operations (Staffing and Security)	38.529
ISFSI Property Taxes	29.539
ISFSI Engineering, Licensing, Construction Costs	60.655
NRC and State Fees	11.717
ISFSI Insurance	3.504
Other Costs (ISFSI Decommissioning)	5.436
Total	149.379

Two rates (i.e. 7% mandated for public investment and regulatory analyses to approximate the marginal pre-tax rate of return on an average investment in the private sector in recent years, and 3.8% based on a nominal rate for municipal bonds) are used to calculate the present value of costs and benefits for the scenarios.

Table I-3 presents PFS's cost assumptions for an AFR cask storage system.

PFS also included the loading and transportation costs for SNF that is assumed to be shipped to either the proposed PFSF or a permanent repository.

Table I-4 provides the cost estimates using a 3.8% and 7% discount rate for the scenarios discussed. It shows that the net economic benefits of the proposed PFSF are very sensitive to the discount rate, the size of the proposed PFSF, and whether the permanent repository opens in 2010 or 2015.

TABLE I-3. COSTS FOR AFR STORAGE (PFS) (1999 DOLLARS)

Cost Component	1994-2000 Storage Only Systems	2001+ Dual-Purpose Canister Systems
Costs of Dry Storage Capacity[a]		
Upfront Dry Storage[b]	$9 184 000	9 184 000
Dry Transfer Capital[c]	8 084 620	8 084 620
Incremental[d] 125T BWR/PWR ($/MTU)	77 661	93 737
Incremental[d] 75T BWR/PWR ($/MTU)	143 516	152 596
Incremental Truck[d] BWR/PWR ($/MTU)	117 576	115 780
Annual Operating, Maintenance[e]	600 000	600 000
Annual Operating Cost for Post-Shutdown Storage Operation ($/year per site)[f]	8 000 000	8 000 000

[a] A common cost for both PWR and BWR reactor types was used by PFS and was based on PFS's analysis of current market costs for SNF canisters.

[b] Upfront costs include construction, licensing, equipment, design and engineering, and startup testing.

[c] Dry transfer system costs are only included for sites unable to handle large SNF storage and transport systems.

[d] Incremental costs include overpacks, canisters, loading and unloading costs, consumables and dry storage facility decommissioning costs.

[e] Annual operating costs for dry storage at operating reactors include personnel costs to administer and manage the reactor's on-site dry storage projects, incidentals such as electricity, lighting and security, and NRC annual licence fees.

[f] Annual operating costs for post-shutdown operation of SNF storage (pool and/or on-site dry storage) includes costs for security, maintenance and engineering, insurance, licence fees, taxes, etc.

TABLE I-4. COSTS AND BENEFITS FOR ALTERNATIVE SCENARIOS PRESENTED BY PFS (PRESENT VALUE IN MILLIONS OF 1999 DOLLARS)

	Discount Rate 3.8%	Discount Rate 7%
Scenario I — Medium Throughput (21 000 MTU Capacity; Throughput = 27 000 MTU; 2015 Repository)		
• Storage Costs Without PFSF	$4 504	$3 021
• Storage Costs with PFSF	2 504	1 925
• Avoided Costs or Benefits Attributed to PFSF	2 000	1 096
• Cost of PSFS Facility	1 160	841
• Net Benefit of PFSF (compared to the no action alternative)	840	255
Scenario II — Medium Throughput (19 400 MTU Capacity; Throughput = 27 000 MTU; 2010 Repository)		
• Storage Costs Without PFSF	$3 994	$2 804
• Storage Costs with PFSF	2 430	1 904
• Avoided Costs or Benefits Attributed to PFSF	1 564	900
• Cost of PSFS Facility	1 160	841
• Net Benefit of PFSF (as compared with the no action alternative)	404	60
Scenario III — Maximum Throughput (38 000 MTU Capacity; Throughput = 38 000 MTU; 2015 Repository)		
• Storage Costs Without PFSF	$7 902	$4 924
• Storage Costs with PFSF	4 465	2 999
• Avoided Costs or Benefits Attributed to PFSF	3 437	1 925
• Cost of PSFS Facility	1 442	1 004
• Net Benefit of PFSF (as compared with the no action alternative)	1 995	921
Scenario IV — Maximum Throughput (38 000 MTU Capacity; Throughput = 38 000 MTU; 2010 Repository)		
• Storage Costs Without PFSF	$6 849	$4 493
• Storage costs with PFSF	3 910	2 842
• Avoided Costs or Benefits Attributed to PFSF	2 939	1 651
• Cost of PSFS Facility	1 442	1 004
• Net Benefit of PFSF (as compared with the no action alternative)	1 497	647

Annex II

SOFTWARE TOOLS

II–1. COMFAR

COMFAR, the **CO**mputer **M**odel for **F**easibility **A**nalysis and **R**eporting developed by the United Nations Industrial Development Organization (UNIDO) is a valuable aid in the analysis of investment projects. COMFAR III Expert for Windows, first released in 1995, has been upgraded yearly and is based on the experience recommendations, comments and needs of more than 3000 users in 140 countries.

The main module of the program accepts financial and economic data, produces financial and economic statements and graphical displays and calculates measures of performance. Supplementary modules also assist in the analytical process. Cost benefit and value-added methods of economic analysis developed by UNIDO are included in the program.

COMFAR III Expert allows users greater flexibility in specifying the following:

- Variable planning horizon – up to 60 years;
- Variable time structure – construction and startup;
- Up to 20 items can be specified;
- Data may be entered in up to 20 currencies;
- Economic analysis option;
- Direct costing option;
- Price escalation/inflation option.

