On the comparison between single purpose and dual purpose casks for research reactors spent fuel elements transport and storage

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1. INTRODUCTION

The management of spent fuel is an integral part of the nuclear fuel cycle. For various reasons, it stands among the most vital issues for all countries with operating nuclear reactors. Because technologies, needs and circumstances vary from country to country, there is no single, standardized approach to spent fuel management. Three basic scenarios, characterized by combinations of fuel cycle approaches and spent fuel management policies, are considered in this report. They include the following:

(1) The first scenario is a closed fuel cycle where spent fuel is reprocessed. This results in recycling of the uranium and use of recovered plutonium as mixed oxide (MOX) fuel in thermal or fast reactors;

(2) The second scenario is a once through fuel cycle with direct disposal of spent fuel into a final repository (e.g. a deep geological repository); and

(3) The third scenario is known as a “wait-and-see” approach which delays a decision to choose a final approach until further development improves the technologies of interest, or until other options become available.

These approaches cannot be considered as equivalent or easy to exchange alternatives. Reprocessing of spent fuel (approach 1) has been successfully performed for decades in various countries and has been proven a safe and reliable technology. Because of the experience base associated with reprocessing, costs for constructing and operating these facilities can be estimated with reasonable certainty. However, even when recycling of spent fuel is chosen, high-level radioactive waste will be generated, and will have to be disposed.

For countries that use a once through fuel cycle (approach 2) the current method being developed is direct geological disposal of spent fuel. Because direct geological disposal is still under development, it cannot be looked at as an established technology. As with any large-scale technology that is not fully developed, one can expect uncertainties in performance, cost, and operations.

For approaches 2 and 3, experience indicates that interim storage of spent fuel is required. In the case of the direct geological disposal, spent fuel being generated at reactors has to be stored until a repository facility is developed and operational.

The wait-and-see approach obviously requires interim storage until a spent fuel management strategy is selected and developed. It should also be noticed that even after being fully developed,

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direct geological disposal of spent fuel may require interim storage to provide appropriate cooling times to match future repository acceptance criteria. In countries following the closed fuel cycle, additional storage capacity may be needed to balance the increasing amounts of spent fuel with the available capacities of reprocessing plants.

Spent fuel management includes the following steps:

(1) After unloading the fuel from the reactor, it is moved into an AR storage. The nuclear reactors are built with pools with a wide range of capacities depending on the features of the plant. Due to increasing requirements, nuclear reactors often provide the capacity for several decades of operation. It is also possible increase the existing pool-storage capacity by reracking their spent fuel pools. This can be done by using neutron-absorbing materials between the assemblies, or simply by improving distribution of fuel in the cooling pools. Such modifications may result in significantly increasing storage capacities over original design capacities. In many cases these capacity additions still do not provide sufficient storage, and separate away-from-reactor (AFR) storage facilities have had to be constructed. Most of these are at the reactor site where the spent fuel is generated {AFR(RS)}.

(2) In cases where a closed fuel cycle policy is used and interim storage is not required at an AFR facility, the fuel is transported directly to a reprocessing plant. The recovered fissile material is used for fresh fuel elements, which are returned to reactor facilities for use in the reactors. Current reprocessing plants include large storage facilities, which serve as buffers between fuel reception and plant operation.

(3) In many countries interim storage facilities for spent fuel are operating, are under construction, or are planned as AFR installations. AFR spent fuel storage facilities may be on the reactor site AFR (RS) or at an independent location AFR (OS) possibly serving several power plants.

(4) Final disposal of spent fuel in deep geological repositories is under development in various countries (e.g. Germany, Sweden, USA). Typically, a disposal package is designed to include special containers into which spent fuel is placed for disposal. The spent fuel may also be conditioned for disposal prior to insertion onto the canister (e.g. consolidation). These containers, in which the spent fuel is held, may be designed to fulfil some criteria expected of final disposal in the chosen repository. These containers could also be designed for other purpose such as storage and transportation. Some countries have chosen to develop casks with a requirement for storage and transport, also referred to as dual-purpose casks (e.g. Belgium, Czech Republic, Germany, Russian Federation, Spain). In the USA, multi-purpose canister system for storage, transport, and eventual geological disposal are being developed. This development activity has been started by the government, and is now being performed by private cask vendors.

(5) Transportation is the link between all steps dealt with above. Transport is taking place from AR to AFR (OS) facilities, and from the AR or AFR (RS) and (OS) facility to a reprocessing plant. Transport of spent fuel to final geological repository will be necessary in a once through fuel cycle. Transport of high level radioactive waste for eventual disposal will likely be necessary when recycling of spent fuel is performed.

From the above it could be concluded that spent fuel management systems which use dual-purpose or multi-purpose containers could provide links between various steps of spent fuel management. Dual-purpose and multi-purpose container technologies reduce the amount of handling of bare spent fuel assemblies. Reduced handling of bare spent fuel would likely reduce occupational radiation exposure, and possibly reduce the risk of radioactive release and airborne contamination. These technologies have the potential to simplify the design and operation of the connected facilities, which make achievement of safety easier, and less costly.

From the previous decisions in IAEA RLA/4/018 it can be said that the situation is similar to the scenario known as a "wait-and-see" approach which delays a decision to choose a final approach until further development improves the technologies of interest, or until other options become available. It is where the dual-purpose cask is included with purpose to transport and storage, only.

2. GENERAL REQUIREMENTS

Multi-purpose containers, as the name implies, satisfy more than one purpose in the area of spent fuel management. The opposite of the multi-purpose system is the single-purpose system. The single-purpose system is designed to fulfil only one function for spent fuel management. For this report, the spent fuel management functions considered are storage, transport, and disposal. In terms of spent fuel management, two design categories are being considered:

(1) designs used for storage and transport; and

(2) designs used for storage, transport, and disposal.

In many countries, the first category, storage and transport, is referred to as dual-purpose, while the term multi-purpose is reserved for the second category. Only the first category will be discussed here.

The dual-purpose option can be found as cask-based or canister-based systems. For the cask-based systems one integral unit serves all purposes for which the system is designed. For canister-based systems, a sealed canister contains the spent fuel, and is a common component or subsystem to the storage and transport system, as applicable to the design. Typically, canister-based systems will use overpacks to house the canister for the purposes of storage and transport. The container system for spent fuel storage and transport shall be designed to satisfy specific radiological safety functions. In general, it shall contain the radioactive material, limit emission of ionizing radiation, dissipate internal heat, and assure subcriticality.

The container shall also be designed to assure structural integrity and thermal performance that allows proper functioning of the systems' radiological safety features. Cask-based systems have been developed for storage and transport of spent fuel. These have generally been metal systems. For these cask designs, the same integral cask unit provides all radiological safety functions needed for storage and transport. For canister-based systems the specific overpack along with the canister provide the level of performance for each safety feature for each purpose. The canister may provide one or more of the required safety functions. For example, the canister includes a fuel support structure or basket, which generally provides criticality control for storage, transport, and disposal, as applicable. The canister may also provide confinement of radioactive material for storage, but the transport overpack is generally used for containment of radioactive material during transport. The shielding required for storage and transport is typically provided by the appropriate overpack.

2.1. Mobility

Mobility is the ability to move a system from place to place. The fact that the systems being considered are transportable means, in terms of the definition for mobility used, that they are mobile. In contrast, single purpose storage does not provide this attribute. The transport only system is mobile, but is generally not used for storage. If it is, it is dual-purpose. This attribute has value for the wait-and-see approach. This situation is expected to require long term storage of spent fuel. Mobility allows relocation during the storage period without bare fuel transfer.

2.2. Retrievability

Retrieval will be defined as the ability to remove the cask, package, canister or spent fuel from its enclosure or emplacement. Mobility could be considered as a part of retrievability. It is generally recognized that retrieval of spent fuel during a period of storage may be necessary or desired. In either case, retrieval is always possible. The concern is whether retrieval, if necessary, will be easy or difficult to accomplish. Retrieval from storage is expected to be uncomplicated for any storage technology used. However, the ease of retrieval for stored spent fuel may vary depending on the method of storage and the design of the storage system. At a minimum, retrieval requirements should be specified so that design specific procedures are developed to assure ease of spent fuel retrieval throughout the period of emplacement, and until completion of a formal performance confirmation period. It should be noted the retrievability beyond this set period of time is always possible, but the cost of such retrieval may be high.

Retrieval from any dry storage facility is expected to be uncomplicated. Retrieval could be simplified by the use of any of systems designed for multiple uses, as compared to the use of a storage only system. This simplification is due to the avoidance of bare spent fuel transfer operations between storage and transport system components. However, since neither one option is always clearly superior to the other, it is best to evaluate both options for specific applications and designs.

2.3. Modularity

Modularity is the ability to be separated into distinct and standard units. Modularity is an obvious feature of the dual-purpose container technology. The feature allows the designer to select canisters or casks of some preferred standard size and configuration. The advantage shall always be compared with the inherent modularity of bare uncontained fuel. The designer shall consider the number and variety fuel assembly designs (e.g. size and weight) that must be dealt with before deciding that a larger module for one of more designs with several fuel assemblies would be beneficial. Again, modularity appears to be a feature that shall be evaluated on a case by case basis.

2.4. Installation and operation

One of the main advantages of dual-purpose container technology is the reduction of bare spent fuel transfers from a dry storage facility to a transport cask, thereby:

- lowering the probabilities of human error and accidents associated with handling bare spent fuel assemblies;
- working towards the ALARA principle;
- minimizing design and cost of the transfer facilities;
- facilitating safeguards control because of the reduction in individual fuel assembly movements from a storage only system to a transport cask and/or to a different geological disposal canister;

- developing a technology that is compatible with storage, transport and possible geological disposal thus reducing interface complications.

