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Multi-purpose container technologies for spent fuel management

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FOREWORD

The management of spent nuclear fuel is an integral part of the nuclear fuel cycle. Spent fuel management resides in the back end of the fuel cycle, and is not revenue producing as electric power generation is. It instead results in a cost associated power generation. It is a major consideration in the nuclear power industry today. Because technologies, needs and circumstances vary from country to country, there is no single, standardized approach to spent fuel management.

The projected cumulative amount of spent fuel generated worldwide by 2010 will be 330 000 t HM. When reprocessing is accounted for, that amount is likely to be reduced to 215 000 t HM, which is still more than twice as much as the amount now in storage. Considering the limited capacity of at-reactor (AR) storage, various technologies are being developed for increasing storage capacities. At present, many countries are developing away-from-reactor (AFR) storage in the form of pool storage or as dry storage. Further these AFR storage systems may be at-reactor sites or away-from-reactor sites (e.g. centrally located interim storage facilities, serving several reactors). The dry storage technologies being developed are varied and include vaults, horizontal concrete modules, concrete casks, and metal casks.

The review of the interim storage plans of several countries indicates that the newest approaches being pursued for spent fuel management use dual-purpose and multi-purpose containers. These containers are envisaged to hold several spent fuel assemblies, and be part of the transport, storage, and possibly geological disposal systems of an integrated spent fuel management system.

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EDITORIAL NOTE

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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, standardised approach to spent fuel management.

Three basic scenarios, characterised 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, which are the subjects of this report, 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 noted that even after being fully developed, 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 power plants (NPPs) are built with pools with a wide range of capacities depending on the features of the power plant. Due to increasing requirements, advanced power plants often provide the capacity for several decades of operation. Nearly all countries operating nuclear power plants are increasing their 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 have resulted in significantly increasing storage capacities

over original design capacities. In many countries 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.

The purpose of this report is to review the status of dual-purpose and multi-purpose containers, and considerations for their implementation, design, and operation. Examples of representative container designs are provided in the appendix.

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. In this report, the term dual-purpose will be used when discussing category 1 systems, and multi-purpose when discussing category 2 systems.

Both categories are 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, transport, and disposal system, as applicable to the design (category of the multi-purpose system). Typically, canister-based systems will use overpacks to house the canister for the purposes of storage, transport, and disposal.

The container system for spent fuel storage, transport, and disposal, shall be designed to satisfy specific radiological safety functions. In general, it shall contain the radioactive material, limit emission of ionising 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, transport, or disposal is typically provided by the appropriate overpack.

For cask-based technologies that are designed to meet the needs of storage, transport, and geological disposal, the cask shall also be designed to meet the long term requirements of a geological repository. This should include features to ensure subcriticality conditions, perform as engineered barrier to ensure substantially complete containment, and meet thermal requirements for many thousands of years in the geological repository environment.

A canister-based technology may rely on the repository overpack to meet the long term requirement for substantially complete containment. Although designs are being developed, there are currently, no available casks or canister-based systems that have been proven suitable for geological disposal in a repository.

Several considerations are important regarding any decisions related to deployment of multi-purpose container technologies. These factors are defined and discussed in the subsequent sections.

2.1. Mobility

Mobility is the ability to move a system from place to place. The fact that both systems being considered in this report are transportable means, in terms of the definition for mobility used, that they are mobile. In contrast, single purpose storage or disposal packages do not provide this attribute. The transport only system is mobile, but is generally not used for storage or disposal. If it is, it is either dual-purpose or multi-purpose. This attribute has value for the once through cycle, or the wait-and-see approach. Both of these situations are 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 in this report as the ability to remove the cask, package, canister or spent fuel from its enclosure or emplacement. Although mobility could be considered as a part of retrievability, that is not done in this report. It is generally recognised that retrieval of spent fuel during a period of storage or disposal 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. In the case of geological disposal the question of retrievability becomes somewhat more complicated. The complication arises because geological disposal requires consideration of the spent fuel for an extended period of time. For countries now developing geological repositories, a formal period of spent fuel retrievability for some specified time after emplacement is anticipated. 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.

There are two obvious reasons to retrieve spent fuel from emplacement from geological disposal. The first reason is to correct any problem associated with the performance of the geological repository. The second reason for retrieval of spent fuel might be to use a new technology that is developed after emplacement of the spent fuel in a repository.

In the first situation, related to performance of the disposal package in the repository, the waste package may be affected. When the waste package is affected, multi-purpose containers will not necessarily make retrieval easier. For this situation, removal of spent fuel and repackaging will likely be required. For a canister-based system the canister and overpack will both have to be dealt with, a circumstance that will complicate the recovery. However, in some cases, when the overpack, but not the canister is affected, the need to handle bare fuel can be avoided. For the situation where new scientific data indicate that the performance of the geological barriers of the repository may not be as originally predicted, removal and relocation of the disposal package may be necessary. In cases where the disposal package is not affected, its internal configuration is not a factor in the operation. If the disposal package is also affected the previous arguments concerning package repair apply.

For situations where a new use or treatment is found for spent fuel, and this may result in a decision to remove the SNF from a repository, a disposal system designed and licensed to also facilitate transport and storage could be beneficial. However, if emplacement results in damage or degradation of the package or its components, repackaging for storage or transport may be necessary. Repackaging raises the issues already discussed.

2.3. Modularity

Modularity is the ability to be separated into distinct and standard units. Modularity is an obvious feature of the dual-purpose and multi-purpose container technologies. 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 or multi-purpose container technologies is the reduction of bare spent fuel transfers from a dry storage facility to a transport cask and/or to a geological disposal canister, thereby:

- lowering the probabilities of human error and accidents associated with handling bare spent fuel assemblies;
- working towards the ALARA principle;
- minimising 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 multi-purpose container technologies 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 and multi-purpose container technologies have 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 and multi-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.
- Multi-purpose container technologies may simplify operations at the time of spent fuel emplacement at an interim storage facility or repository (i.e. there is no need to further manipulate the bare fuel assemblies or open the sealed container).
- Multi-purpose canisters can potentially complicate operations at a repository. The design of the canister is based on the current knowledge of repository characteristics. Changes due to additional information gathered during the characterisation and licensing process, a change in public policy, or a change in the regulatory environment may necessitate that the canister be opened and potentially discarded.
- In spent fuel management systems that have to deal with a multiplicity of fuel types a technology that takes a step toward developing standardised equipment is seen as a benefit.

2.5. Decommissioning of reactors, storage facilities, and containers

The use of multi-purpose containers may facilitate the decommissioning of facilities and containers. The following Section describes some considerations related to decommissioning with the use of dual-purpose and multi-purpose containers.