The standard structure of investment, operating and marketing costs may be expanded to allow the entry of sub-items. Sources of finance include equity, long term loans, short term finance and definition of conditions of profit distribution.

The COMFAR system distinguishes cash flows in domestic and foreign currencies while allowing for changes in exchange rates. A number of standard functions are available to compute net working capital, debt service, annual depreciation of fixed assets and corporate tax. From a variety of financial and efficiency ratios, the user may select those needed for project appraisal.

For financial analysis, COMFAR III Expert produces the following result schedules:

- Summary sheet;
- Investment costs;
- Production costs;
- Production and sales programme;
- Sources of finance and debt service;
- Business results (financial cash flow, discounted cash flow, income statement, balance sheet (with ratios), data on direct costing and product profitability);
- Financial and efficiency ratios;
- Breakeven conditions.

COMFAR III Expert facilitates assessment of alternative project scenarios and determination of critical variables. A variety of graphic charts is available to analyse the structures of project inputs and outputs, variable and operational margins and breakeven points.

II–2. EPRIDRY

A proprietary computer program (EPRIDRY-) designed explicitly for such a determination was developed under the sponsorship of the Electric Power Research Institute. EPRIDRY is a PC-based analysis tool for evaluating and comparing alternative spent fuel dry storage systems as to[in terms of?] physical performance, costs and impacts. It is specifically designed to support and facilitate utility evaluations of alterative dry storage vendor designs and cost proposals. It consists of two related but separate components: a program to evaluate and compare the physical characteristics and costs and a program to evaluate and compare the non-cost factors such as timely licensing, vendor capability, and implementation and operational risks. These two components are summarized as follows:

(1) The EPRIDRY Cost Module requires user input of pool or site spent fuel inventory, discharge projections and assumed removal schedules. It also requires physical and cost descriptions of each vendor dry storage offering. The program determines the life cycle number and timing of all dry storage procurements, loadings, unloadings, off-site removals, and related radiological impacts and costs for each vendor. It provides side-by-side comparisons of all vendor offerings in terms of physical and operational performance, and in terms of total and unit dry storage costs. The program also provides a complete set of default data, including data on generic dry storage types, permitting users to make immediate runs to confirm the proper operation of the program, and to provide reasonable data for familiarization with the program.

(2) The EPRIDRY Non-Cost Module provides a systematic method of first identifying and weighting independent non-cost attributes for each vendor. The independent attributes include vendor technology status, vendor resources, operational impacts and public perception, for which the user develops relative weights by means of a pairwise comparison process. There are also specific sub-attributes within each of the foregoing categories for which relative weights are also developed, and hence the overall user-developed weighting of each sub-attribute. Once the overall weighting of the sub-attributes is developed, the program provides systematic criteria for the users to score each vendor within each sub-attribute category. An overall score for each of the alternative technologies considered is then developed using the previously developed sub-attribute weighting factors.

At the overall level, the EPRIDRY evaluation method identifies potential disqualification criteria, and outlines approaches for combining the cost results from various storage scenarios and for evaluating the frequently contradictory conclusions of the cost and non-cost evaluations.

II–2.1. SECS (Storage Evaluation Code System)

CKA Associates' Storage Evaluation Code System (SECS) is a 50 year net present value (NPV) life cycle cost methodology that evaluates all costs associated with a particular project and discounts these costs from the time of actual expenditure to a common reference date. This methodology is useful when comparing investment in a number of different options with different technologies, cost or expenditure schedules. It involves setting out the entire cash flow based on price projections and timing for the various expenditures for related goods and services. From this cash flow, the net present value of the total life cycle cost may be determined.

The total NPV is the summation of a number of sets of expenditures (cash flow). In the case of spent fuel storage, these broadly comprise:

- Facility capital costs;
- Off-site transport costs;
- Handling costs;
- Long term facility operating costs;
- Facility decommissioning costs.

The ranking of a number of competing options is obtained by comparing their NPV. The lower the NPV, the greater the economic worth of the option.

The Base SECS model can compare six alternative dry store options. Economic data has been pre-programmed for five technologies typically offered for use in the commercial markets as follows:

(1) Modular Vaults
(2) Multi-Purpose Canister Systems (MPC):
(3) With transportable overpack (dual-purpose);
(4) With storage only overpack (i.e. deferred transport investment);
(5) Bare Fuel Metal Cask (storage only);
(6) Bare Fuel Metal Cask (dual-purpose);

The sixth option is open for user discretion (wet storage, central vaults, reprocessing, etc.) or for sensitivity analysis of one of the pre-programmed options.

Current reference economic parameters (default assumptions) that are pre-programmed into SECS are based on recent procurement activity. This gives the user the benefit of current market knowledge. However, all pre-programmed parameters can be modified by the user to study the sensitivity to assumptions or to include job specific data. SECS also considers special or ‘periodic’ costs that may be technology-dependent, such as cask recertification, licence changes or equipment refurbishment, and other costs that may be common to all technologies, such as the cost of bringing spent fuel from another site to the evaluated facility or temporary removal to another facility. These options are at the user’s discretion and are explained more fully in the SECS User’s Manual.