Another aspect related to the installation and operation of dual-purpose container technology deals with the requirements to be imposed to the storage, receipt, and conditioning installations. In this regard, the following factors are among the ones to be considered:

- At dry storage installations, dual-purpose container technology has lower operational and maintenance requirements compared with wet storage facilities thereby resulting in lower operational and maintenance costs. This results from the fact that dry storage technologies do not need to maintain water chemistry, operate pool heat removal pumps, heat exchangers and pool filtration systems. Additionally, they do not generate secondary low-level wastes due to these support operations.
- For all dual-purpose containers, transfer installations at an interim storage facility/repository will be simpler than single-purpose cask-based technologies as the fuel assemblies will not need to be individually transferred.
- In spent fuel management systems that have to deal with a multiplicity of fuel types a technology that takes a step toward developing standardized equipment is seen as a benefit.

2.5. Decommissioning of reactors and storage facilities

As at-reactor spent fuel pools reach their maximum capacities, additional storage will continue to be needed or developed. Much of the storage that is being developed uses single purpose dry storage systems. Therefore, the capability to transfer the spent fuel to a certified transport cask shall remain in place even if a reactor has been shut down. The use of dual-purpose system may provide a partial solution to this predicament. Although full pool capability is not needed when storage systems are transportable, retrievability shall generally be maintained. Shut-down reactors that are unable to fully decommission their facilities because of the need to maintain a pool transfer capability, will incur additional costs

In addition, a dry storage facility itself may be easier to decommission with the use of dual-purpose containers. With the use of a cask-based technology, the cask with the spent fuel will be removed and all that will be left to decommission is the uncontaminated support facilities such as a concrete pad and additional support facilities. With the canister based technology, an uncontaminated, or minimally contaminated, storage overpack will also remain for decommissioning. Additionally, canister transfer equipment, which may be slightly contaminated, will have to be disposed.

With single-purpose storage facilities, the cask, building, or canister will need to be decontaminated or be disposed of as low-level waste after all the spent fuel has been shipped off-site. In the case of the dual-purpose canister, recovery from containment failure could be accomplished by transferring the canister into a licensed transport overpack. The overpack could then be used to transport the canister to a licensed handling facility where the spent fuel could be repackaged in a replacement canister. For some systems, and some regulatory jurisdictions, an on-site transfer facility may be required, even for canister-based systems.

The use of dual-purpose containers at interim storage facilities may facilitate the decommissioning of these facilities by reducing the potential release of radioactive particulates and airborne contamination associated with handling bare spent fuel. Furthermore, transporting a unit or its components away from the reactor site after the storage period ends, avoids the need for disposal of some or all components as low-level radioactive waste. Without the need to decontaminate fuel handling facilities or dispose of used storage units as low-level radioactive waste, the decommissioning operation of interim storage facilities are simplified. For cask-based systems there is no fuel handling before transport, and the entire unit is transported away from the reactor site. For canister-based systems storage overpacks will have to be disposed of at the end of their use. Canister-based systems also require equipment to perform canister transfers between storage and transport overpacks. This equipment may be slightly contaminated, and will have to be disposed accordingly.

2.6. Public acceptance

Although attempts to predict public acceptance are subjective and speculative, there are several factors that should be considered in any such assessment. A common public concern related to temporary storage is that temporary storage measures may be extended and eventually become permanent. The public perception of permanence related to temporary storage systems may be alleviated when movable dual-purpose systems are used. Although canister-based and cask-based systems are regulated in the same way, and are expected to be equal from a radiological safety standpoint, the public perception of safety might be enhanced when canister-based systems are used. The canister might be perceived to provide an additional barrier of containment, even if not licensed, nor proven to do so. It also reduces the direct handling of bare spent fuel.

2.7. Economics

A dual-purpose system can replace single-purpose systems that are used for storage and transport of spent nuclear fuel. For these systems, the requirements for storage and transport shall be satisfied by the system or components of the system designed to perform in each functional area. One can expect to derive certain economic advantages from any system where its individual components are used to satisfy more of the systems requirements. Such a situation can reduce costs by reducing the number of components of the system and the number of operations. Balanced against these potential cost savings is the possibility of increasing costs for the individual components and operating procedures. For the hardware, or system components, designs may become more complex and more difficult to fabricate, because they have to satisfy additional requirements. Increased complexity and difficulty of fabrication usually increase costs. Similar arguments apply for operations. That is, the multi-use component may reduce the number of operations required, but increase their difficulty and cost.

Storage and transport are performed sequentially rather than concurrently for any specific spent fuel inventory. Assessing and comparing the economics of single-use and their alternative multi-use systems is further complicated by increasing the period of time that has to be considered. The difficulties associated with this area of concern manifest themselves in several ways. These concerns include, but are not limited to the followings:

(1) The timing of an investment as it relates to the cost or value of money,

(2) The availability of a pre-paid feature when it is needed, and

(3) The economic risks associated with advanced investment in technologies that have not reached full maturity.

Timing, as it relates to the cost of money, is always an important consideration for any decision on investment in a costly technology that is developed and used over extended periods of time. Early investments result in money being unavailable for other uses, such as investment, which may earn additional money. The need to spend money, before it is in hand, requires borrowing. The cost of borrowing is the interest that has to be paid to the lender. Early investment is sometimes good, especially in a situation where the cost of a product or service is expected to increase. The value of such early investment depends on the expected rate of increase in cost. For single-purpose systems, investments can be postponed until the system is needed, or can be made early if there is a perceived advantage. For dual-purpose systems, paying for an immediate need requires early payment for all future needs. For any of these systems, the negative aspects associated with the cost of money can be minimized by progress payment, rather than large sums of money "up-front".

Another economic factor associated with a dual-purpose system is the availability of performance features when they are needed. For single-purpose systems, use can begin as soon as a unit is available. For dual-purpose devices, only one purpose is served at a time, while the other features of the system are on stand-by until they are needed. In addition to the cost of this early investment in a feature that is not immediately needed, is the issue of availability of the device to perform the required function when it is needed. This amounts to a question of component reliability, repair, and replacement. In general, increasing a components reliability increases the cost of the component. If the component is not available upon demand, it has to be repaired or replaced, both of which have associated costs. Improving the availability of a dual-purpose system is expected to increase its cost. However, since a system is available for service if it is reliable, or replaced or repaired if failed, several options exist. That is, there is an opportunity to trade the early cost of increased reliability against later costs of repair or replacement. Which approach one chooses may be based on least overall cost or scarcity of available funds.

Finally, we will consider the economic risks associated with investment in technologies that are not fully matured. There are two aspects of risk considered in this discussion. The first is the problem of early commitment of funds to a technology that is subsequently improved or overtaken by a superior technology. The second is the problem of early commitment of funds to a technology that is later found unacceptable. A finding of unacceptability could be based on technical reasons, regulatory concerns, or public perception. In the first case, the system is not at its highest efficiency, and replacement may be considered. In the second case, replacement is not simply a matter of choice, we may have to discard what we have and start over.

Having discussed some basic economic considerations associated with decisions on selection of spent fuel management technologies, we can apply these economic considerations to the technology choices available to us. That is, we will apply the economic concepts to single-purpose and dual-purpose systems that are either cask-based or canister-based. The general discussion that follows should be used as a guide for assessments of specific choices being considered under specific circumstances. The discussion is not intended to suggest that any general economic principles have been found for ranking the options considered.

Single-purpose storage and transport systems constitute developed technologies. Both types of systems have been designed, licensed, built, and used. The economic advantage of using a single-purpose system, is that you build what you need when you need it. If efficiencies improve with later designs, conversion to the improved designs can be done, as new units are needed. Because purchases can be made as needed, and progressively, adverse affects of the cost of money can be minimized. The system can be designed for a set lifetime, making the reliability, replacement and repair cost estimates relatively uncomplicated. One disadvantage of storage-only system is that the storage units are generally discarded after the storage period. For many storage-only systems such as vault or concrete module designs, the spent fuel is held in a canister. There is no obvious economic advantage for using canisters for metal storage-only systems. Transport-only systems are generally cask-based and reusable with units that are removed from service at the end-of-life.

A dual-purpose system may be more expensive than one designed for transport-only or storage-only. The savings from a dual-purpose system arise when the dual-purpose system is less expensive than the combined system, using single-purpose devices for storage and transport. For a cask-based dual-purpose system, a single integral unit provides for storage and transport of an inventory of spent fuel. For the typical canister-based system, each canister with its spent fuel inventory is held in a vault or storage module (which is generally not reused). For transport, the canister is shipped in a reusable transport overpack. The canister in a dual-purpose system will usually satisfy some of the requirements for storage or transport. For storage the canister will provide confinement of the radioactive material and criticality control. For transport, the transport overpack provides containment of radioactive materials, but the criticality control function of the canister remains.

3. DESIGN ASPECTS

To reiterate, dual-purpose container concepts mean that a cask or canister contains the fuel during storage and transport. Canister-based systems use overpacks for transport. For storage, they may use either overpacks or modular vault structures. An overpack usually holds a single canister, while a vault will hold several canisters. Cask-based dual-purpose systems use a single integral unit for transport and storage without the need of an additional overpack.

The design considerations for transport and storage of spent nuclear fuel are similar. However, the performance conditions under which each system is used are different. Storage systems have generally been designed for several decades of service in relatively static conditions, and in a natural outside environment defined by the location where the system will be used. Storage systems are also designed to withstand certain anticipated operational and accident conditions, some of which may be site dependent. Transportation systems are designed for continuous service over an expected lifetime of two to three decades. They are designed for both normal and accident conditions which are prescribed and identical for all transport systems. Because transport systems have to service many sites in various locations, transport design specifications are not site-dependent.

3.1. Design objectives

The major design objectives to be considered for dual-purpose (storage and transport) functions are as follows, e.g.:

- radiological safety;
- operations;
- safeguards;
- quality, reliability, maintenance, and repair; and
- cost.

3.1.1. Radiological safety

Radiological safety is important in its own right. For equipment used in the management of spent nuclear fuel it is especially important because it is the basis for licensing and regulatory control. It is also noted that radiological safety is expected to be uniform regardless of the specific design or type of system used (e.g. single-purpose versus dual-purpose, cask-based versus canister-based). The reason for this expectation is the fact that the regulations, which are performance based, are applied uniformly.