2.5.1. Reactors

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 or multi-purpose systems 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 and multi-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 and multi-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.

Away-from-reactor off-site storage facilities

The use of dual-purpose or multi-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.

2.5.2. Containers

When considering the container that holds the spent nuclear fuel assemblies, there will be different approaches to decommissioning depending on whether the technology used is dual-purpose or multi-purpose (i.e. includes geological disposal). Dual-purpose containers will require decontamination, and if necessary, disposal as low-level waste at the time of disposal of the spent fuel it had contained. In this case, the spent fuel will be transferred from the dual-purpose canister to a waste package for disposal. The canister will then be a candidate for disposal. A multi-purpose container that is used for storage, transport, and geological disposal will not require this step. Similarly, single purpose transport casks that are used to transport bare spent fuel will have be decontaminated and disposed of as low-level radioactive waste. Transport overpacks that are components of dual-purpose or multi-purpose systems that have carried sealed canisters will be easier to decommission than single purpose casks when their service life has been completed. Also, any handling equipment that might be contaminated will have to be disposed as low level radioactive waste.

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 and multi-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. Issues associated with geological disposal

When considering the use of multi-purpose container technologies and whether to implement a technology that is dual-purpose (transport and storage) or multi-purpose the status of the geological disposal program should be considered. Currently, requirements for final geological disposal are not well defined. Requirements for transport and storage are established. This is because transport and storage requirements have been shown by experience to provide assurance that these activities can be safely accomplished, whereas geological disposal requirements for repositories are still evolving. These requirements may change for final geological disposal as the site characterisation process for a repository proceeds and the performance criteria become established. Under these circumstances, there is some uncertainty related to the development of casks and canisters that are to be used for geological disposal. This introduces a potential economic risk that will be discussed in the next Section.

2.8. Economics

A dual-purpose system or a multi-purpose system can replace single-purpose systems that are used for storage, transport, or disposal of spent nuclear fuel. For these systems, the requirements for storage, transport, and disposal 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 system's 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, transport, and disposal 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 and multi-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 minimised by progress payment, rather than large sums of money "up-front".

Another economic factor associated with a dual-purpose system or a multi-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 and multi-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 component's 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 or a multi-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, dual-purpose, and multi-purpose systems that are either cask-based or canister-based. More specific discussions on estimating unit cost and lifecycle cost for spent fuel management systems will be presented in Section 3.5. 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 minimised. 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. For disposal-only systems, regulations and designs are still evolving.

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.

It is expected that requirements imposed on a multi-purpose system to satisfy the geological disposal function will result in higher costs than would be necessary to meet storage and transport needs. When viewed from the perspective of a total system, the multi-purpose technologies may be less expensive because of the multiple uses of components and reduction in low-level waste generation. The multi-purpose system may also allow for increased standardisation or modularity over single-purpose and dual-purpose systems. In a multi-purpose canister system, the internal basket that is integral to the canister is used for storage, transport, and geological disposal, thereby sharing the cost burden over all three functions. This may reduce the cost of the total system. In the case of multi-purpose casks there is the elimination of the need to develop separate technologies for both transport and storage. Other cost reductions may be realised through simplification of handling facilities needed at reactors, interim storage facilities, and final repositories.

Although components may be used for several performance functions, it should be recognised that the cost of satisfying one of the features may disproportionately drive the system cost up. This consideration is especially pertinent when dealing with requirements that have a high degree of uncertainty (e.g. disposal requirements). All of these factors need to be considered in system evaluations to determine the appropriate cost for implementing multi-purpose technologies.

In 1994, the US Department of Energy investigated various concepts for multi-purpose container systems that could be used for storage, transport, and disposal of spent fuel [1]. The goal of the Department of Energy's effort was to select a container technology that could be used to handle the vast majority of commercial spent nuclear fuel generated by US reactors at a reasonable cost. The study suggested that a canister based multi-purpose concept would serve the needs of the USA at the time of the study. The Department of Energy subsequently embarked on a program to develop such a canister-based multi-purpose system. The Department of Energy's report is instructive. However, the results and conclusions of the study should not be viewed as universally applicable. The study was based on the situation in the USA in 1990. Those conditions may have changed which could affect the conclusions reached. Furthermore, the study may not apply for other countries or other situations.

3. DESIGN ASPECTS

To reiterate, dual-purpose container concepts within the context treated in this paper mean that a cask or canister contains the fuel during storage and transport. The multi-purpose concept extends that of dual-purpose to include geological disposal. 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. In the case of multi-purpose canister-based systems, the canister is designed to serve as an inner fuel container for the spent fuel geological disposal container system. In this case, the canister will generally be used for criticality control, and it may provide one segment of an engineered barrier. Cask-based dual-purpose systems use a single integral unit for transport and storage without the need of an additional overpack. These integral units could also be used for direct geological disposal of spent fuel.

The design considerations for transport, storage, and disposal 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. Disposal systems will be designed for continuous service for thousands and tens of thousands of years. The disposal waste package will be designed to withstand the harmful affects of its natural environment, and to take advantage of its natural environment to preclude or limit release of radioactive material to the environment.

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 [2]. 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 [3]. Regulations for disposal are being developed at the IAEA [4], and in several countries.

Safety provisions are mainly directed to minimise 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 analysed and either precluded or mitigated to the maximum extent practical. These particular considerations are not addressed in this report.

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 as discussed in the following sections.

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.

The design requirements used to assure radiological safety are reviewed in the subsequent Sections. 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, transport, and geological disposal. This report 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, storage, or geological disposal container. 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. Boiling Water Reactor (BWR) fuel generally has smaller cross section dimensions than pressurized water reactor (PWR) fuel, and neutron absorber panels between spent fuel assemblies are generally found to be more effective than they are for PWR systems. For BWR fuel, the neutron absorbing panels may be sufficient, while neutron flux traps may be needed for PWR systems. The use of flux traps usually add to the challenges of the structural design and tend to reduce system capacities.

Since there are no licensed designs for geological disposal facilities in the world today, no approved approach for long term criticality control exists. However, the US Department of Energy has recently submitted a topical report to the US Nuclear Regulatory Commission for a proposed method for dealing with disposal criticality safety [5]. The method being proposed in the USA uses burnup credit as part of its criticality safety demonstration.

The general topic of burnup credit for storage, transport, and disposal in spent fuel management systems enjoys worldwide attention. Over the past several years the IAEA has been reviewing, evaluating, and reporting on activities related to the use of burnup credit in spent fuel management systems [6]. 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 noted 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.

For many container designs, burnup credit may be used to maximise the effective system capacity, and reduce the cost and number of units needed. Burnup credit may prove to be a basis for demonstrating long term criticality safety following geological disposal of intact spent nuclear fuel assemblies for all designs.