Annex III

SAMPLE CALCULATIONS USING COMFAR-III

III–1. ZWILAG (SWITZERLAND)

ZWILAG is an interim storage facility at Würenlingen, owned by the Zwischenlager Würenlingen AG. It features a storage hall for dry storage of spent fuel and vitrified high level waste (HLW) that can accommodate 200 transport and storage casks, a storage building for long-lived intermediate level waste with a capacity of 4000 m^3 of waste, and a storage hall for low and intermediate level waste with a capacity of 16 500 m^3 of waste. Further, ZWILAG has installations for the sorting and decontamination of materials as well as for the conditioning of waste. It also has a plasma furnace for the incineration and vitrification of radioactive waste. The storage hall for spent fuel and high level waste and the building for intermediate level waste were commissioned in 2001. The conditioning installations and the plasma furnace came into operation later (2004).

III–1.1. Input data and assumptions

ZWILAG is a shareholder company of the Swiss nuclear utilities and operates as a cost centre. However, the intention of testing COMFAR was to assess the economic and financial viability of an interim storage facility from a private investor's point of view, hence certain assumptions were made to adopt the ZWILAG data. The input data and the assumptions are summarized below.

The data relevant to the ZWILAG HLW facility is summarized in the table below.

(1) Planning horizon

The construction duration was five years.

The spent fuel and vitrified high level waste is planned to be stored at the ZWILAG HLW facility for 40 years.

(2) Discount rate

A discount rate of 5% was assumed for two pricing (i. e. storage cost per kg HM) options considered.

(3) Investment cost

Item	Cost (in million CHF)
Land	3.3
Site preparation and development	20.0
Civil works structures and buildings	25.0
Machinery and equipment	50.0
Total	98.3

(4) Disbursement of investment cost

Since the exact disbursement of the investment cost was not available, it was assumed to be disbursed as follows:

Investment	1996%	1997%	1998%	1999%	2000%
Land	100	—	—	—	—
Site preparation	30	17.5	17.5	17.5	17.5
Civil works	20	20	20	20	20
Machinery	20	20	20	20	20

(5) Decommissioning cost

ZWILAG HLW facility will be retained after its useful life, i.e. the facility will not be demolished after the removal of the spent fuel and vitrified high level waste from the HLW storage facility. Thus, no decommissioning cost is assumed.

(6) Depreciation

ZWILAG uses different periods for depreciation depending on the type of equipment and facilities. In order to make the evaluation simple, the depreciation period for the equipment and facilities has been assumed to be 40 years.

(7) Production (operation and maintenance) cost

ZWILAG informed that the annual operation and maintenance cost related to the HLW facility is fixed. The variable cost for HLW facility is negligible and thus has been assumed to be zero.

Item	Cost (in million CHF)
Repair, maintenance	0.1
Labour	0.9
Direct overhead	3.0
Administrative	0.5
Total	4.5

Storage and pricing

The HLW storage hall in ZWILAG can accommodate 200 transport and storage casks equivalent to 3027 t HM. It is assumed that five casks per year (equivalent to 75 675 kg HM) will be delivered from the nuclear power plants. Thus, at the end of 40 years, the 200 storage places would be full.

To test the model, two pricing policies were used:

- *Lump sum price* – Under this pricing, the NPP operators would have to pay a one-time lump sum amount at the time the spent fuel is received at the storage facility. A price of CHF 150/kgHM/year was used which resulted in a positive net present value at a 5% discount rate.
- *Fixed annual price* – Under this pricing, the NPP operators would have to pay an annual fixed amount during the duration of storage from the time the spent fuel is received at the storage facility. A price of CHF 11/kg HM was used which resulted in a positive net present value at a 5% discount rate.

Source of finance

ZWILAG was financed by the Swiss NPP operators out of the reserves built-up internally over the years for waste management activities. Hence, for the purpose of evaluation, the following financing scheme has been assumed.

Equity capital	20% of the investment cost
Long-term loan	80% of the investment cost.

Loan conditions:

Items	Conditions
Loan duration	45 years
Grace period (construction period)	5 years
Repayment period	40 years
Repayment type	Annuity method
Repayment duration	Yearly
Interest rate	5% per annum (during loan duration)
Interest during construction	Capitalized during construction period
Fees	None

Tax rate

A tax rate of 15% is assumed.

Comments

Overall, the COMFAR software package was easy to use. However, there are some short-comings in the COMFAR software package experienced in application for ZWILAG storage:

- Since the software is designed for a broad range of projects there is limited flexibility and cannot be customized to a specific project. As a result, in the printout, there are many lines with zero.
- The maximum length currently supported is 50 years.
- The activity titles in the data input module of the standard structure are fixed and cannot be customized. However, the user has the possibility to define his or her preferred user-defined names below the standard structure.
- There is no flexibility in the input for the price. Only simplified pricing can be used. A realistic pricing structure for spent fuel storage projects would include at least dual pricing structure (e.=g. a lump sum amount at the beginning before the spent fuel arrives and a fixed amount in subsequent years) or better yet, variable pricing structure. Such pricing will have to be separately calculated and input manually.
- There is no possibility to perform risk analysis, although the program allows for a broad range of sensitivity and break-even calculations that could be assigned risk probabilities to achieve risk analyses.