The radiological safety provisions are intended to protect the public from potentially harmful affects of the radioactive material being stored, transported, or disposed of. national transportation regulations generally follow those established by the IAEA through international consensus. The use of internationally accepted standards for spent fuel transport is important since shipments may cross international borders. The IAEA also provides guidance in the area of spent fuel storage safety.

Safety provisions are mainly directed to minimize to the greatest extent practical radiation hazards to the public, environment, and operators. Conventional hazards due to normal operation and events such as fire, flooding, operator error, equipment failure will be analyzed and either precluded or mitigated to the maximum extent practical.

Radiation hazards can basically be caused by:

- release of particulate or airborne radioactive material,
- direct radiation and skyshine from the transport and storage device surfaces; or
- surface contamination.

To mitigate these hazards by technical means, several design considerations have to be addressed. Any activity involving handling and packaging of fissile nuclear material can result in the following specific risk categories:

- criticality hazard,
- contamination from activity release,
- exposure to radiation.

Although a criticality is a radiological safety concern that could lead to activity release and radiation emission, it is considered separately. For systems containing radioactive materials, releases and emissions can be reduced to insignificantly small quantities, but they can never be eliminated. Criticality presents a different situation from that of containment or radiation protection, it can be precluded. The aim of criticality safety is to preclude criticality rather than devise ways of dealing with a criticality accident.

In addition, two important design factors that affect radiological safety, that is, structural integrity and heat removal, are considered.

3.1.2. Criticality control

Criticality control shall be maintained throughout all phases of spent fuel management. This includes operations during: handling, storage and transport. One will not discuss criticality control during storage in spent fuel pools or during loading operations. Criticality control will be provided primarily by the basket of the transport and storage. Therefore, the discussions relating to criticality control for canisters or casks should not be different.

Methods for providing criticality control for storage and transport have been approved in several countries. The approved methods include moderator exclusion (for storage only), use of neutron absorbing materials (e.g. B^{10}), and the use of water gaps (i.e. neutron flux traps) in conjunction with neutron absorbing materials. The use of flux traps usually add to the challenges of the structural design and tend to reduce system capacities.

The general topic of burnup credit for storage and transport in spent fuel management systems enjoys attention. Burnup credit, a term used for allowing credit for the fact that the fuel has been burned in a reactor, thus reducing the reactivity of the fuel. It should be noticed that although spent fuel is less reactive than fresh fuel, it can still achieve criticality, depending on its configuration and surroundings. To date, burnup credit has only been approved to a limited extent in some countries. The reduced reactivity of spent fuel due to burnup credit can be attributed to three components:

(1) the net reduction in the amount of available fissile material (e.g. reduced fissile uranium and generated fissile plutonium isotopes);

(2) the increase in the amount of actinide neutron absorbing material; and

(3) the increase in the amount of fission product neutron absorbing material.

3.1.3. Containment

Dual-purpose containers are used for transport and storage. In the case of cask-based technologies, the cask fulfils all relevant safety requirements for the enclosure of the fuel during transport and storage. For canister-based systems, the canister is designed to perform some of the safety functions required for storage and transport, but overpacks are used to address the safety requirements not performed by the canister.

The requirements for the transport of spent fuel are stated in standards or guides such as the IAEA Safety Series No. ST-1: Regulations for the Safe Transport of Radioactive Material (previously Safety Series No. 6). According to ST-1, spent fuel is transported in a "Type B" package. It is assumed that the multi-purpose modules are designed, built, and licensed in accordance with these standards.

This means that:

- in the case of cask-based technologies the casks are licensed, or
- in the case of canister-based technologies the canister in combination with an overpack is licensed according to the “Type B” package requirements.

Although quite similar due to the function (containment) the requirements for transport packages are different from those for storage. The major difference is that the safe containment of the radioactive material has to be maintained over a period of several decades in the case of storage. As the material is continuously enclosed within the module over the total storage period, any release of radioactivity from the module can be practically avoided, with the actual leak rate depending on the closure and sealing system. Bolted lid sealing systems are available to achieve very low standard helium leak rates for a barrier in a typical range of at least 10^{-7} h Pa l/s. It is obvious that penetrations through the lids are sealed to an equivalent level.

The closure systems generally consist of a combination of barriers (static and/or dynamic) and monitoring systems, which prevent a leakage to the environment even in the case of failure of one barrier. It seems desirable to provide technical solutions and procedures to check the integrity of the closure system by continuous monitoring or periodic checks. Consequently, a procedure has to be developed to address degradation of these components.

For the cask-based concept, the cask used for transport is also used for storage, and the cask design has to be licensed for both sets of requirements. It is necessary to meet the long term aspects of storage. One element of this is adequate choice of materials for the cask body, the lid system, and the closure seals. The selection process should take into account corrosive agents internal and external to the cask.

A typical design concept for the closure system of a storage cask provides one or two lids. A primary lid closing the cask cavity and a secondary lid can be bolted or welded to the cask body above it. Bolted lids can be equipped with long lasting, high efficiency, metallic seals. Overpressure can be used in the space between the two lids, or between the seals. The overpressure can be continuously monitored during the storage period as a reliable indication of seal integrity.

If the sealing of a secondary, outermost, lid shows reduced leak-tightness, it can be repaired without affecting the, inner, primary containment. This type of repair can be done at the storage facility without the need of any particular equipment. If the primary, or single lid is not in accordance with the leak-tightness specification, a replacement of the corresponding gasket necessitates the dismantling of the lid and thereby opening the cask. Depending on the equipment available at the storage facility, repair may be done at the site or the cask has to be shipped to another nuclear facility for repair. Alternatively, the cask concept can include repair by placing a third lid above the secondary one (or a second one on a single-lid system) and thus re-establishing the double barrier. This work can also be done at the storage site.

For transportation, analysis has to be made to verify the containment capability of the cask under accident conditions. Since the cask is certified as a type B package for transport, it shall be shown to withstand severe mechanical, thermal, and water immersion test conditions. Successful completion of the tests and analysis proves the containment capability of the cask under the accident conditions.

A canister based technology opens a variety of possibilities to provide for a monitored enclosure of the fuel during storage. The canister itself should be designed to provide containment during transfer between the transport package and the storage structure. To be able to rely on the canisters leak-tightness, it should be proven by compliance with the operating technical specifications. The canister concept implies the use of outer structure to form a storage module. The storage outer structure or overpack will protect the canister from mechanical and thermal loads during normal operation and anticipated operational occurrences.

3.1.4. Shielding

When considering shielding requirements for multi-purpose technologies, it will be important to consider requirements for both the transport and storage. The approach to providing shielding will vary depending on whether a cask-based or canister-based system is being considered.

International radiation protection standards for the transport of radioactive materials are defined in IAEA transport regulations. The dose rate limits are 2 mSv/h at the accessible cask surface and 0.1 mSv/h at a distance two meters from the conveyance. For exclusive use shipments however, a dose rate limit at the cask surface of 10 mSv/h may be allowed. The cask shall also meet the dose rate limit of 10 mSv/h at a distance of one meter after the cask has been subjected to the transport accident test conditions as specified in IAEA ST-1. For the storage environment, the standards for radiation protection usually apply to a total off-site dose rate that may be permissible at the site boundary of the storage facility. These limits vary from country to country. There will also need to be consideration of the occupational dose limits to workers at the facilities. The dose limits for occupational workers are based on recommendations of the International Commission for Radiation Protection.

For cask based technology, shielding for storage and transport is by the cask unit itself and the dose rate limits in the transport regulations are likely to be the controlling factor for cask shielding design. If additional shielding is needed to meet the site requirements for storage, that shielding could be provided by features at the site, such as moving site boundary or providing supplemental shielding such as concrete barriers or earthen berms.

Radiation protection shall consider the need to shield from neutron and gamma radiation. Typical materials used for gamma shielding are dense metals such as steel, cast iron, lead, and depleted uranium. Shielding for neutrons is usually provided by materials containing hydrogen or carbon. Water is a good candidate for neutron shielding, but for dual purpose cask systems solid materials such as hydrogenous polymers are preferred, because they require less monitoring and maintenance.

The same standards will apply with respect to radiation protection for storage and transport regardless whether a cask-based or canister-based approach is used. However, in the canister-based system, the majority of radiation shielding is provided by the transport and storage overpacks. Because this storage structure is stationary and is generally not weight limited as is the case for transport, it is possible to use a low cost material, such as steel reinforced concrete, for radiation protection in the storage overpack. For the transport overpack, shielding will be provided in the same manner as in the cask based system.

For canister-based technologies, the canister itself will usually require full gamma shielding on the top and/or bottom of the canister in order to facilitate handling. A shield plug made of carbon or stainless steel, or of lead or depleted uranium encased in steel can be placed on the top of the canister after loading and prior to sealing. The shielding at the bottom end of the canister can be of similar materials but would be built into the canister during fabrication.

3.1.5. Structural considerations

The goal of the structural design of a container system is to assure that the radiological safety components perform as intended when subjected to mechanical forces occurring in the container operating environment. The operating environments of interest here are those for storage, transport, and disposal. The radiological safety conditions that the structural design has to meet are provided in the regulations of the country in which the spent fuel will be stored, transported, and disposed. Generally, these requirements are based on international consensus documents. The transport regulations will generally conform to those developed by the IAEA. The transportation test conditions are prescribed in the regulations, and include both normal and accident conditions (e.g. drop tests, puncture tests, pressure conditions). For storage, site-specific design base events should be established and applied as design conditions (e.g. seismic conditions, projectiles).

The structural design and analysis of cask-based and canister-based systems will be similar, any differences will be handled in developing design specific structural models. The analysis should address storage and transport requirements, depending on the intended use of the container system. The structural components that are of interest are the basket for criticality control, the containment vessel that prevents release of radioactive contents, and the shielding that provides radiation protection. For dual-purpose systems, the designer should assure that the radiological safety components satisfy requirements for each of the intended purposes.