Although burnup credit has been approved for AR pool storage, and for dry storage and transport in several countries, additional work continues worldwide. A number of technical and regulatory issues are being pursued in the areas of criticality prediction and implementation. The work on prediction methods includes development of data to benchmark tools for calculating isotopic inventory and criticality for spent fuel. Other issues relate to modelling affects (e.g. axial distribution of burnup). In addition to work on computational tools and modelling, issues have to be addressed related to the assurance of proper loading of burned fuel into a system that relies on burnup credit for criticality safety. Most practitioners and regulatory authorities believe that verification procedures are necessary to assure correct loading of spent fuel systems. For transport, the common consensus is that measurements of spent fuel assemblies will be used.

Long term criticality control for spent nuclear fuel following emplacement in a geological repository is a major consideration if geological disposal is the intended use of the container. It is anticipated that a probabilistic analysis approach will be used to demonstrate criticality safety for long term geological disposal. It is expected that this approach will assign failure probabilities to the engineered barriers such as spent fuel package container, multi-purpose canister shells, spent fuel basket geometry and the dispersion of neutron absorber poison materials. The method will also require estimates of various natural events. The material properties and long term capabilities will be used when considering the frequency of events, such as water intrusion, to assure in a probabilistic manner the unlikelihood of a spent fuel disposal package criticality event occurring during the spent fuel isolation period. In addition to expected degradation of engineered systems and variations in natural environments over time, the variations in criticality potential over time shall also be considered. The issue is that the criticality potential of spent nuclear fuel will change cyclically with time due to the different half-lives of the various fissile and neutron absorber isotopes contained in spent fuel.

After discharge from the reactor, the reactivity of spent nuclear fuel first decreases for approximately 150 years, and then increases for approximately 20 000 years before decreasing again. Figure 1 [1] provides a graphic representation of the time effects on criticality potential assuming a fully flooded condition.

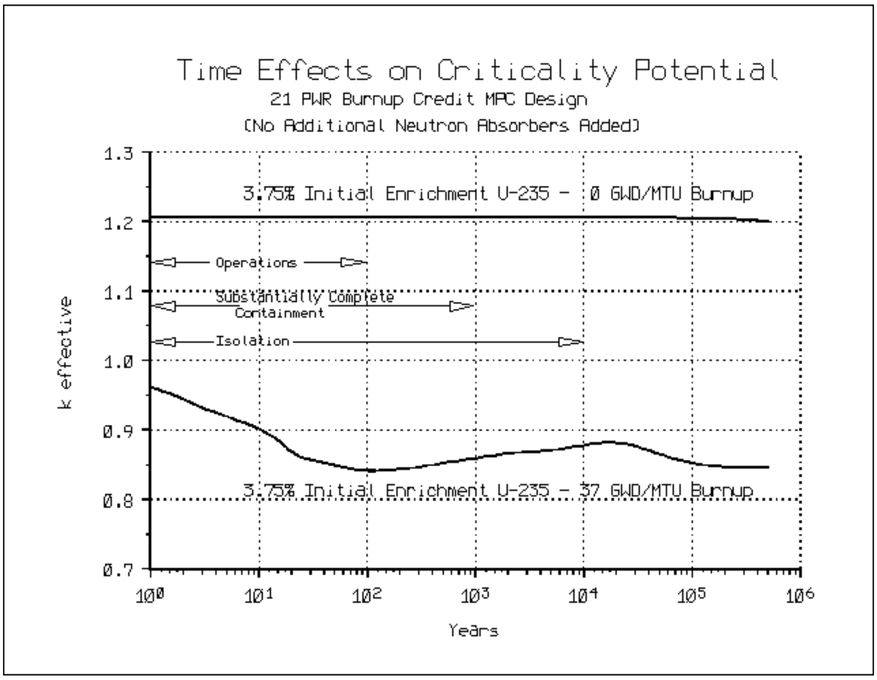

FIG. 1. Time effects on criticality potential.

As can be seen from the Fig. 1, the initial decrease in criticality potential is primarily caused by the decay of ^{241}Pu, a fissile material. The subsequent increase in criticality potential results from the radioactive decay of neutron absorbers, like ^{240}Pu. This is followed by a subsequent decrease in criticality due to the decay of ^{239}Pu, a fissile isotope of plutonium. Designs for multi-purpose containers that are intended for use in a repository should account for these variations in criticality potential and provide for criticality control during the entire "isolation" phase, or geological disposal period.

Long term criticality control in a geological repository should also take into consideration any possible neutronic coupling effect between spent fuel columns. Coupling may occur even when spent fuel is separated by rather long distance, due to the moderator content in the intermediate medium that varies as a function of moisture (water vapour) and carbon dioxide concentrations. These variations are due to movement of these substances in the geological medium.

Materials used for constructing the basket in a multi-purpose canister will degrade over the life of the repository. Degradation of the neutron absorber material over the geological disposal period needs to be addressed with regard to criticality control. Neutron absorber material may be depleted due to neutron flux and leaching caused by corrosion. Preliminary evaluations indicate that a reduction of up to about 16 per cent of ^{10}B could occur during the geological disposal period [1]. Sufficient neutron absorbing material shall be provided in the design to satisfy these concerns by including additional ^{10}B content in the neutron absorber material.

Approaches other than the one discussed here may be used for maintaining criticality control for long term geological disposal. One method that may prove useful is to include additional materials in the container to prevent or limit the ingress of moderating fluids (e.g. water exclusion). Another method is consolidation of fuel before disposal. This approach would alter the fuel's geometry, thereby, precluding or limiting the introduction of moderating fluids between the spent fuel rods.

The introduction of a filler material to exclude moderator would probably involve the addition of neutron absorbing material that would be selected to last much longer than those typically used for transport and storage. The moderator exclusion substance shall have an expected useful life that exceeds that of the fuel while it remains reactive. This approach will complicate the design of a system where canisters are welded and are intended for use in the geological repository. This consideration will require the designer of a canister to be able to demonstrate the ability to open and reseal the container after the addition of additive materials, unless the additive materials have been already introduced at the time of the first loading of the canister.

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 the IAEA Safety Series No. ST-1: Regulations for the Safe Transport of Radioactive Material (previously Safety Series No. 6) [2]. 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.

The IAEA regulations are accepted worldwide for transport packages. It is not necessary to treat this subject in this report.

Although similar to containment the requirements transport packages, those for storage are different. The major difference is that the safe containment of the radioactive material has to be maintained over a period of several decades. 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 canister's 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. If the technology is to be used for geological disposal, shielding for geological disposal purposes should not be a major design factor as the requirements for storage and/or transport will be controlling. However, the design should take into account that some shielding materials may not be suitable for the geological disposal environment. 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 and are found in Ref. [7].