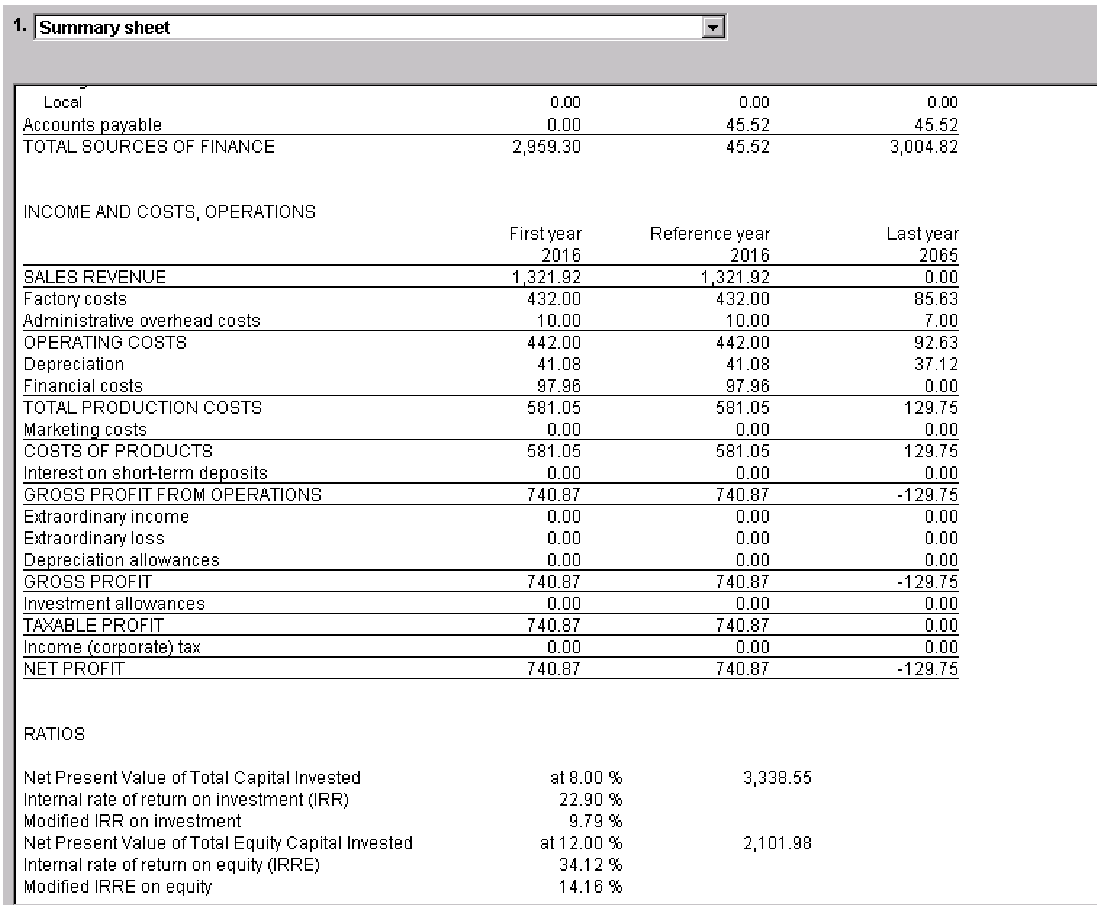
III–2. WET STORAGE FACIILITY (ROK)

1. ASSUMPTIONS

- A centralized AFR storage pool facility;
- An initial storage facility of 3000 MTU capacity with reception facility is constructed by 2015 beginning from 2011;
- Additional storage facilities of 3000 MTU are built in 2020, 2025 and 2030 respectively, with a total capacity of 12 000 MTU;
- An annual reception rate of 600 MTU;
- The operation period of this facility is 50 years (by 2065);
- The period from 2016 to 2035 is for reception/storage and the period from 2036 to 2065 is for storage only.

2. OUTPUTS FROM COMFAR

The following tables and figures demonstrate the type of outputs that can be obtained by COMFAR software.



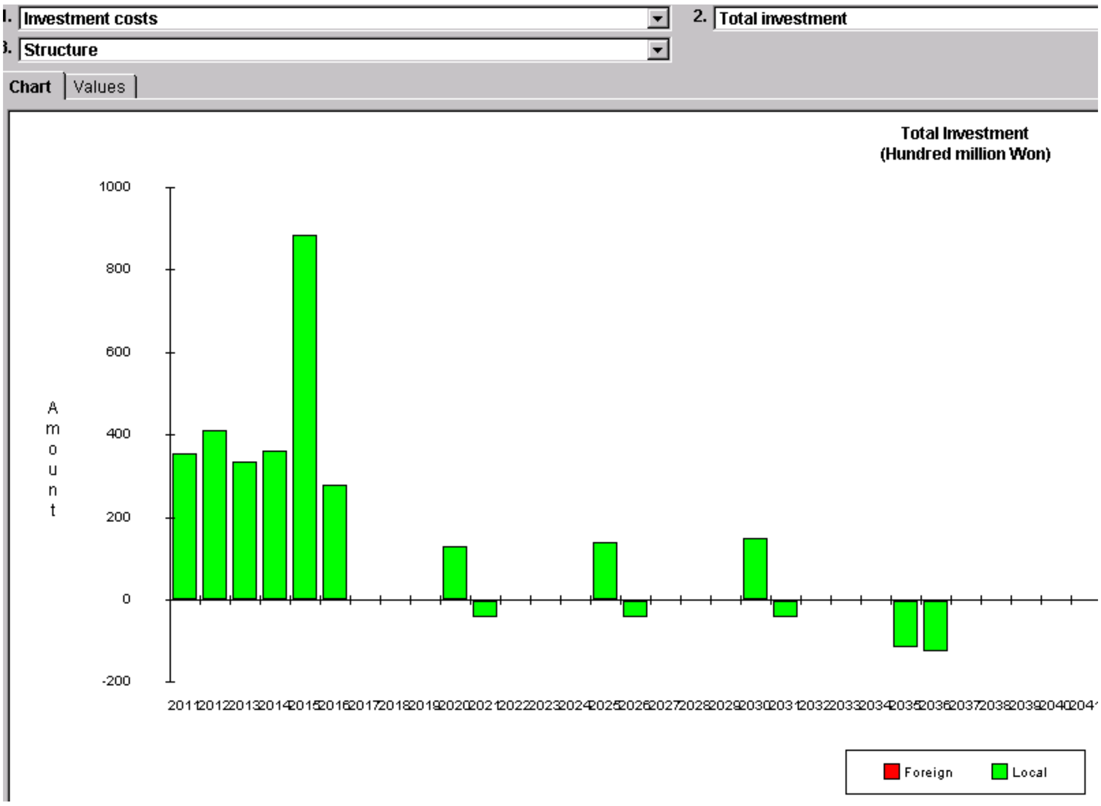
Local	0.00	0.00	0.00
Accounts payable	0.00	45.52	45.52
TOTAL SOURCES OF FINANCE	2,959.30	45.52	3,004.82