The structural analyses of any dual-purpose container technology will be based on the regulatory tests required by the IAEA ST-1 (e.g. nine-meter drop test). The cask or the canister in an overpack should support the basket structure during normal transport conditions and possibly during the impact of a side drop, if this is required to prove criticality safety. In this case, the canister shell should not deform significantly. Analysts shall determine an appropriate design that will be adequate to meet the requirements. For a canister, since a major factor in shell strength is overall configuration and not only material tensile strength, a rather thin (less than 2.5 cm) shell thickness is adequate for a variety of shell materials, such as alloy 825, stainless steel 316L, and ferritic steel A-516 Grade 60.

The bottom end, inner lid, and shell of the canister-based systems provide the containment barrier during storage. The design of these components should consider the pressure resulting from failure of large number of the fuel elements, in some cases up to 100%. Therefore, the canister-based systems should be designed to withstand this inner pressure load on the containment barrier. This pressure will control the design of the bottom and inner lids of the canister, which will result in bottom and inner lid thickness being more than twice the thickness of the canister shell.

The outer lid of a canister could provide redundant containment for storage. The outer lid can also provide the mounting locations for lifting the loaded canister during transfer operations. Since the consequences of dropping assemblies could be significant, stringent safety factors are required for design of lifting mechanisms and lift attachment points. These lifting considerations could control the thickness of the outer lid. This could result in an outer lid, which will have a greater thickness than the inner lid.

The basket structure in a canister or cask should support the weight of the spent nuclear fuel assemblies during the drop accident scenario, unless criticality control can be shown by other means. For transport of cask-based and canister-based package, impact limiters are used to restrict impact loads to less than the design value. This will provide substantial stress margins for the transport package designs. Taking into account the design of impact limiters, specific drop scenarios (e.g. corner, end, side, or slapdown) need to be evaluated to determine the g-loads. It should also be noted that depending on the orientation being analyzed, a greater g-load may not result in greater stress at a given position on the cask being evaluated. Significant structural margin should be available for the hypothetical nine-meter drop accident. When an outer shell is used to enclose the neutron shielding, its thickness requirement is influenced by capture gammas produced in neutron shielding material and possibly by the one-meter puncture test.

3.1.6. Thermal considerations

The thermal design of a container system is intended to assure that the radiological safety components perform as intended when subjected to thermal forces incident to the container in its operating environment. The operating environments of interest here are those for storage and transport. In the case of thermal design, the forces that challenge the container performance come from internal and external sources. The internal heat source is the spent fuel that continues to generate heat due to decay of its radioactive isotopes. The radiological safety conditions that the thermal design should meet are provided in the regulations of the country in which the spent fuel will be stored and transported. The transport regulations will generally conform to IAEA ST-1. The transportation test conditions are prescribed in the regulations, and include both normal and accident conditions (e.g. heat, cold, fire conditions). For storage, site-specific design basis events should be established and applied as design conditions (e.g. ambient environments defined by temperature and solar heating). Because the thermal design shall protect against the external thermal environment and internal heat generation, it may often have to meet conflicting requirements. The design should provide thermal protection against external heat sources, a task that may be accomplished by using insulating materials, and heat absorbers. At the same time, the design should include mechanisms to efficiently remove internally generated heat, a task that may be accomplished by using highly conductive material (the opposite of insulation).

Thermal design will be similar for cask or canister-based containers, and differences will be handled by development of the design-specific thermal model. The goal of the thermal analysis is to identify potential damaging affects and design the system to handle them. The parameters of interest in thermal analysis are temperature, heat, and heating rates. For the design, the thermal analysis is influenced by the burnup and cooling time of the fuel, the number of assemblies in any one container, and the ability of the container to dissipate heat. This last aspect is closely related to the thermal performance of the internal basket (mainly to the material of which it is constructed). There is a tendency to increase the capacity of containers to be as large as possible for economic reasons as well as public health and safety due to the reduced number of containers. This places an additional burden on the cask to dissipate heat and may require an increase in its outer cooling surface area (e.g. fins can be added to the cask). With a canister based system, heat dissipation can be facilitated by increasing the air flow rate over the canister while it is in its storage configuration. This is generally possible even when only natural convection is required. In a dual-purpose container system there are other design features that may be used for increasing heat dissipation. Some examples include the use of aluminum or copper in the basket. When the neutron absorbing material is of an insulating type, additional consideration needs to be given to heat removal through this shield. In many cases, impact limiters could also be thermal insulators, however, this should not normally be a major concern since this is not the area of major heat flow.

A number of thermal considerations are suggested here. One area of interest is temperature effects on material properties (e.g. structural strength). Heating can have significant effects on shielding materials that have low melting temperatures (e.g. lead melting). Thermal conditions may also affect containment systems (e.g. decomposition and degrading of seals), and performance of spent fuel clad material (e.g. creep rupture and bursting).

Another important issue is the behavior of the dual-purpose container during the thermal test for accident conditions of transport defined in IAEA ST-1. The maximum cladding temperatures should be established and justified by the designer. The performance limit should be based on the response of the contents of a transport cask exposed to the regulatory thermal test of a fully engulfing fire of 800 °C for a period of 30 minutes. Depending on national regulations, the fuel cladding should be below a predetermined cladding temperature limit. The cladding temperature limit should protect against failure, which could in turn lead to generation of a releasable radioactive source (e.g. fission product gases and particulate matter).

3.2. Operations

Several design requirements for cask-based and canister-based concepts derive from their operational requirements (e.g. loading the container with fuel as well as transport and storage of the module). For either technology, the operating procedures (e.g. for loading and handling) should be established at the earliest stage of design. This allows early identification of the equipment needed (e.g. equipment for draining, drying, inerting, and leak testing), and resolution of equipment and procedural interfaces.

The loading of fuel into the container normally takes place in the spent fuel cooling pool of the nuclear plant. The handling of dual-purpose casks does not differ significantly from loading a transport cask. However, it is noticed that fitting the primary lid to the cask at the reactor is done in accordance with the storage specifications. If canister-based designs are used, special procedures to load the fuel into the canister in the pool will be needed. In addition, special procedures for sealing the canister are generally needed (e.g. canister welding and insertion of the canister into the transport overpack). All of this will require design-specific equipment at the reactor.

Written operating procedures should be prepared for handling the casks or canister based modules at the various facilities to make sure that a coherent safety concept is observed. The written procedures should include all tests, inspections, maintenance, and measurements.

It is also important to consider how the various steps in the overall process relate to each other. When the concept of operations is developed, the designer should not only consider the planned operations, but contingencies as well. It is essential to know the effects of each step on the overall system. Contingencies should address possible errors, faults, and corresponding corrective actions.

For storage, the design has to take into account the connection to the leak monitoring system, if applicable. It is assumed that during storage a system is available to monitor the container seal integrity (e.g. by checking an overpressure in the space between two sealed barriers).

However, before transporting a cask-based or a canister-based package after a long term storage, an inspection procedure has to be performed that deals with transport related issues (e.g. closure seals, lifting devices, shock absorbers, dose rates, contamination). System operating plans can also influence the design of the dual-purpose container technology. In cases where long periods of storage at a reactor are anticipated before spent fuel is to be transported in a dual-purpose system, the delay can be used to improve a system overall performance. This situation has been effectively used to specify different cooling times for the storage and transport phases of such systems. For example, we find a dual-purpose system requiring a minimum cooling time of 5 years for storage and 10 years for transport.

3.3. Safeguards

Physical protection, or safeguards, measures are used for all spent fuel management activities. The principal concern associated with spent fuel is the possibility of sabotage. Safeguards measures have been used effectively for storage and transport of spent fuel. There is no reason to expect difficulties in providing adequate physical protection for disposal of spent fuel. Safeguards measures are operational in nature, and are not expected to be different for cask-based or canister-based systems that are used for single-purpose, dual-purpose, or multi-purpose designs.

3.4. Quality, reliability, maintenance, and repair

The design, construction, and use of all system components (e.g. casks, canisters, and overpacks), procedures, and ancillary equipment should be conducted under appropriate quality assurance programs. In brief, quality assurance calls for careful planning, written procedures, use of standards, thorough documentation, and the possibility to trace all steps.

Reliability is also an important performance consideration. Equipment and procedures that affect performance should work when called upon. There are two types of reliability considerations for spent fuel management systems. The first consideration is the useful service life of the essentially passive devices that comprise storage and transport units. These include such things as seals, closure devices, radiation shields, neutron absorbers, structural load limiting devices, and thermal protection devices. The second type of equipment are those that are essentially dynamic in their performance. These might include such things as lifting hardware, pressure relief devices, water-levelling systems used for liquid neutron shield devices. Some of these exist in a state of standby.

The objective of reliability analysis is to gain confidence that these systems are working and available to work when called upon. Reliability analysis can also help determine maintenance plans for systems. We cannot expect all components of a system to last forever, but we can maintain, repair, and replace components on a schedule that assures operation of the total system. Reliability estimates are likely to be more difficult as we go from transport to storage, and from storage to disposal. The reason for the difficulty lies in the fact that the duration involved and degree of remoteness increases for each activity.

Maintenance includes servicing hardware (e.g. oiling a bearing) and routine, scheduled replacement of parts (e.g. seals). The servicing function aims at assuring continued reliability of component. Replacement should be done before a component is expected to fail and lead to a system failure.

Finally, we come to discussion of repair. A component or system can be repaired when it reaches a weakened state, or because it has failed. These are two entirely different situations. Repair of a weakened part is a way of restoring a system to an "as-good-as-new" state without having to replace parts. Systematic tests or inspections of a system can dictate such repairs. The need to repair a failed part, which could include replacement, should generally be avoided. One exception to this principle is a system that is failure tolerant. That is, redundancy is used to avoid situations where a single component failure brings the system down. The use of redundant components is a good design strategy. It is a most effective strategy for components that are difficult to inspect and repair, and when the components to be duplicated are small and more failure prone than other system components.

The overall design approach should include assessment of the systems and its parts in terms of reliability, maintenance, and repair. The three factors should be considered jointly because they are strongly interrelated. If we increase the reliability of a system that is already adequate, we may have reduced the need for maintenance and repair. Likewise, if we use a less reliable component we can expect higher maintenance, more inspection, and more frequent replacement.