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's 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 approach to design of a disposal package is expected to be similar to the design for storage. That is, the design base conditions will be set in terms of a specific repository.

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, transport, and disposal 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 and multi-purpose systems, the designer should assure that the radiological safety components satisfy requirements for each of the intended purposes.

The structural analyses of any multi-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 rods, 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 analysed, 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, transport, and disposal. In the case of thermal design, the forces that challenge the container's 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, transported, and disposed. 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). The design of a disposal package is expected to be similar to the design for storage. That is, the design basis conditions will be set in terms of a specific repository.

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 multi-purpose container system there are other design features that may be used for increasing heat dissipation. Some examples include the use of aluminium 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 behaviour of the multi-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 $800^{o}C$ 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).

If one is considering using the container for geological disposal as well as storage and transport, the interfaces of the container with the geological repository and spent fuel disposal package will need to be considered. This may be difficult at the present time because repository designs will evolve with time as more is learned about the geological disposal environment. There may be advantages to maintaining temperature limits of spent fuel cladding during geological disposal and cladding temperatures in the spent fuel disposal package should be evaluated to confirm compliance of the canisters design with the repository limit. Maintaining fuel cladding condition will add to the overall performance of the geological repository.

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 power plant. The handling of dual-purpose and multi-purpose casks does not differ significantly from loading a transport cask. However, it is noted that fitting the primary lid to the cask at the NPP 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 NPP.

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 affects 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 multi-purpose container technology. In cases where long periods of storage at an NPP are anticipated before spent fuel is to be transported in a dual-purpose or multi-purpose system, the delay can be used to improve a system's 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. Although diversion of nuclear materials that contain fissile isotopes is of general concern, for spent fuel discharged from light water reactors it is not considered likely because of the small concentration of fissile material and the presence of highly radioactive isotopes.

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 was discussed in Section 2.8 as an economic consideration. 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, transport, and disposal 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.

Disposal is the most difficult area for this type of assessment. Once emplaced, the waste package is not accessible for maintenance or repair. Therefore, reliability is the only safety tool. The difficulty of relying on reliability alone is especially burdensome due to the long periods of performance for a disposal package placed in a repository.

3.5. Cost

The general concepts of cost have already been discussed under the topic of economics in Section 2.8. In this Section we will apply some of those concepts to evaluate unit costs and life cycle costs for spent fuel management systems. Cost estimates should address unit costs and total system life cycle costs. It is noted 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 optimise the design with regard to unit and total life cycle cost.

The economic advantages of going from a single-purpose to dual-purpose, and finally to multi-purpose have already been discussed in Section 2.8. 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. The greatest economic risk is expected for the disposal element of the multi-purpose system. There are no current waste packages approved for disposal, and the duration involved for these designs is extreme.

The purpose of this section is to discuss some of the cost elements associated with hardware and systems for spent fuel storage, transport, and disposal of cost. The discussion will not be exhaustive, but will address some of the main aspects of the subject of unit and lifecycle costs.

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. Single-purpose disposal packages

There is no experience to cite when discussing disposal packages. In general, it is expected that disposal packages will be constructed of concentric layers of material that will serve to preclude release of radioactive material to the environment for long periods of time. Some of these layers will provide containment, others will be sacrificial. The sacrificial layers will delay ingress of the natural environment. The repository program in the USA is currently designing a single-purpose disposal package [8]. Although the reference design for the repository in the USA is a single-purpose disposal unit, optional waste package designs that will accommodate multi-purpose canisters are included as contingencies.

3.5.4. 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 or repository 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.

3.5.5. Multi-purpose systems

The multi-purpose system is an extension of the dual-purpose system previously discussed. However, there are additional factors that should be addressed when considering multi-purpose systems. One factor, which is in the form of a caution is the fact that the technology for waste package design, licensing, construction, and use is not fully developed for multi-purpose systems. The result of this immaturity of the underlying technology is the introduction of economic risk that was discussed at length in Section 2.8. The risk is compounded by the fact that the design life of a repository and waste package is significantly longer than the design life for storage or transport systems.

Cask-based multi-purpose systems have the same issues as their dual-purpose counterparts. That is, the one expensive unit serves a limited amount of spent fuel. The added complication here is the economic risk factor that is introduced by disposal. Of course, this may be a risk well worth taking if we are relatively sure of the repository requirements, or if the incremental cost of extending the system's capabilities to include disposal is small.

For canister-based multi-purpose systems, the canister is the only component that contributes to economic risk. If it is unusable for disposal it is discarded at the repository and dealt with as low-level waste. The costs incurred in this situation are the incremental additional costs associated with extending the canister's capabilities from storage and transport to also include disposal.

4. 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.

Appendix

EXAMPLES OF MULTI-PURPOSE SYSTEMS

This appendix is included to present some examples of multi-purpose systems that are currently being used or developed. The concept of multi-purpose is used in its more general sense in this appendix. That is, multi-purpose refers to any system that serves more than one purpose. It will include dual-purpose systems that are used to store and transport spent fuel. It will also be used for the triple-purpose systems that are intended to provide for storage, transport, and disposal of spent fuel.

There are a number of multi-purpose systems in use and under development at this time. Some of these are being used only in their country of origin, while others are being used in several countries. Since the list of such systems keeps growing, it will not be inclusive of every existing system. The systems described will include the following: CASTOR, HI-STAR, NAC-STC, NAC-UMS, NUHOMS/MP-187, POLLUX, TN24, TN-68, TranStor, and Wesflex.

The descriptions included in this appendix vary in detail. This variation in detail is primarily a result of the information sources used by the writers of this appendix, and does not necessarily reflect the maturity of the design, or the status of the licensing of the system. Because many of the systems described are under development, changes to design descriptions are to be expected. Although accuracy in these descriptions was a goal, it may not have been achieved in every instance. Keeping the several admitted limitations of this appendix in mind, those readers who are interested in more detail, or better accuracy, are advised contact system suppliers identified under the heading of vendor. Those readers who are interested in the names of additional suppliers are advised to search such sources as the trade journals and conference proceedings. To assist those seeking more detailed or accurate information, the vendor entry includes the company name, city, and country.

An additional caution is noted with regard to the accuracy of the information provided. Several of the systems described in this appendix are being develop in the USA. Those systems will be licensed by the US Nuclear Regulatory Commission (NRC). The NRC has recently begun publishing projected schedules for their storage and transport reviews on their web-site (http://www.nrc.gov). The projected dates given for issuing approvals by the NRC are given without pre-judgement of the applicant’s submittals. The schedules, which assume no technical or regulatory complications, cannot be guaranteed.