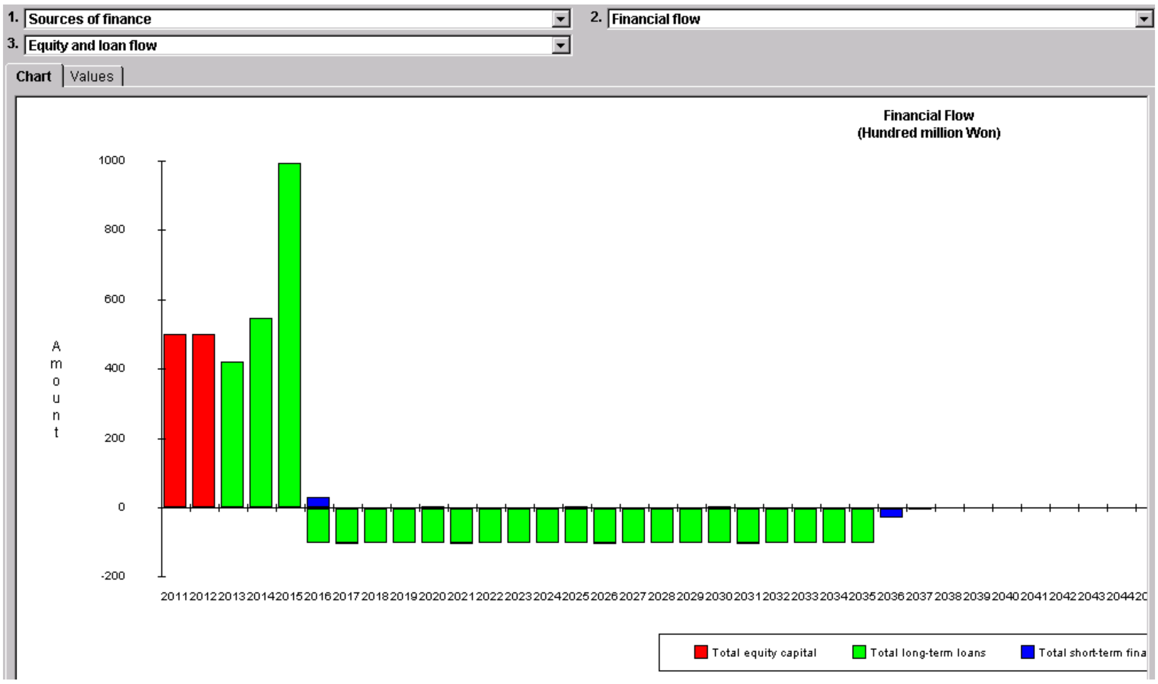
INCOME AND COSTS, OPERATIONS

	First year 2016	Reference year 2016	Last year 2065
SALES REVENUE	1,321.92	1,321.92	0.00
Factory costs	432.00	432.00	85.63
Administrative overhead costs	10.00	10.00	7.00
OPERATING COSTS	442.00	442.00	92.63
Depreciation	41.08	41.08	37.12
Financial costs	97.96	97.96	0.00
TOTAL PRODUCTION COSTS	581.05	581.05	129.75
Marketing costs	0.00	0.00	0.00
COSTS OF PRODUCTS	581.05	581.05	129.75
Interest on short-term deposits	0.00	0.00	0.00
GROSS PROFIT FROM OPERATIONS	740.87	740.87	-129.75
Extraordinary income	0.00	0.00	0.00
Extraordinary loss	0.00	0.00	0.00
Depreciation allowances	0.00	0.00	0.00
GROSS PROFIT	740.87	740.87	-129.75
Investment allowances	0.00	0.00	0.00
TAXABLE PROFIT	740.87	740.87	0.00
Income (corporate) tax	0.00	0.00	0.00
NET PROFIT	740.87	740.87	-129.75

RATIOS

Net Present Value of Total Capital Invested	at 8.00 %	3,338.55
Internal rate of return on investment (IRR)	22.90 %	
Modified IRR on investment	9.79 %	
Net Present Value of Total Equity Capital Invested	at 12.00 %	2,101.98
Internal rate of return on equity (IRRE)	34.12 %	
Modified IRRE on equity	14.16 %	