For storage, with anticipated duration 20 to 40 years, scheduled maintenance is a must. Because of the duration involved for storage, repair and replacement of parts can be expected. For transport, casks and transport overpacks will have service lives of 20 to 30 years. However, transport systems will be operated cyclically. That is, they will be used to transport the spent fuel, and then return, where inspection, maintenance, and repair can be done. Canister-based systems may have an advantage over cask-based systems here. For a cask-based system all parts are used for storage and transport. For canister-based systems, the canister is used for storage and transportation, but separate overpacks are only used over the period for which they are designed.

3.5. Cost

Cost estimates should address unit costs and total system life cycle costs. It is noticed that an inexpensive unit may cost a great deal over its lifetime if maintenance, repair, and operating costs are high. Furthermore, there may be limits to the benefits derived from increasing reliability because it generally increases cost. Ideally, one can select the most cost-effective system for a given application, and optimize the design with regard to unit and total life cycle cost.

If one unit can be used to perform several functions and reduce the need for hardware and operations, cost savings can be expected. These expected savings should be balanced with such potential cost factors as increased unit costs, increased operating costs, and the introduction of economic risk. For example, a component that should function in a storage and transport environment may be over-designed for storage because it has been designed to meet a more stringent requirement for transport.

Economic risk is an issue that should be considered in selecting a spent fuel management technology. It relates to uncertainty involved in design and licensing of storage, transport, and disposal systems. Expected cost and design uncertainties are the components of economic risk. Single-purpose storage and transport systems have been developed, licensed, and constructed, they are not considered to be high economic risks. If one combines them into a dual-purpose system, this may introduce some new risks. These risks arise from increased complexity, and from the reduced flexibility of a dual-purpose system compared to two single-purpose systems.

3.5.1. Single-purpose storage systems

Single-purpose dry storage systems are being used for AFR (RS) and AFR (OS) applications. The systems used include cask-based designs, canisters in vaults, and overpacks. The earlier applications used metal casks while newer applications use canisters with vaults or cask-like overpacks. Both vaults and overpacks are typically constructed of reinforced concrete. These concrete structures are inexpensive and can be formed in place at the storage site. In general, the canister-based storage-only devices are less expensive than the metal cask devices. A crude cost estimate puts the canister-based systems at about 20% to 25% of the cost of metal casks. Both may require decontamination and low-level waste disposal at the time of decommissioning.

3.5.2. Single-purpose transport systems

Single-purpose transport systems are being used to transport spent fuel from reactors to storage and reprocessing facilities. Although spent fuel destined for storage tends to be much older than fuel destined for reprocessing, the costs of these devices are similar and comparable. Because of the transport design requirements, transport casks may cost slightly more than metal storage casks (anywhere from 50% to 300%). However, few transport casks are needed for a spent fuel management system. Transport casks are typically designed for 25 years or more of useful service. During that lifetime, a cask may make from 10 to 25 shipments per year. Transport-only casks are generally not canister-based designs.

3.5.3. Dual-purpose systems

A dual-purpose system is one unit or set of components that provides storage and transport capability. Numerous dual-purpose systems are currently being developed, some are already in use. The earliest dual-purpose technologies where cask-based. Those currently under development are more likely to be canister-based technologies.

Cask-based dual-purpose systems are, of necessity, metallic casks. The same unit provides monitored dry AFR (RS) storage and transport to an AFR (OS) facility when appropriate. The cost of most metal cask dual-purpose devices will be about the same as transport-only metal casks. Obviously, such a system could be expensive. The unit cost of the metal cask is driven by the high cost of the transport device, but this system has limited, if any, reuse. The systems may still be cost effective in situations where spent fuel inventories are small, when less expensive one-time transport systems can be developed, and because higher payload per cask unit can be achieved compared to canister based systems.

Canister-based dual-purpose systems will usually have the spent fuel canistered at the reactor site and stored in inexpensive concrete vaults or overpacks. These costs are similar to those of storage-only canister systems, except that the cost of the canister goes toward reducing the cost of the transport overpack. For transport, the canistered fuel is transferred to a transport overpack which is similar to a transport-only cask, except that the canister provides a basket which reduces the cost of the transport device. Baskets are estimated to cost about 5% to 15% of the cost of a transport cask. Transfer of canistered spent fuel will be less complicated and less expensive than transfer of bare spent fuel, which is necessary for the cask-based dual purpose system.

Dual-purpose systems, whether cask-based or canister based, avoid some of the decontamination and low-level waste disposal activities and associated costs that occur at the reactor facility when single-purpose technologies are used. Of course, these activities are not eliminated, only delayed. Casks and canisters will have to be handled at the final destination, the repository. For both types of dual-purpose system, monitoring and maintenance are expected to be similar in complexity and cost as they are for single-purpose systems. One area that needs to be considered is preparation for transport after long periods of storage. For some design concepts, this could be a cost raiser.

4. American Requirements for Dry Storage Casks and Transport Casks

From the USNRC documents, the references:

NUREG – 1536 Standard Review Plan for Dry Cask Storage Systems
NUREG – 1617 Standard Review Plan for Transportation Packages for Spent Nuclear Fuel

are used to compare the American requirements for dry storage casks and transport casks.

NUREG –1536 Standard Review Plan for Dry Cask Storage Systems	NUREG-1617 Standard Review Plan for Transportation Packages for Spent Nuclear Fuel
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1.0 GENERAL DESCRIPTION

I. Review Objective

The purpose of reviewing the general description of the cask or dry cask storage system (DCSS) is to ensure that the applicant has provided a non-proprietary description that is adequate to familiarize reviewers and other interested parties with the pertinent features of the system.

II. Areas of Review

The general description should enable all reviewers, regardless of their specific review assignments, to obtain a basic understanding of the DCSS, its components, and the protections afforded for the health and safety of the public. Regulatory Guide (RG) 3.61[1] provides general guidance regarding information that should be included in the general description. Because much of the information relevant to this initial aspect of the DCSS review is presented in more detail in other chapters of this standard review plan (SRP), this chapter focuses on familiarization with the DCSS and should be consistent with the remaining sections of the safety analysis report (SAR). Specifically, this focus may encompass the following areas of review:

1. DCSS description and operational features
2. drawings
3. DCSS contents
4. qualifications of the applicant
5. quality assurance
6. consideration of 10 CFR Part 71[2] requirements regarding transportation

2.0 PRINCIPAL DESIGN CRITERIA

I. Review Objective

The purpose of evaluating the principal design criteria related to structures, systems, and components (SSC) important to safety is to ensure that they comply with the relevant general criteria established in 10 CFR Part 72[1], further guidance can be found in NUREG/CR-6407[2] "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety." Material provided in this chapter will form the basis for accepting the safety analysis report (SAR) for staff review.

The applicant should present details of the principal design criteria in either Section 2 or defer the details to the associated sections of the SAR. If the applicant chooses deferral, a general reference to these criteria must be presented. Regulatory Guide (RG) 3.61[3] provides general guidance concerning information that should be included in the principal design criteria for a dry cask storage system (DCSS). In general, these criteria include specifications regarding the fuel or other material to be stored in the DCSS, as well as the external conditions that may exist in the casks operating environment during normal and off-normal operations, accident conditions, and natural phenomena events. A detailed evaluation of how the DCSS design meets the principal design criteria should be presented in Sections 3 through 14 of the safety evaluation report (SER).

II. Areas of Review

The following areas of review have been adopted by the NRC staff, and include those areas noted in RG 3.61[3].

1. structures, systems, and components important to safety

2. design bases for structures, systems, and components important to safety
    a. spent fuel specifications
    b. external conditions

3. design criteria for safety protection systems

    a. general
    b. structural
    c. thermal
    d. shielding/confinement/radiation protection
    e. criticality
    f. operating procedures
    g. acceptance tests and maintenance
    h. decommissioning
    i. material compatibility[4]

(1) Normal Conditions

For a given spent fuel specification, the primary external conditions that affect DCSS performance are, the ambient temperatures, insolence, and the operational environment experienced by the DCSS.

(2) Off-Normal Conditions

SARs generally address several off-normal conditions. These should include variations in temperatures beyond normal, failure of 10 percent of the fuel rods combined with off-normal temperatures, failure of one of the confinement boundaries, partial blockage of air vents, human error, out-of-tolerance equipment performance, equipment failure, and instrumentation failure or faulty calibration.

(3) Accident Conditions

The staff has generally considered that the following accidents should be evaluated in the SAR. Because of the NRC's defense-in-depth approach, each should be evaluated regardless of whether it is highly unlikely or highly improbable. These do not constitute the only accidents that should be addressed if the SAR is to serve as a reference for accidents for the site-specific application. Others that may be derived from a hazard analysis could include accidents resulting from operational error, instrument failure, lightning, and other occurrences. Accident situations that are not credible because of design features or other reasons should be identified and justified in the SAR.

(a) Cask Drop

The SAR should identify the operating environment experienced by the cask, as well as the drop events (i.e., end, side, corner) that could result. Generally the design basis is established either in terms of the maximum height to which the cask may be lifted when handled outside the reactor site spent fuel building or in terms of the maximum acceleration that the cask could experience in a drop

(b) Cask Tipover

Although cask system supporting structures may be identified and constructed as being important to safety (i.e. designed to preclude cask tipovers), the NRC considers that cask tipover events should be analyzed. In some cases, cask tipover may be determined to be a credible hazard, and the associated analysis should reflect the conditions (e.g., heights and accelerations) associated with that hazard.

In the absence of an identified hazard, the NRC has accepted a non-mechanistic cask tipover about a lower corner onto a receiving surface from a position of balance with no initial velocity. The receiving surface for a horizontal or vertical drop may be either an unyielding hard surface; or, the receiving surface may be modeled as a reinforced concrete pad on an engineered fill[9]. The NRC has also accepted analysis involving the dropping of a cask with its longitudinal axis in the horizontal position that, with analysis of a vertical axis drop, could bound a non-mechanistic tipover case.