A-1. THE GNS CASTOR SYSTEM

Model Name: CASTOR

Vendor: GNS Gesellschaft für Nuklear-Service, Germany

System Classification: There are several *cask-based, dual-purpose* CASTOR designs.

Contents: Several designs are available for storage and transport of spent light water reactor fuel assemblies (i.e. BWR, PWR, RMBK, and WWER).

Hardware Description: The CASTOR dual-purpose casks are cylindrical in shape. They are comprised of a monolithic ductile cast iron body with bolted lids. The thick ductile iron casting provides containment and shielding during storage, and for normal and accident conditions of transport. Fuel assemblies are held in steel baskets.

Operations: The CASTOR is a cask-based system, which does not require fuel transfer between storage and transport operations. GNS has also developed a steel lined reinforced concrete storage cask for storage only applications.

Licensing Status: CASTOR casks are approved and used worldwide (Europe, Asia, North America) for away-from-reactor (on-site, off-site) dry storage applications. The transport cask meets IAEA Type B(U)F transport requirements, and are used extensively in Europe for storage and transport applications.

A-2. THE HOLTEC INTERNATIONAL HI-STAR / HI-STORM SYSTEM

Model Name: HI-STAR / HI-STORM

Vendor: HOLTEC International, Marlton, New Jersey, USA

System Classification: The HOLTEC HI-STAR / HI-STORM is a *canister-based, dual-purpose* system. HOLTEC is designing its canister to meet expected disposal requirements being set by the US Department of Energy. If determined to be acceptable at the time of disposal, the canister would be part of the waste package.

Contents: Three canister designs with the same outer dimensions are available for BWR or PWR assemblies. The MPC-68 is designed for 68 BWR assemblies with maximum initial enrichment of 4.2% U-235. The MPC-24 is designed for 24 PWR assemblies with maximum initial enrichment of 4.6% U-235. The MPC-32 is designed for 32 PWR assemblies with maximum initial enrichment of 5.0% U-235. However, the MPC-32 relies on the use of transportation burnup credit, which is still under consideration by the US Nuclear Regulatory Commission.

Hardware Description: The HOLTEC HI-STAR / HI-STORM canister-based system consists of a canister and overpacks for storage and transport. The canisters for BWR and PWR assemblies are the same and can be used with the HI-STAR or HI-STORM overpack. The HI-STAR can be used as an overpack for transport and storage which eliminates the need for canister transfer between storage and transport operations. Alternatively the canister can be used in conjunction with a HI-STAR overpack for transport, and a HI-STORM overpack for storage. This alternative requires transfer of the canister between the two overpacks for storage or transport. HOLTEC's HI-TRAC device has been designed for these canister transfer operations.

The canisters are constructed of alloy steel and have fuel baskets that are described as a honeycomb geometry. The maximum design weights of the MPC-68, MPC-24, and MPC-32 canisters are 88,000, 80,000, and 90,000 pounds, respectively. The canister's outside dimensions allow insertion into the HI-STAR or HI-STORM overpack.

For transport, the HI-STAR overpack is used with one of the three canisters. The HI-STAR is a layered alloy steel construction, it uses a Holtite-A$^{\text{TM}}$ neutron shield. The transport overpack which is shipped horizontally has a length of 203-inches, outside diameter of 96-inches, and an inside diameter of 68.75-inches. When empty, the transport overpack weighs 154 000 pounds, when shipped (maximum weight loaded canister and impact limiters) it weighs 274,000 pounds. The bolted lid closure is fitted with two concentric o-rings for containment during transport. The transport overpack is back-filled with helium.

For storage, either the HI-STAR or HI-STORM overpack is used. When used for storage, the HI-STAR overpack is placed vertically (i.e. height of 203-inches) without the transport impact limiters. The maximum loaded weight without impact limiters is 248 000 pounds. The alternative storage configuration uses the HI-STORM overpack with one of the three canister designs. The HI-STORM is a vertical ventilated cylindrical overpack. It is a concrete structure with steel casing. It is designed as a free-standing device, but can be anchored if necessary or preferred. The HI-STORM overpack has a height of 231-inches, outside diameter of 132.5-inches, and an inside diameter of 73.5-inches. The empty overpack weighs 269 000 pounds, when loaded with the maximum weight canister, it weighs 358 000 pounds. The HI-STORM overpack has four ducts at the top and bottom for natural convection cooling of the loaded canister.

Operations: When the HI-STAR system is used for storage and transport of a loaded canister there is no transfer required. For example, the loaded HI-STAR system may be stored at a reactor site until it is transported to another location for storage or disposal, at which time it is shipped away as a unit. When the HI-STAR / HI-STORM combination is used, the loaded canister has to be transferred to the appropriate overpack for storage or transport. Transfer of the canister requires the use of the specially designed HI-TRAC transfer equipment. For example, if the loaded HI-STORM overpack is used at a reactor site for storage the canister has to be transferred to the HI-STAR overpack for off-site transport. If the destination is to an off-site interim storage facility, the empty HI-STORM overpack may be shipped to the facility for storage, a new HI-STORM overpack may be used, or storage in the HI-STORM overpack can be chosen.

Licensing Status: The HI-STAR 100 has received transport certification from the US Nuclear Regulatory Commission (10 CFR Part 71). The system was certified for storage of spent fuel in 1998 (10 CFR Part 72). The HI-STORM system is under review by the NRC.

A-3. THE NAC INTERNATIONAL NAC-STC SYSTEM

Model Name: NAC-STC

Vendor: NAC International, Norcross, Georgia, USA

System Classification: The NAC-STC is a *canister-based, dual-purpose* system.

Contents: The cask is designed for 26 PWR assemblies of various designs. The cask is designed for fuel with a maximum 4.2% ^{235}U initial enrichment, a maximum burnup of 45 000 MW·d/t U, and a minimum decay time of 6.5 years for transport and 10 years for storage.

Hardware Description: The body of the NAC-STC consists of inner and outer stainless steel shells separated by lead radiation shielding. The NAC-STC body uses dual stainless steel lids, installed for transport and storage. The inner lid provides primary containment; the outer lid, secondary containment. Two metallic o-rings associated with the inner and outer lids are used for containment. Further, the outer lid provides protection of vent and drain ports, which are located on the inner lid. This dual-lid design facilitates periodic verification leak testing on containment seals. The basket consists of stainless steel, BORAL neutron poison, and aluminium. The NAC-STC spent nuclear fuel basket is a flux trap design that uses support disks to locate and separate fuel guide tubes containing BORAL (enriched ^{10}B) neutron absorber panels. The spacing of the basket tubes is maintained by steel support discs.