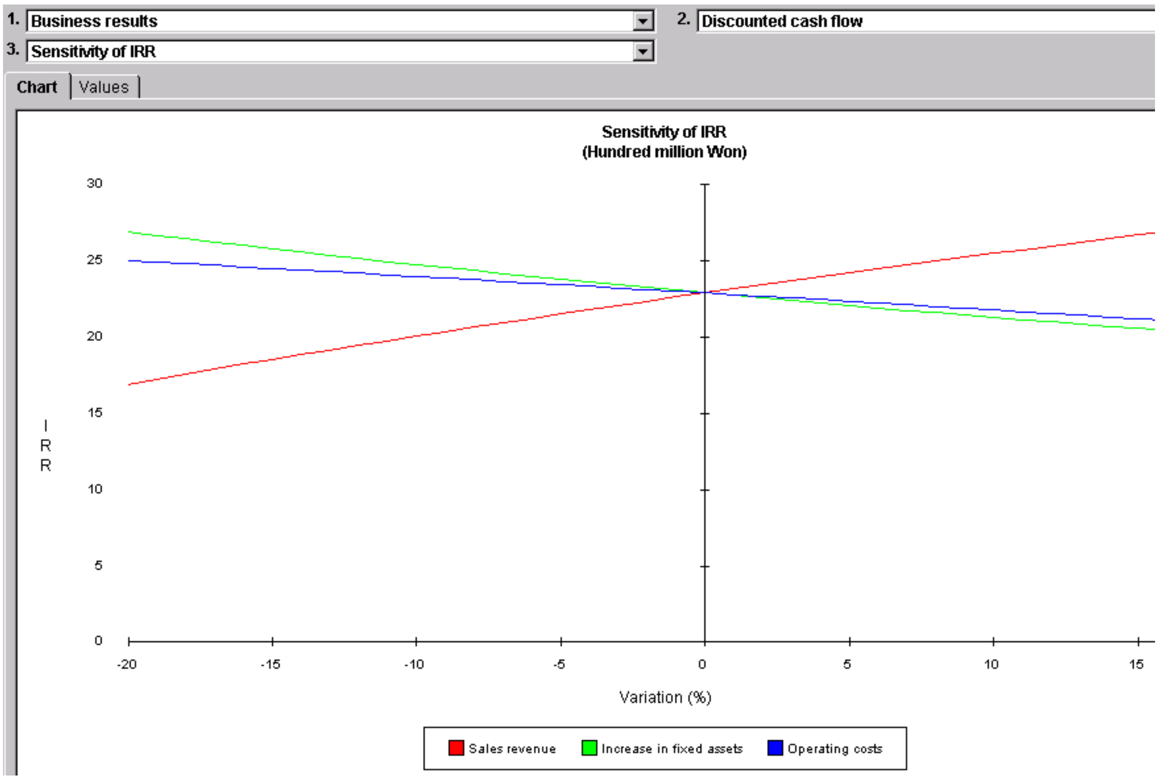




1. Sources of finance

2. Financial flow

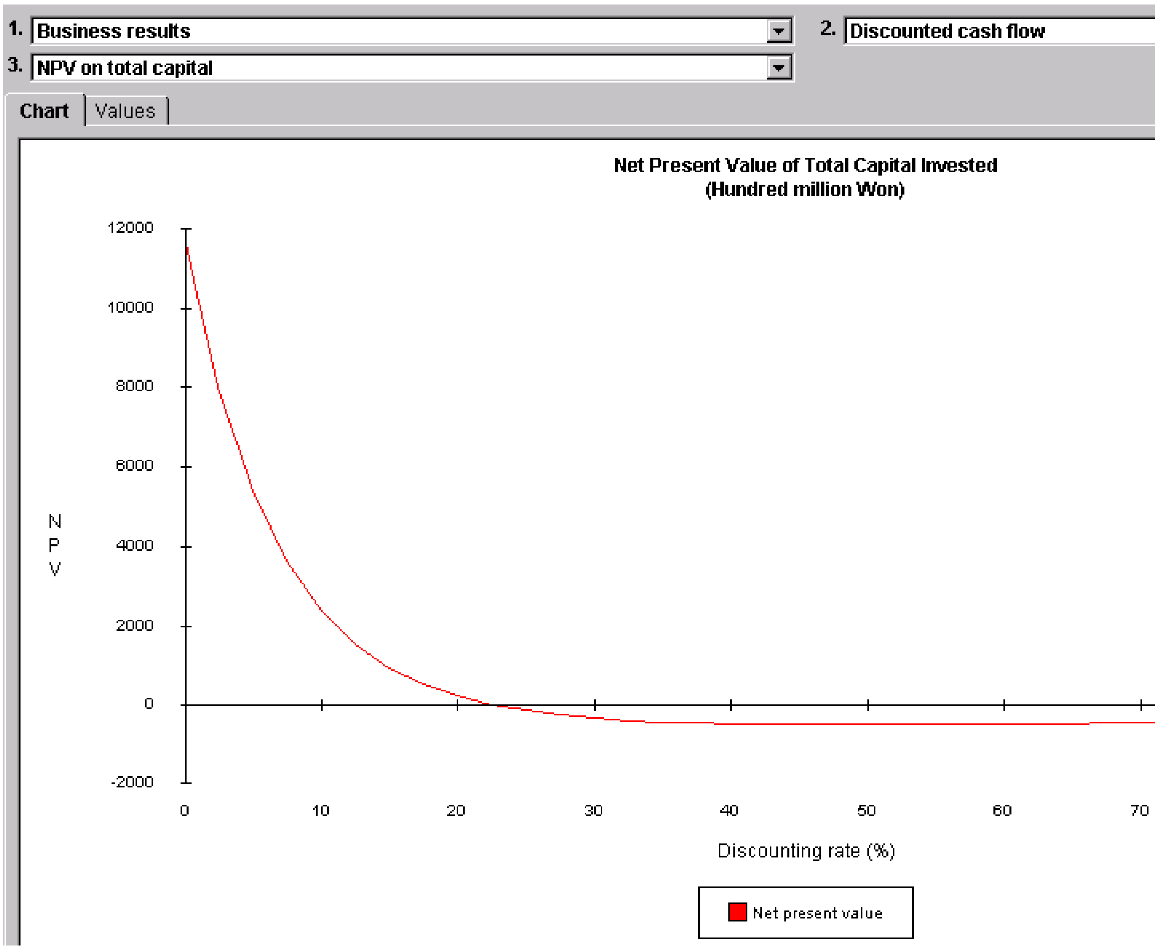
3. Equity and loan flow



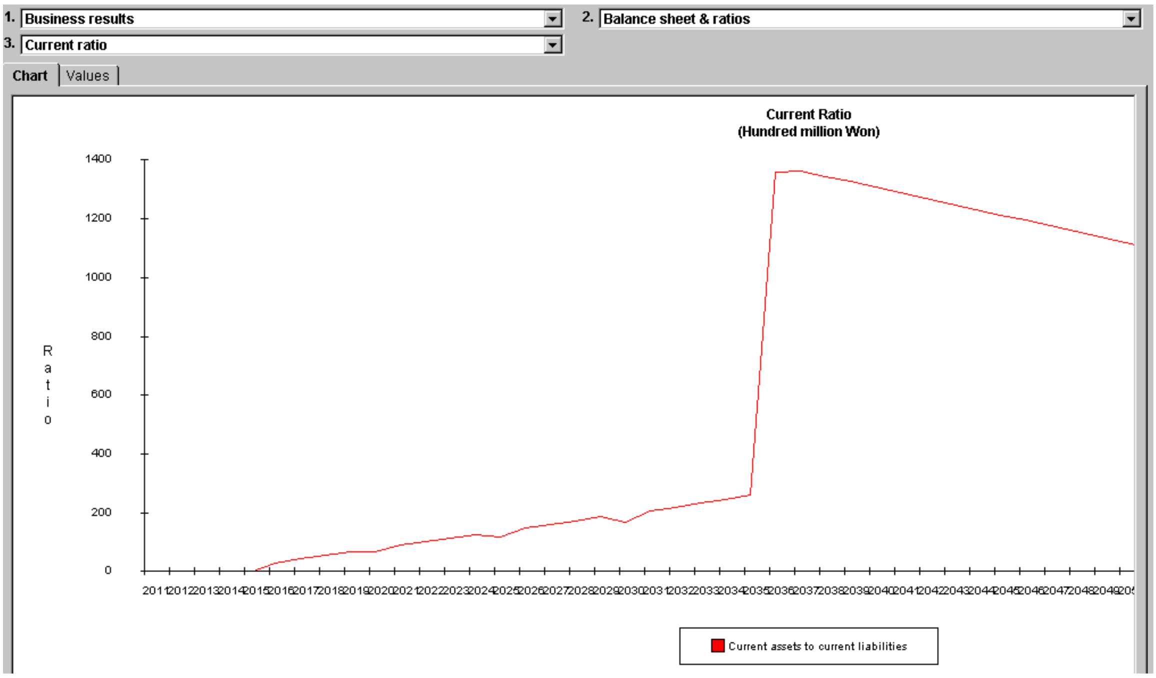
1. Business results

2. Discounted cash flow

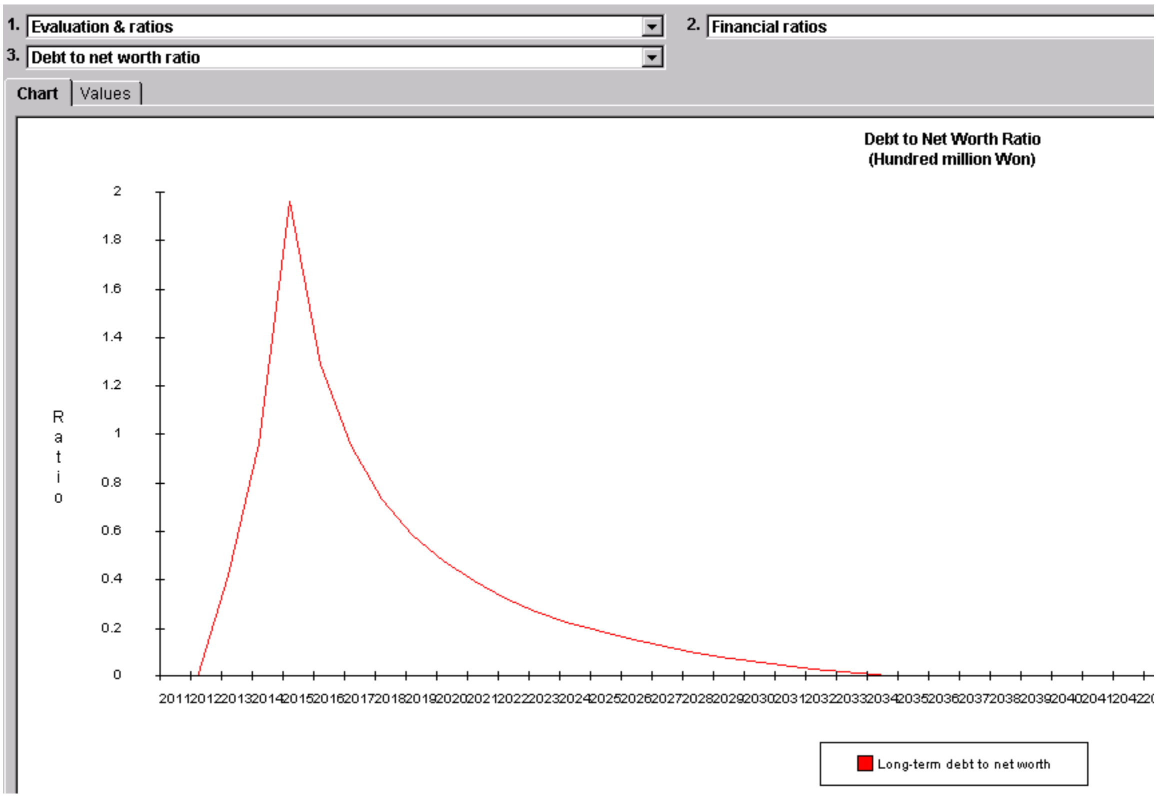
3. Sensitivity of IRR



1. Business results
2. Discounted cash flow
3. NPV on total capital