(c) Fire

The fire conditions postulated in the SAR should provide an "envelope" for subsequent comparison with site-specific conditions. The NRC accepts the methods discussed in 10 CFR Part 71.73. The NRC staff also accepts that the applicant may consider a fire based upon the limited availability of flammable material at an ISFSI (e.g., only that associated with vehicles transporting or lifting the cask or possibly nearby foliage). Regardless of which approach the applicant takes, the SAR should specify and justify the bounding conditions for a "design basis" fire

(d) Fuel Rod Rupture

The regulations require that the cask be designed to withstand the effects of accident conditions and natural phenomena events without impairing its capability to perform safety functions. Consequently, the NRC has assumed and the applicant should assume, during the cask analysis for conditions resulting from design-basis accidents and natural phenomena, a release of 100 percent of the initial rod fill gases and a release of 30 percent of the fission product gases from the fuel rods into the cask interior. The remaining 70 percent of the fission product gases are presumed to be retained within the fuel pellet.

(e) Leakage of the Confinement Boundary

Casks are designed to provide the confinement safety function under all credible conditions. Nevertheless, the NRC staff considers that, for assessment purposes and to demonstrate the overall safety of the storage cask system, the DCSS should be evaluated for the effects of a confinement boundary failure. The SAR should identify this failure as a bounding release caused by a non-mechanistic event and the effects should be evaluated as described in the Sandia National Laboratories Report 80-2124[12].

(f) Explosive Overpressure

The conditions under which an ISFSI may be exposed to the effects of an explosion vary greatly among individual sites. Generally, explosive overpressure is postulated to originate from an industrial accident. The effects of various sabotage methods on cask systems were evaluated separately by the Division of Fuel Cycle Safety and Safeguards in developing appropriate regulations in 10 CFR Part 73[11]. Therefore, explosive overpressures from sabotage events are not be considered in this SRP.

The extent to which explosive overpressure is addressed in the SAR directly affects the degree of site-specific review required. The principal concern in the SAR should be the effects of explosive overpressure on the storage system, rather than descriptions of hypothesized causes. Design parameters for blast or explosive overpressures should identify pressure levels as reflected ("side-on") overpressure, and should provide an assumed pulse length and shape. This discussion should provide sufficient information for licensees to determine if the effects of their site-specific hazards are bounded by the cask system design bases

(g) Air Flow Blockage

For storage systems with internal air flow passages, the applicant should consider blockage of air inlets and outlets in an accident condition. The NRC staff considers that the effects of such an assumption should be utilized in determining the appropriate inspection intervals, and/or monitoring systems, for the DCSS.

(4) Natural Phenomena Events

The staff has generally considered that the following events should be evaluated in the SAR.

(a) Flood

The SAR should establish a design-basis flood condition. This condition may be determined on the basis of the presumption that the cask cannot tip over and the yield strength of the cask will not be exceeded. Alternatively, the SAR can show that credible flooding conditions have negligible impact on the cask design.

If the SAR establishes parameters for a design-basis flood, all of the potential effects of flood water and ravine flood byproducts should be recognized. Serious flood consequences can involve effects such as blockage of ventilation ports by water and silting of air passages. Other potential effects include scouring below foundations and severe temperature gradients resulting from rapid cooling from immersion.

(b) Tornado

The NRC staff accepts design-basis tornado wind loading as defined by RG 1.76 (Region I)[12] and tornado missile impacts defined by NUREG-0800, Section 3.5.1.4[11]. Design criteria should be established for the cask on the basis of these wind loading and missile impact definitions. The cask should not tip over and that the capability to perform the confinement safety function should not be impaired. The NRC considers that tornados and tornado missiles may occur without warning. The review should note that in general, the effects of a tornado missile bound those of a light general aviation aircraft directly impacting a DCSS.

(c) Earthquake

The SAR should state the parameters of the DBE. For ISFSIs at reactor sites, this is equivalent to the SSE used for analysis of nuclear facilities, under 10 CFR Part 50. An analysis for an "Operating-Basis Earthquake" (OBE) is not required for an DCSS SAR prepared in accordance with 10 CFR Part 72. Cask tipover accidents are analyzed, but tipover caused by an earthquake may not be a credible event.

(d) Burial under Debris

Debris resulting from natural phenomena or accidents that may affect cask system performance may be addressed in the SAR or may be left to the site-specific application. Such debris can result from floods, wind storms, or land slides. The principal effect is typically on thermal performance.

(e) Lightning

Lightning typically has a negligible effect on cask systems; however, the requirements of the Lightning Protection Code and National Electric Code should be applied to the design of the cask system structures. These codes should be cited as part of the general design criteria for the cask system (see Section II.3.a, above). Lightning should also be addressed as a natural phenomenon in the SAR if cask system performance may be affected if lightning affects a component that is important to safety.

(f) Other

10 CFR Part 72 identifies several other natural phenomena events (including seiche, tsunami, and hurricane) that should be addressed for spent fuel storage. The SAR may include these as design-basis events or show that their effects are bounded by other events. If they are not addressed in the SAR and they prove to be applicable to a specific site, a safety analysis is required prior to approval for use of the DCSS under either a site specific, or general license.

Design Criteria (Specify normal/off-normal/accident, if applicable)

Design Life (License restricted to 20 years)

Structural
- Design Code
  - Containment (e.g., ASME*, AISC*)
  - Non-containment
  - Basket
  - Trunnions
  - Storage radiation and protective shielding and enclosure
  - Transfer radiation and protective shielding and enclosure
  - Cooling structure or system

- Design Weight

- Design Cavity Pressure   Normal/Off-Normal/Accident

- Response and Degradation Limits   Normal/Off-Normal/Accident

Thermal

- Maximum Design Temperatures
  - Cladding   5-yr Cooled Fuel (As Applicable)
    10-yr Cooled Fuel

  - Other Components

- Insolation
  - Side/Top/Bottom

- Fill Gas

Confinement

- Method of Sealing

- Maximum Leak Rates
  - Primary Seals
  - Redundant Seals
  - Cask Body

- Monitoring System Specifications

Retrievability

- Normal and Off-Normal

- After DBE and Conditions

Criticality

- Method of Control
  - (Geometry, Fixed Poison, Borated Pool Water)

- Minimum Boron Concentration
  - Fixed
  - Pool Water

- Maximum k_{eff}

- Burnup Credit (None currently permitted)

Radiation Protection/Shielding

Confinement Cask
- Surface   Normal/Off-Normal/Accident
- Position

Exterior of Shielding   Normal/Off-Normal/Accident
- Transfer Mode Position
- Storage Mode Position

ISFSI Controlled Area Boundary
- Normal/Off-Normal/Accident Dose Rate
- Annual Dose

Design Bases

Spent Fuel Specifications
- Type
- Configuration/Vendor
- Enrichment
- Weight or range of weights
- Burnup
- Type of Cladding
- Assemblies/Cask
- Dimensions

- Decay Heat/Assembly
  - 5-yr Cooled Fuel
  - 10-yr Cooled Fuel, etc.

- Gas Volume (@ Temperature)
- Fuel Condition/Damage Allowed
- Control Components

Normal Design Event Conditions

- Ambient Temperature
  - Maximum
  - Minimum

- Loading
  - (Wet/Dry)

- Storage Handling Orientation
  - (Vertical/Horizontal)

- Max lift height
- Other Conditions Considered in V.2.b.(1)

3.0 STRUCTURAL EVALUATION

I. Review Objective

In this portion of the dry cask storage system (DCSS) review, the NRC evaluates aspects of the DCSS design and analysis related to structural performance under normal and off-normal operations, accident conditions and natural phenomena events. In conducting this evaluation, the NRC staff seeks a high degree of assurance that the cask system will maintain confinement, subcriticality, radiation shielding, and retrievability of the fuel under all credible loads for normal and off-normal accident conditions and natural phenomenon ("accident-level") events.

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in evaluating the design and analysis of the proposed cask system, with regard to its structural performance. All storage cask systems include a confinement cask that may have both internal components and integral external components. In addition, some cask systems have a variety of other components that are subject to NRC evaluation and approval.

Recognizing the diversity of the various cask system components, the NRC has broadly categorized the applicable review procedures and acceptance criteria, as follows:

- confinement cask
- reinforced concrete (RC) components
- other system components important to safety
- other components subject to NRC approval

Within these broad categories, the NRC focuses the DCSS structural evaluation, as described in Section V, "Review Procedures," using the following areas of review, as appropriate.

1. scope
2. structural design criteria and design features
   a. design criteria
      i. general structural requirements
      ii. applicable codes and standards
   b. structural design features
3. structural materials
4. structural analysis
   a. load conditions
      i. normal conditions
      ii. off-normal conditions
      iii. accidents
   b. structural analysis methods
      i. finite-element analysis
      ii. closed-form calculations
      iii. prototype or scale model testing
      iv. structural analysis of specific components
   c. structural evaluation
      i. summary structural capability
      ii. fabrication and construction
      iii. structural compatibility with functional performance requirements

4.0 THERMAL EVALUATION

I. Review Objective

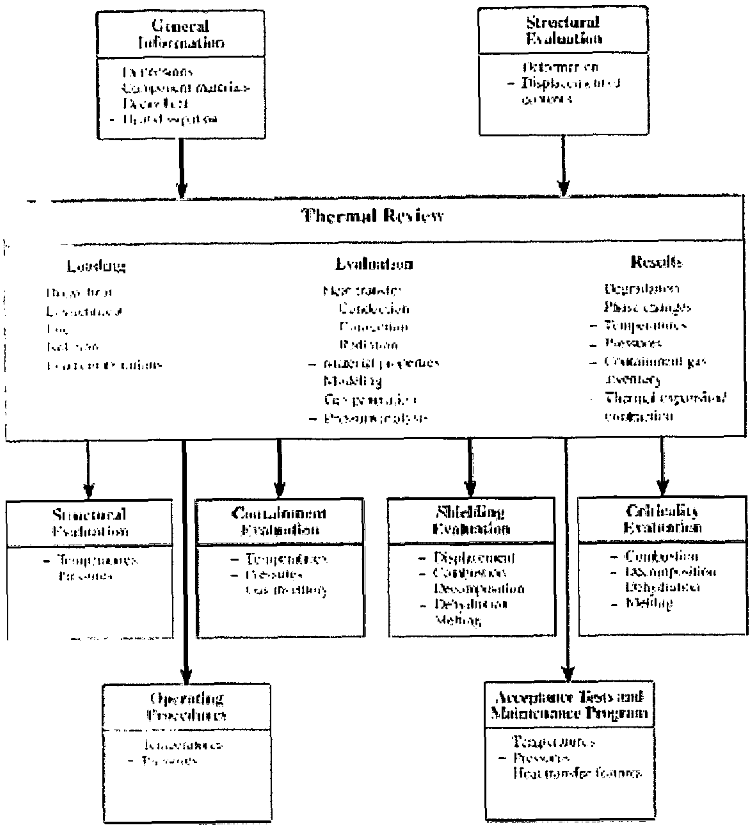
The thermal review ensures that the cask and fuel material temperatures of the dry cask storage system (DCSS) will remain within the allowable values or criteria for normal, off-normal, and accident conditions. This objective includes confirmation that the temperatures of the fuel cladding (fission product barrier) will be maintained throughout the storage period to protect the cladding against degradation that could lead to gross rupture. This portion of the DCSS review also confirms that the thermal design of the cask has been evaluated using acceptable analytical and/or testing methods.