NAC-STC uses redwood- and balsa wood-filled stainless steel transport impact limiters. The cask has four lifting trunnions and two rotation trunnion recesses. The rotation trunnions may be used to restrain the cask, and a steel shear ring is provided at the top end of the radial neutron shield to supply longitudinal restraint during transport. The fully loaded package and its accessories weigh 113 metric tons.

NAC-STC Specifications

Weight (tons) Loaded	116 (with 26 PWR assemblies)
Empty	103
Dimensions	
Overall Length (in/cm)	193/490.2
Overall Diameter (in/cm)	99/251.5
Cavity Length (in/cm)	165/419.1
Cavity Diameter (in/cm)	71/180.3
Neutron Shield	
Neutron Shield	Bisco NS4FR

Operations: The spent fuel is loaded into the cask at the reactor spent fuel pool, and may be stored at the reactor site, and transported from the reactor site for later storage in the same cask.

Licensing Status: Nuclear Assurance Corporation has a licensed storage cask in use for interim dry spent fuel storage at Virginia Power Company's Surry nuclear station (storage only under 10 CFR Part 72). The licensed cask, the NAC S/T I28, is similar to the NAC-STC. The NAC S/T I28 has a general license for storage under 10 CFR Part 72 and this cask is listed in 10 CFR Part 72.214, Subpart K. The NAC-STC has been licensed for transportation.

A-4. THE NAC INTERNATIONAL NAC-UMS SYSTEM

Model Name:	NAC-Universal MPC System (NAC-UMS)
Vendor:	NAC International, Norcross, Georgia, USA
System Classification:	The NAC-UMS is a *canister-based, dual-purpose* system. NAC is designing its canister to meet expected disposal requirements being set by the US Department of Energy. If determined to be acceptable at the time of disposal, the canister would be part of the waste package.
Contents:	The NAC-UMS is designed for 24 PWR assemblies or 56 BWR assemblies.
Hardware Description:	A stainless steel canister for 24 PWR assemblies can be placed in a transport or storage overpack. The BWR canister holds 56 assemblies. The canister has five designs ranging in lengths of 175 to 192-inches. All canisters are 67-inches in diameter. The heaviest weighs 19 tons empty or 38 tons when loaded. All canisters use a tube and disk basket design. The transport overpack is a stainless steel and lead construction with solid polymer neutron shield. The overpack is 209-inches in length and 93-inches in diameter. The impact limiters are redwood and balsa wood in stainless steel shells. The empty weight without impact limiters is 83 tons. The maximum loaded weight including impact limiters is 126 tons. The transport overpack is shipped in the horizontal position. The storage overpack is a carbon steel lined vented Portland concrete construction, reinforced with steel rebar. The storage modules come in five lengths ranging from 211 to 226-inches, and an outside diameter of 136-inches. The maximum empty weight is 121 tons, and loaded weight 160 tons.
Operations:	The NAC-UMS is a canister-based design. The canister is loaded with fuel in the reactor spent fuel pool. Canistered fuel has to be transferred from the storage overpack to the transport overpack for transport.
Licensing Status:	The transport license application was submitted to the NRC in April 1997, and approval (certification under 10 CFR Part 71) is expected by January 2000. The NAC-UMS has been approved for storage, subject to rulemaking, which should be completed by February 2000.

A-5. THE TRANSNUCLEAR WEST NUHOMS® - 24P / MP-187 SYSTEM

Model Name: NUHOMS® - 24P / MP-187

Vendor: Transnuclear West, Fremont, California, USA

System Classification: The NUHOMS® -24P / MP-187 is a canister-based, dual-purpose system. Transnuclear West is factoring expected disposal requirements being set by the US Department of Energy into their canister design specifications.

Contents: The design basis PWR fuel used for all MP-187 is 424 cm long, and 21.6 × 21.6 cm wide. For transport and storage, the fuel decay heat is maximum 0.746 kW per assembly, with a maximum total allowable heat load of 13.5 kW. The maximum initial enrichment is 3.43% ^{235}U and the burnup is 40 000 MW·d/t U.

Hardware Description: The system consists of a canister, MP-187 transport overpack, and a NUHOMS® -24P storage module. There are three shielded canisters designs that can be used for transport and storage. All three PWR canisters have the same outside dimensions.

The canister is a common component of the storage and transport system. One type of canister is designed to hold 24 fuel assemblies without control rod components. A second type of canister is designed to hold 24 fuel assemblies with control rod components. The third type of canister is designed to hold 13 failed fuel assemblies. The stainless steel canisters contain the fuel in a basket arrangement. The basket design provides support strength for the PWR assemblies with the basket guide sleeves and 26 spacer disks. Axial support is provided by the four support rods, which run the entire length of the cask. After being loaded, the canisters are back-filled with dry helium. The canister provides confinement of the fuel, and biological shielding in the axial direction. For the 24 assembly canisters, axial shielding is accomplished by carbon steel shield plugs located at the top and bottom. The canisters used for fuel assemblies with control components and failed fuel have lead shield plugs.

The MP187 transport cask is a cylindrical cask that provides the biological shielding and structural support necessary to transfer and transport canisters containing PWR spent fuel assemblies. The cask is comprised of an inner shell, which is part of the containment boundary, and the outer shell, which provides an environmental barrier. Lead between the two shells provides gamma shielding. Neutron shielding material is outside the structural shell and is bound by a jacket of stainless steel. The containment vessel includes the cask inner shell, the ram access plug, the vent and drain ports, and the associated seals. Penetration of the containment vessel includes the ram access plug, the vent and drain ports, and the top cover plate. O-ring seals are used for containment. The preferred transportation seal material is a fluorocarbon elastomer. The seal has to be changed regularly. For criticality control, the MP187 basket contains fixed neutron absorbing panels. Impact limiters, placed at the ends of the cask during transport, are made of Polyurethane foam and aluminium honeycomb. The transport cask can be lifted using 113 metric tons capacity crane.

For storage, the canisters containing spent fuel are stored in the NUHOMS® -24P dry horizontal storage module. The storage module is a free-standing, prefabricated, reinforced concrete structure. It is designed to provide decay heat removal through passive convective cooling. The storage module provides shielding and physical protection of canisters from natural phenomena such as tornadoes, earthquakes, and floods. With this exclusion of a moderator in the storage mode, there is no potential for the fuel to approach criticality. Each rectangular module holds one canister. The modular storage units can be installed in the storage area as needed.