1. Business results
2. Balance sheet & ratios
3. Current ratio



1. Evaluation & ratios
2. Financial ratios
3. Debt to net worth ratio

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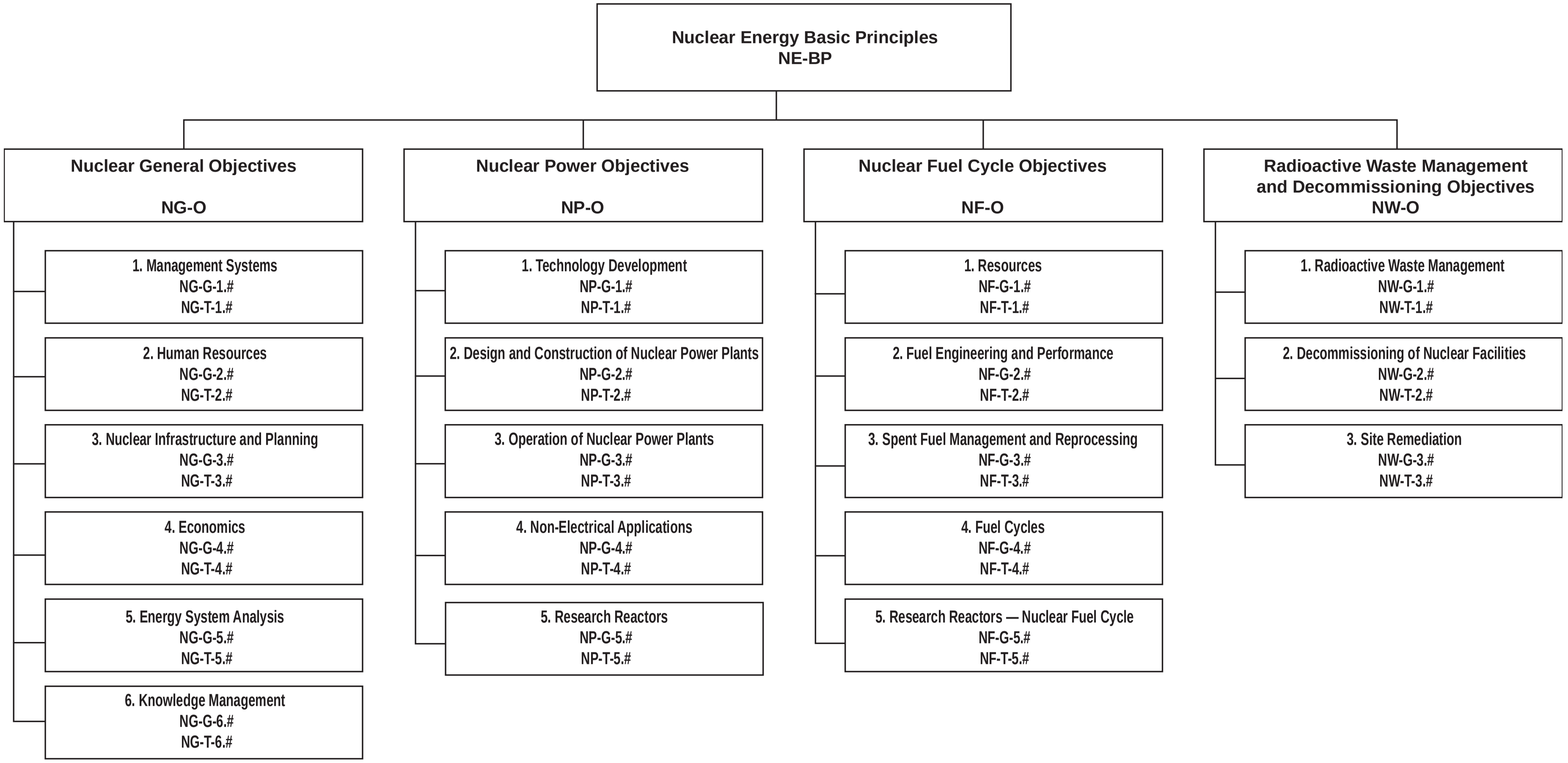

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T: Technical Reports
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#: Guide or Report number (1, 2, 3, 4, etc.)

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NF-T-3.6: Nuclear Fuel (**NF**), Report (**T**), Spent Fuel Management and Reprocessing, **#6**
NW-G-1.1: Radioactive Waste Management and Decommissioning (**NW**), **G**uide, Radioactive Waste (topic **1**), **#1**

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