II. Areas of Review

This portion of the DCSS review evaluates the design and analysis of cask thermal performance for normal, off-normal, and accident conditions. Consequently, this chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in reviewing thermal design criteria, design features, model specifications, and material properties. In addition, this chapter provides guidance for evaluating thermal analysis methods, including computer programs, temperature and pressure calculations, confirmatory testing, and independent evaluations done by staff.

As described in Section V, "Review Procedures," a comprehensive thermal evaluation *may* encompass the following areas of review:

1. spent fuel cladding
2. cask system thermal design
   a. design criteria
   b. design features
3. thermal load specification/ambient temperature
4. model specification
   a. configuration
   b. material properties
   c. boundary conditions
5. thermal analysis
   a. computer programs
   b. temperature calculations
   c. pressure analysis
   d. confirmatory analysis
6. supplemental information


General Information
Dimensions
Component materials
Decay heat
- Heat dissipation
Structural Evaluation
Deformation
- Displacement of contents
Thermal Review
Loading
Decay heat
Environmental
Fire
Insolation
Load combinations
Evaluation
Heat transfer
Conduction
Convection
Radiation
- Material properties
Modeling
Gas generation
- Pressure analysis
Results
Degradation
Phase changes
- Temperatures
- Pressures
- Containment gas inventory
- Thermal expansion/contraction
Structural Evaluation
- Temperatures
Pressures
Containment Evaluation
- Temperatures
- Pressures
Gas inventory
Shielding Evaluation
- Displacement
- Combustion
Decomposition
- Dehydration
Melting
Criticality Evaluation
- Combustion
- Decomposition
Dehydration
- Melting
Operating Procedures
Temperatures
- Pressures
Acceptance Tests and Maintenance Program
Temperatures
- Pressures
Heat transfer features

7.0 CONFINEMENT EVALUATION

I. Review Objective

In this portion of the dry cask storage system (DCSS) review, the NRC evaluates the confinement features and capabilities of the proposed cask system. In conducting this evaluation, the NRC staff seeks to ensure that radiological releases to the environment will be within the limits established by the regulations and that the spent fuel cladding and fuel assemblies will be sufficiently protected during storage against degradation that might otherwise lead to gross ruptures.

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in evaluating the design and analysis of the proposed cask confinement system for normal, off-normal, and accident conditions. This evaluation includes a more detailed assessment of the confinement-related design features and criteria initially presented in Sections 1 and 2 of the applicant's safety analysis report (SAR), as well as the proposed confinement monitoring capability, if applicable. In addition, the NRC staff assesses the anticipated releases of radionuclides associated with spent fuel, by independently estimating their leakage to the environment and the subsequent impact on a hypothetical individual located beyond the controlled area boundary.

As prescribed in 10 CFR Part 72, the regulatory requirements for doses at and beyond the controlled area boundary include both the direct dose and that from an estimated release of radionuclides to the atmosphere (based on the tested leaktightness of the confinement). Thus, an overall assessment of the compliance of the proposed DCSS with these regulatory limits is deferred until Chapter 10, "Radiation Protection," of this SRP. In addition, the performance of the cask confinement system under accident conditions, as evaluated in this section, may also be addressed in the overall accident analyses, as discussed in Chapter 11 of this SRP.

As described in Section V, "Review Procedures," a comprehensive confinement evaluation *may* encompass the following areas of review:

1. confinement design characteristics
    a. design criteria
    b. design features
2. confinement monitoring capability
3. nuclides with potential for release
4. confinement analyses
    a. normal conditions
    b. leakage of one seal
    c. accident conditions and natural phenomenon events
5. supplemental information

8.0 OPERATING PROCEDURES

I. Objective

In this portion of the dry cask storage system (DCSS) review, the NRC seeks to ensure that the applicant's safety analysis report (SAR) presents acceptable operating sequences, guidance, and generic procedures for three key operations:

1. cask loading
2. cask handling and storage operations
3. cask unloading

The operating sequences described in the SAR should provide an effective basis for the development of the more detailed operating and test procedures required by the cask user. The user will then use applicant supplied procedures as guidance when preparing and implementing detailed site-specific procedures, as required by the licensee's quality assurance (QA) and procedure writing programs. The NRC normally inspects selected site-specific procedures.

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance in evaluating the applicant's general operating sequences, and generic procedures related to cask operations (i.e., cask loading, cask handling, storage operations, and cask unloading). A comprehensive evaluation of this generic guidance may also encompass those areas of review, as defined in Section V, "Review Procedures." Within each area, the NRC staff assesses the effectiveness of the applicant's generic guidance on a technical and safety basis for the subsequent development of operating detailed procedures. As required by the regulations, [10 CFR 72.234(f)] these procedures are to be provided to each cask user, for the subsequent preparation and implementation of detailed site-specific procedures by the ISFSI licensee.

The purpose of this review,

- loading operations include the selection and placement of fuel into the cask, cask draining and drying, cask decontamination, inerting the cask and sealing the cask
- ISFSI operations include transferring the cask to the ISFSI site and any maintenance or surveillance activities required to ensure the safe storage of the radioactive materials
- Unloading operations required in response to currently unforseen problems that may be encountered during storage or prior to final disposal, including retrieving the cask and preparations for transfer off site
- to recover from an unforeseen problem during storage or to prepare the fuel for offsite transportation or ultimate disposition.

9.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

I Review Objective

In this portion of the spent fuel dry cask storage system (DCSS) review, the NRC seeks to ensure that the applicant's safety analysis report (SAR) includes the appropriate acceptance tests and maintenance programs for the system. A clear, specific listing of these commitments will help avoid ambiguities concerning design, fabrication, and operational testing requirements when the NRC staff conducts subsequent inspections

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in evaluating the acceptance tests and maintenance programs outlined in the SAR. The acceptance tests demonstrate that the cask has been fabricated in accordance with the design criteria and that the initial operation of the cask complies with regulatory requirements. The maintenance program describes actions that the licensee needs to implement during the storage period to ensure that the cask continues to perform its intended functions.

As defined in Section V, "Review Procedures," a comprehensive evaluation *may* encompass the following acceptance tests and maintenance programs:

1. acceptance tests
    a. visual and nondestructive examination inspections
    b. structural/pressure tests
    c. leak tests
    d. shielding tests
    e. neutron absorber tests
    f. thermal tests
    g. cask identification
2. maintenance program
    a. inspection
    b. tests
    c. repair, replacement, and maintenance

10.0 RADIATION PROTECTION

I. Review Objective

In this portion of the dry cask storage system (DCSS) review, the NRC evaluates the radiation protection capabilities of the proposed cask system. In particular, the NRC staff considers the following aspects:

- Do the proposed DCSS radiation protection features meet the NRC's design criteria for direct radiation?
- Has the applicant proposed engineering features and operating procedures for the DCSS that will ensure the worker's exposures remain as low as is reasonably achievable (ALARA)?
- Will the radiation doses to the general public meet regulatory standards during both normal operation and accident situations?

In ISFSI operation, the major mode of radiation exposure associated with spent fuel storage cask handling results from direct radiation. Because of the cask design requirements, radionuclides are not expected to be released from the cask during either normal operations or design-basis accidents (DBAs).

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in evaluating the radiation protection capabilities of the proposed cask system. As defined in Section V, "Review Procedures," a comprehensive radiation protection evaluation may encompass the following areas of review:

1. radiation protection design criteria and features
2. occupational exposures
3. public exposures
   a. normal conditions
   b. accident conditions and natural phenomenon events
4. ALARA

11.0 ACCIDENT ANALYSES

I. Review Objective

In this portion of the dry cask storage system (DCSS) review, the NRC evaluates the applicant's identification and analysis of hazards, as well as the summary analysis of system responses to both off-normal and accident or design-basis events. This review ensures that the applicant has conducted thorough accident analyses, as reflected by the following factors:

1. identified all credible accidents
2. provided complete information in the safety analysis report (SAR)
3. analyzed the safety performance of the cask systems in each review area
4. fulfilled all applicable regulatory requirements

II. Areas of Review

This portion of the DCSS review evaluates the applicant's identification and analysis of hazards, with particular emphasis on the safety performance of the cask system under off-normal events and conditions and accident or design-basis events. Consequently, this chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in reviewing the applicant's identification and analysis of hazards, as well as the summary analysis of system responses. A comprehensive accident analysis evaluation *may* encompass the following areas of review:

1. cause of the event
2. detection of the event
3. summary of event consequences and regulatory compliance
4. corrective course of action

13.0 QUALITY ASSURANCE

I. Review Objective

In this portion of the dry cask storage system (DCSS) review, the NRC evaluates the applicant's proposed quality assurance (QA) program, as described in the safety analysis report (SAR). In conducting this evaluation, the NRC staff seeks to ensure that the program provides adequate control over all activities related to the design, fabrication, assembly, testing, and use of DCSS structures, systems, and components (SSCs) that are important to safety.