Operations: The MP187 is designed to be loaded with fuel by placing the appropriate canister into the transportation cask. The cask is filled with water, and placed into the spent fuel pool where for loading of the canister. Although demineralised water or pool water may be used to fill the canister, the annulus between the cask and canister has to use demineralised water to prevent contamination of the canister surface. Assemblies must be similar in terms of containing control rod components to match the canister design that is being loaded. After loading, the shield plug is emplaced and the cask is moved to a decontamination area. The shield plug facilitates reduced occupational dose and allows crews to position the remote welder to seal the canister. The cask outer surface is decontaminated. One of two canister lids is emplaced and welded to the canister using a remote welding machine. The canister is then vacuum dried and back-filled with helium. The second canister lid is then welded to the canister using the remote welder. The cask lid is bolted to the cask. The cask is then moved to the transport trailer and secured with necessary tie-downs. At this point, the cask is ready for transfer to on-site storage or transport off-site.

For transfer operations to on-site storage, the MP-187 containing spent fuel is moved from the fuel pool area to the storage module location. Upon arrival at the storage area, the MP187 is aligned with the storage module. The canister is pushed into the storage cask using the hydraulic ram. The hydraulic ram is equipped with a grappling device to facilitate insertion and eventual removal of the canister.

Licensing Status: The MP-187 was approved by the NRC for transport (10 CFR Part 71) in 1998. The NRC had certified the NUHOMS® -24P for storage (10 CFR part 72) in 1995. Transnuclear West is considering modifying the MP-187 to accommodate the 52B BWR canister.

A-6 THE TRANSNUCLÉAIRE TN24 SYSTEM

Model Name: TN24

Vendor: Transnucléaire, Paris, France

System Classification: The TN24 design has several versions that are *cask-based, dual-purpose* systems.

Contents: According to cooling time and fuel characteristics, the cask capacity varies from 24 to 37 PWR and from 52 to 97 BWR fuel assemblies. Table I. shows spent fuel capacities for various TN24 cask versions. Versions of the TN24 cask designs are available also for WWER spent fuel.

Hardware Description: The TN24 cask provides a means of interim storage followed by a possible transport to a reprocessing plant or to a centralised storage facility. The TN24 casks can transport and store spent fuel assemblies with a cooling time of 5 to 10 years. The casks comply with the IAEA Transport Regulations (1985 Edition as amended 1990). Compliance with the 1996 edition of the IAEA regulations can be certified when needed. Individual versions also meet the Storage Criteria in force in countries where they are used.
The TN24's are constructed of a thick forged steel wall, varying from 220 mm to 350 mm, and an outer layer of borated resin, varying 80 mm to 180 mm. The solid resin material is enclosed within an external steel envelope. The forged steel and borated resin provide gamma and neutron shielding. Longitudinal copper plates, embedded in the resin, connect the forged steel wall to the external envelope for heat transfer.

The cask is handled by means of trunnions bolted to the forged steel wall. Optionally, one or two pairs of trunnions, located at the side of the lid-end, can be used for lifting the cask. Another pair of trunnions is fitted at the lower end to allow its tilting to the horizontal position on transport equipment. During transport, the cask is protected at both ends by impact limiters which are shock absorbing covers designed to absorb energy developed during accident impacts. These covers consist of specially selected and oriented blocks of wood held in a circular stainless steel envelope. During storage, the impact limiting transport covers are removed, and the cask is placed vertically on a concrete pad.

Several sealing arrangements of two independent lids have been designed to provide containment. In all cases the sealing arrangement includes, as minimum, the following:

- For the transport configuration, two concentric seals are used to provide an internal space for leak testing.
- For the storage configuration, two concentric metallic seals provide containment barriers. The space between the seals is

> filled with pressurized helium that is continuously monitored to assure zero-release over a period of possibly 50 years. In addition, provisions have been made to allow, if desired, the installation and welding of the secondary lid or of a ternary lid. The primary lid is equipped with a single orifice to accommodate any of the operations that may be needed after the fuel assemblies have been loaded into the cask.

The cask cavity is fitted with a removable basket designed as a structural support for the fuel assemblies. It also provides criticality control. It consists of mechanically assembled partitions in borated aluminium defining an array of cells, one for each fuel assembly.

Operations: The cask is loaded under water in the reactor cooling pool using the established procedures used for standard transport casks. These operations include draining water from the cavity, venting, drying and backfilling with a neutral gas. This orifice is connected to a draining tube that reaches to the lowest part of the cavity. Its leak-tightness is also ensured by metallic gaskets and test devices are provided. Because this a cask-based system there is no need to open and transfer contents for storage or transport. During storage the two containment barriers are continuously monitored. Maintenance operations during the storage period are mainly limited to visual inspection and repainting when needed.

Licensing Status: The licensing status of various versions of the TN24 cask system are presented in Table II.

TABLE I. MAIN CHARACTERISTICS AND PERFORMANCE OF VARIOUS TN24 CASKS

	VERSION 1 24 P	VERSION 2 TN24 B	VERSION 3 TN24 D	VERSION 4	VERSION 5 TN24 XL	VERSION 6 TN24 G	TN 24 DH	TN 24 XLH	TN 24 SH	TN 97 L	TN 52 L
Fuel assembly type	PWR 17 × 17	BWR 8 × 8	PWR 17 × 17	PWR 17 × 17	PWR 17 × 17	PWR 15 × 15	PWR 17 × 17	PWR 17 × 17	PWR 14 × 14	BWR 8 × 8	BWR 8 × 8
Number of assemblies	24	52	28	32	24	37	28	24	37	97	52
Min. cooling time (years)	5	5	8	10	8	8	7	7	5	12	2.5
Average burnup (MW d/t U)	33 000	33 000	36 000	37 500	40 000	46 000	50 000	50 000	55 000	26 000	50 000
^{235}U enrichment	3.5%	3.5%	3.4%	3.5%	3.4%	3.8%	4.1%	4.25%	4.25%	4%	5%
Max thermal power (kW)	24	24	26	28	23	30	33	33	30	18.6	53
Loaded weight (transport conditions) t	93	95	114	115	112	135	124	123	105	135	118
Heavy metal weight (t U)	11	10	13	13	16	> 15	13	13	11	18	9.7

TABLE II. LICENSING STATUS OF VARIOUS TN24 CASKS

	TN 24 P	TN24 D	TN24 XL	TN 24 XLH	TN 24 DH	TN 24 SH	TN 97 L	TN 52 L	TN24 G
Licensing status	US NRC licence for Storage	French and Belgian licences for Transport, Belgian licence for Storage		Review of the application in progress					

A-7. THE TRANSNUCLEAR-NY TN-68 SYSTEM

Model Name: TN-68

Vendor: TRANSNUCLEAR-NY, White Plains, New York, USA

System Classification: The TN-68 is a *cask-based, dual-purpose* system.

Contents: The TN-68 is designed to hold 68 BWR assemblies with a maximum initial enrichment of 3.3% ^{235}U, maximum burnup of 40 000 MW·d/t U, and minimum cooling time of 10 years.