To assess "adequate control," the staff determines whether the applicant's proposed QA program defines and assigns specific quality measures and controls to the various activities and SSCs. Moreover, the applicant should apply these quality measures and controls using a graded approach. The graded approach is described in NUREG/CR-6407[1]. That is, the effort expended on an activity or SSC should be consistent with its importance to safety. The QA program description provided in the SAR must identify both the procedures that the applicant will use to implement the QA program, as well as the activities and DCSS SSCs that are important to safety.

This evaluation should yield reasonable assurance that the applicant's proposed QA program will ensure that the DCSS will perform its intended functions in a satisfactory manner.

II. Areas of Review

This chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in evaluating the applicant's proposed QA program. As described in Section V, "Review Procedures," a comprehensive evaluation involves examining the QA program in terms of the 18 criteria defined in 10 CFR Part 72[2], Subpart G, "Quality Assurance." Reviewers should obtain reasonable assurance that the applicant has implemented accepted QA principles in the design, fabrication, assembly, testing, and use of the DCSS SSCs. In addition, the SAR should address the assignment of specific QA levels to each activity and SSC important to safety.

It is essential that the SAR provide sufficient detail to enable the NRC staff to assess the adequacy of the proposed QA program. In addition, since many of the QA program controls may be detailed in other sections of the SAR, the description of the QA program in SAR Section 13 should reference other sections that contain relevant information. The QA program evaluation should therefore be coordinated with other aspects of the DCSS review. Such coordination will allow reviewers to derive a more accurate and complete assessment of the applicant's level of commitment to the overall QA program, the selection of quality criteria and quality levels, and the proposed implementation methods.

To control activities related to the design and development of the DCSS, the applicant must *first* establish and implement an effective design control program and associated QA program controls and implementing procedures. Consequently, in conducting the QA program evaluation, reviewers should emphasize the area of design control. An effective design control program will provide assurance that the proposed DCSS will be correctly designed and tested and will perform its intended function.

14.0 DECOMMISSIONING

I. Review Objective

The decommissioning review ensures that the safety analysis report (SAR) demonstrates that the applicant has conceived adequate provisions to facilitate transfer of the spent fuel stored in the ISFSI to the DOE and provide for the future decontamination and disposal of the components that make up the dry cask storage system (DCSS).

The NRC recognizes that decommissioning will occur in the distant future (perhaps more than 20 years after the cask is first used) and will employ site-specific procedures available at that time. Consequently, 10 CFR Part 72[1] does not require licensees to develop detailed decommissioning plans until near the time of license termination.

By contrast, during the licensing of a proposed Dry Cask Storage System (DCSS), the applicant need only submit a *conceptual* decommissioning plan for NRC evaluation. Nonetheless, the applicant's conceptual plan must provide reasonable assurance that the owner of the DCSS can conduct decontamination and decommissioning in a manner that adequately protects the health and safety of the public.

Specifically, the conceptual decommissioning plan must identify the types of waste to be generated, the anticipated types of contamination, the proposed practices and procedures for decontaminating the cask and disposing of residual radioactive materials.

To augment the conceptual plan, the NRC requires a commitment that *general* licensees submit a detailed plan for ISFSI decommissioning along with their reactor decommissioning plan. Similarly, *site-specific* licensees will submit a detailed decommissioning plan for review and approval before initiating decommissioning activities at the facility.

II. Areas of Review

This portion of the DCSS review evaluates the applicant's conceptual decommissioning plan to ensure that it provides reasonable assurance that the licensee can conduct decontamination and decommissioning in a manner that adequately protects the health and safety of the public. Consequently, this chapter of the DCSS Standard Review Plan (SRP) provides guidance for use in conducting a comprehensive evaluation of the conceptual plan, which *may* encompass the following areas of review, as described in Section V, "Review Procedures"

1. identification and discussion of the anticipated decommissioning activities, types of waste to be generated, possible types of contamination, and planned waste disposal method(s)
2. commitment to decontaminate the facility to applicable NRC criteria
3. a financial plan, providing adequate financial assurance for the cost of decommissioning, submitted as a separate document, as required by Regulatory Guide (RG) 3.50[2]
4. commitment to submit a timely, detailed decommissioning plan for NRC review and approval before initiating decommissioning activities

5. CONCLUSIONS

The conclusions reached from this investigation of multi-purpose container technologies will not be totally satisfying to those looking for solutions to their specific spent fuel management needs. The reason for this is that this study did not identify one approach that is always superior to all the rest. That finding is an important result of this study. What the report does, is to point out some of the things that should be considered when faced with the task of evaluating and selecting a spent fuel management approach. Each specific case will have varying degrees of the factors considered in this report. In some specific cases, the factors considered here may be found insignificant, in other cases there may be new factors found that should be considered. Although the conclusion of this report does not say which technologies should be used, it does suggest what should be considered, at a minimum, for certain situations. Assessment should not be limited to those recommended below. The guidance provided by the recommendations may help to develop a hierarchy of things to consider in a specific assessment (i.e. a guide of where to where to start). The cost of performing a thorough evaluation is usually low when compared to the cost of developing and using a spent fuel management system.

Safety design and regulatory practices are the same for cask-based and canister-based technologies. The regulatory philosophy that forms the basis for these regulations is uniformly applied to all aspects of spent fuel management. Because of the uniformity in regulatory philosophy, one can conclude that each technology and its variations will provide equal levels of radiological safety.

Single-purpose systems are a good choice when there is a high degree of uncertainty regarding future needs and plans, or when the responsibility of further steps remains with other organizations.

Dual-purpose systems should be considered when AFR (RS) storage is needed and plans include AFR (OS) storage or a repository. Although canister-based systems may appear more cost-effective, cask-based systems should not be ignored in an evaluation, especially when spent fuel inventories are small. One factor in this regard is that cask-based systems avoid the need for large and sometimes complex canister handling equipment at various receipt facilities and can offer larger unit payloads. Other factors that may favour cask-based dual-purpose systems are materials and construction practices that may be suitable for one-time transport operations, but not reusable transport casks.

Multi-purpose systems should be considered if disposal plans and requirements are reasonably well established. The important fact in this regard is the commitment of funds to a disposal device that may not be usable. The issue here for cask-based or canister-based multi-purpose systems, is the incremental cost added to expand a dual-purpose system to cover disposal. That is the only cost at risk.

GLOSSARY

AR storage	Spent fuel storage that is integral or associated with a reactor and part of the refuelling operation.
AFR(RS) storage	Spent fuel storage away from and independent of the reactor(s) but still on the licensed site of the reactor(s).
AFR(OS) storage	Spent fuel storage away from the reactor(s) and off the licensed site of the reactor(s).
basket	(1) An open container (various) used in handling, transport and storage of spent fuel or other radioactive material (2) A structure (various) used in casks with functions including heat transfer, criticality control and structural support
bare spent fuel assembly	An uncontainerised spent fuel assembly in which there is no engineered barrier between the fuel cladding and the local environment.
borated (boronated)	Containing boron as a component of metals or as an independent additive in solids or in liquids used in the handling, transport and storage of spent fuel for criticality safety.
burnup credit	The assumption in criticality safety analysis that takes account of the reduction in reactivity of the fuel as a result of use in a nuclear reactor.
canister (can)	A closed or sealed container used to isolate and contain nuclear fuel or other radioactive material. It may rely on other containers (e. g. cask) for shielding.
cask	A massive container (various) used in the transport, storage and eventually disposal of spent nuclear fuel and other radioactive materials. It provides mechanical, chemical, nuclear and radiological protection and dissipates heat from the fuel.
cask lid (closure)	A removable cover for closing and sealing a cask.
container	A general term for a receptacle designed to hold spent fuel or radioactive material to facilitate movement and storage or for eventual disposal.
containment	(1) Retention of radioactive material such that it is prevented from dispersing into the environment or so that it is only released at acceptable rates. (2) A structure used to provide such retention of radioactive material
criticality safety	Prevention of conditions which could initiate a nuclear chain reaction.
dual-purpose cask	A cask licensed for both transport and storage of spent fuel.
mixed oxide fuel (MOX)	Fuel comprising oxides of uranium and plutonium.
modular design	A concept that allows sequential addition of similar structures or components to increase storage or handling capacity as the need arises.
monitored retrievable	Storage of spent fuel or high level waste in facilities that provides

storage (MRS) (USA term)	sustained monitoring capability and retrievability.
monitoring	A systematic programme to evaluate specified parameters, e.g. impurity levels, temperatures.
multi-purpose canister (MPC). (USA term)	A triple purpose, sealed, metallic container (called canister) that is used for storing, transporting, and disposing of spent fuel. The MPC is contained within an additional package or system designed uniquely for storage, transport and geological disposal.
neutron absorber (poison)	Solid or liquid material that absorbs thermal neutrons and reduces reactivity or prevents criticality.
overpack.	A secondary external enclosure for packaged spent fuel providing additional protection.
package	Container with its radioactive contents as presented for handling, transport, storage and/or disposal.
silo (caisson, concrete canister, concrete cask, sealed storage cask)	A portable or non portable structure comprising one or more individual storage cavities. The silo affords physical, radiological protection
site	The area containing a nuclear installation, defined by a boundary and under effective control of the operating organisation
transfer, fuel	A movement of spent fuel on a licensed site
transport, fuel	Movement of fuel from one facility to another using containers designed to maintain safe radiological and environmental control (thermal and atmospheric) and to preclude criticality both under normal and accident conditions. Transport includes: the design, fabrication and maintenance of packaging, preparation, consigning, handling, carriage, storage in transit and receipt at the final destination. Common modes of transport are water, rail and road
vault	An above- or below-ground reinforced concrete structure containing an array of storage cavities, each of which could contain one or more fuel units. Shielding is provided by the exterior of the structure. Heat removal is principally by forced or natural movement of gases over the exterior of the fuel unit or storage cavity. Heat rejection to the atmosphere is either direct or via a secondary cooling system