Hardware Description: The TN-68 is designed to meet the storage requirements of the country in which the system will be used. The cask is designed to meet IAEA Type B(U)F transport requirements, therefore, allowing its use virtually anywhere in the world. The cask is follows classical Transnuclear-NY and Transnucléaire design practises.

Operations: The TN-68 is a cask-based system, which does not require fuel transfer between storage and transport operations.

Licensing Status: The NRC is currently reviewing Transnuclear's application for spent fuel storage. The NRC's schedule projects completion and certification of the TN-68 storage cask in April 2000. The NRC has not yet developed a schedule for review and certification of the TN-68 cask for transportation.

A-8. THE BNFL FUEL SOLUTIONS TRANSTOR SYSTEM

Model Name: TranStor

Vendor: BNFL Fuel Solutions, California, USA

System Classification: The TranStor is a *canister-based, dual-purpose* storage and transport system.

Contents: The TransStor system is designed for 24 PWR assemblies with a maximum initial enrichment of 5% ^{235}U, maximum burnup depending on cooling is 30 GW·d/t U for 5 year cooled fuel and 40 000 MW·d/t U for a minimum cooling time of 10 years. The system can accommodate 61 BWR assemblies with a maximum initial enrichment of 5% ^{235}U, burnup limitations are the same as for PWR fuel. Permissible heat load: 26 kW for storage and 24 kW for transport

Hardware Description: The TranStor system consists of a welded stainless steel canister, a concrete storage overpack, and a stainless steel and lead transport overpack.

The welded stainless steel canister incorporates a carbon steel internal basket containing boron-containing plates for criticality control. The canister is shielded at the end to accommodate transfer operations. The storage overpack is a vented reinforced concrete construction. The transport overpack is a steel and lead sandwich construction. The transport overpack has a solid neutron shield. It uses a steel encased honeycomb material for impact limiters placed at the ends of the transport overpack during shipment.

Canister: 66" outside diameter × 192.25" length, material: stainless steel

Cask: 140" outside diameter × 295" length, weight ~260 000 lbs, material: stainless/lead/stainless construction with Hexcel impact limiters.

Concrete Storage Cask: 136" outside diameter × 225" length, material: reinforced concrete.

Operations: The TranStor is a canister-based design. The canister is loaded with fuel in the reactor spent fuel pool. Canistered fuel has to be transferred from the storage overpack to the transport overpack for transport.

Licensing Status: The TranStor system is currently being reviewed by the NRC for storage (10 CFR part 72), and for transport (10 CFR Part 71). The current projections for issuance of the Certificate of Compliance for transport is end of 1999, while for storage early 2000. BNFL Fuel Solutions acquired Sierra Nuclear Corporation in 1998. The time required for BNFL Fuel Solutions to acclimate to their newly acquired company may result in some adjustment to these schedule projections.

A-9. THE BNFL FUEL SOLUTIONS WESFLEX™ SYSTEM

Model Name: Wesflex™ system

Vendor: BNFL Fuel Solutions, California, USA

System Classification: The Wesflex™ system a *canister-based, dual-purpose* system.

Contents: The canisters are designed for 44 BWR or 21 PWR spent fuel assemblies.

Hardware Description: The four standardised components of the Wesflex™ system can be used in variety of ways to satisfy specific utility requirements. The Wesflex™ System flexibility with its standardised components allows it to accommodate a variety of plant conditions. Key elements of the system flexibility include:

(1) Standardised handling equipment supporting either PWR or BWR plants.

(2) Vertical or horizontal canister transfer capability.

(3) Compatibility with failed or un-failed fuel.

(4) Capability to store higher burnup and higher enriched fuel in use today.

(5) Ability to support off-site transportation without returning to the spent fuel pool.

The four standardised components of the system are:

Wesflex™ canisters, which contain the spent nuclear fuel assemblies during dry storage and transport and support the various modes of system operation. These canisters are comprised of a cylindrical pressure-retaining stainless steel shell and an internal basket to hold the SNF assemblies.

The storage overpack is designed for vertical storage. This provides radiation shielding, passive cooling and a structural barrier for the canister. It is designed for horizontal and vertical transfer of the canister with the transfer cask and horizontal transfer with the transportation cask. The storage overpack is constructed of reinforced concrete configured in three segments. The centre segment comes in two different standard lengths to accommodate two canister lengths. This modular design provides flexibility.

The Transportation overpack is used for off-site shipment of the canister. The transportation overpack and canister combination is designed as a Type B (U) fissile material package. It complies with IAEA and US Federal transportation regulations (10CFR71).

The on-site Transfer device is a right circular cylindrical vessel with lids on both ends. This cask is comprised of an inner liner and an outer structural shell with lead gamma shielding between them.

A neutron shield, consisting of an outer jacket that forms an annular cavity filled with water, surrounds the structural shell.

Operations: The transport overpack can be directly loaded with a canister from a storage cask or placed directly in a spent fuel pool and loaded with fuel. For plants with crane capacities of up to 100 tons, the neutron shield cavity is typically emptied for operations in the fuel pool and is filled after the loaded cask is placed in the decontamination area. If the crane is large enough, then the cavity may be filled, or partially filled, prior to its immersion in the spent fuel pool. For storage, canisters are transferred to on-site storage overpacks using the on-site Transfer device.

Licensing Status: The Wesflex™ system is currently being reviewed by the NRC for storage (10 CFR part 72). Since the company has been acquired when BNFL Fuel Solutions parent company British Nuclear Fuels plc bought Westinghouse Electric Co's commercial nuclear power business. The NRC issuance of a Certificate of Compliance for storage is delayed. The transportation application was submitted to the NRC in May 1998. The NRC has not developed a review schedule for transport certification (10 CFR Part 71) at this time.

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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 (MRS).(USA term) Storage of spent fuel or high level waste in facilities that provides 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.

ABBREVIATIONS

ASTM	American Society for Testing and Materials
BWR	boiling water reactor
CANDU	Canadian deuterium–uranium reactor — (pressurised heavy water reactor)
GCR	gas cooled reactor
ISFSI	independent spent fuel storage installation
LWR	light water reactor
Magnox	magnesium alloy cladding
MRS	monitored retrievable storage
MOX	mixed oxide fuel
MW d/t	megawatt days per tonne (of uranium or heavy metal)
MW d/t U	megawatt days per tonne of uranium
MW d/t HM	megawatt days per tonne of heavy metal (U, Pu and Th)
PHWR	pressurized heavy water reactor
PWR	pressurized water reactor
RBMK	Russian boiling water cooled graphite moderator channel reactor
SGHWR	steam generating heavy water reactor
WWER	Russian type of PWR, water cooled, water moderated power reactor

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