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FOREWORD

Spent fuel storage is one of the important stages in the nuclear fuel cycle and stands among the most vital challenges for countries operating nuclear power plants. Continuous attention is being given by the IAEA to the collection, analysis and exchange of information on spent fuel management. Its role in this area is to provide a forum for exchanging information and for co-ordinating and encouraging closer co-operation among Member States. Spent fuel management is recognized as a high priority IAEA activity.

In 1997, the annual spent fuel arising from all types of power reactors worldwide amounted to about 10 500 tonnes heavy metal (t HM). The total amount of spent fuel accumulated worldwide at the end of 1997 was about 200 000 t HM of which about 130 000 t HM of spent fuel is presently being stored in at-reactor (AR) or away-from-reactor (AFR) storage facilities awaiting either reprocessing or final disposal and 70 000 t HM has been reprocessed. Projections indicate that the cumulative amount generated by 2010 may surpass 340 000 t HM and by the year 2015 395 000 t HM. Part of the spent fuel will be reprocessed and some countries took the option to dispose their spent fuel in a repository. Most countries with nuclear programmes are using the deferral of a decision approach, a 'wait and see' strategy with interim storage, which provides the ability to monitor the storage continuously and to retrieve the spent fuel later for either direct disposal or reprocessing. Some countries use different approaches for different types of fuel. Today the worldwide reprocessing capacity is only a fraction of the total spent fuel arising and since no final repository has yet been constructed, there will be an increasing demand for interim storage.

The present survey contains information on the basic storage technologies and facility types, experience with wet and dry storage of spent fuel and international experience in spent fuel transport. The main aim is to provide spent fuel management policy making organizations, designers, scientists and spent fuel storage facility operators with the latest information on spent fuel storage technology under wet and dry conditions.

The IAEA wishes to thank the working group which prepared this publication and all those who contributed to its preparation through their comments and participation in discussions. The IAEA officer responsible for this publication was P. Dyck of the Division of Nuclear Fuel Cycle and Waste Technology.

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1. INTRODUCTION

1.1. Background

The IAEA conducted a survey between 1978 and 1980 to collect and summarise information on extended water pool storage in which there was increasing interest. Many utilities could perceive a shortage of storage capacity and only a limited amount of reprocessing capacity. The results of this survey were published in 1982 in Ref. [1].

In 1986, the IAEA considered it was timely to conduct a survey on the emerging field of dry storage and to update the data on wet storage. A considerable amount of R&D was being conducted in the field of dry storage. The results of the survey were published in 1988 in Ref. [2] and gave a detailed assessment of dry storage technology and the associated R&D.

In the period since 1986 very significant progress has been made in dry storage technology and a number of commercial facilities have been commissioned. There have also been a number of large pools constructed but these have largely been central facilities associated with reprocessing facilities or as interim storage for disposal.

The purpose of this report is to collect and describe the worldwide experience that has been gained over the last decade with the storage of spent nuclear fuel. There is no intention to give guidelines regarding the selection of technologies for storage of spent nuclear fuel, as different proven technologies are now available. The selection process has to take into account different criteria (e.g. quantity of fuel, cost of the technology, fuel management options, and individual circumstances) resulting in an optimum system in terms of technology, economics, timetable etc.

International experience with the storage of spent fuel is described in Sections 3 and 4 for wet and dry storage, respectively. Section 5 covers the subject of transportation of spent fuel as the Survey is considered to be a convenient way of incorporating experience in transport.

1.2. Scope

The scope of this report is to review the current technology for storage of spent fuel from power reactors. Storage of fuel from research reactors is not considered. The information and data included has been derived directly from Member States where possible, from a review of previous documentation and from published documents from various sources made available to the IAEA.

Comprehensive information is not available on the storage of spent nuclear fuel in at-reactor (AR) operational pools. Many of these are now designed for plant lifetime arisings at new NPPs and can be considered as a form of interim storage. The spent fuel pool inventory can be obtained by inference from total fuel arisings and the quantity sent for reprocessing. Rod consolidation, as a means of increasing spent fuel storage capacity, is referred to briefly as this technique has not been taken up in spite of intense interest in the 1980s. Information on this technique can be found in Annex G of Ref. [2].

Away-from-reactor (AFR) spent fuel storage is dealt with in some detail and a distinction is made between storage on the reactor site (RS) and storage off site (OS).

The survey was conducted by a group of international consultants and presented to a larger advisory committee for review. Three consultants worked to finish the draft report in December 1997. In 1998 some additional data and information were included.

2. BASIC STORAGE TECHNOLOGIES AND FACILITY TYPES

2.1. Introduction

Virtually all power reactors have some form of spent fuel pools associated with the reactor operations. AR has, in recent years, been used to full capacity in some cases, threatening the continued operation of the power plant. Recent designs of reactors have in fact now incorporated pools that can accommodate lifetime arisings over periods of up to 40 years. However, most older operational plants, due to their limited AR capacity have necessitated the development of AFR storage.

Two technologies have been developed for AFR storage. Initially the storage method was wet but in recent decades dry storage techniques of varying types have been developed. AFR storage can be considered in two categories. The first is where additional interim storage capacity is constructed at the reactor site (RS) but largely or entirely independent of the reactor and its AR pool. This AFR (RS) storage can be wet in the form of secondary or additional pools or most often in the form of dry storage facilities which may or may not have capability for off-site transport. It has been suggested that some of these AFR (RS) facilities may stay operational well beyond the life of the power plant (up to 50 or 100 years).

The second category of AFR storage is off the reactor site (OS) at an independent location. A large proportion of this AFR (OS) capacity is in the form of pools at reprocessing plants particularly in France, the UK and The Russian Federation. AFR (OS) interim storage can also be centrally located at a selected power plant complex and receive fuel from other power plants. So far there are no AFR (OS) facilities at proposed repository sites. By far the majority of AFR storage capacity is wet (approx. 92%) with only the remaining 8% in dry storage.

Both wet and dry storage technologies have to address the following requirements:

(1) Fuel cladding integrity should be maintained during handling and exposure to corrosion effects of the storage environment

(2) Fuel degradation during storage should be prevented through providing adequate cooling in order not to exceed fuel temperature limits.

(3) Subcriticality of the spent fuel is to be maintained under normal and accidental conditions.

(4) Radiological shielding of the spent fuel should protect plant operators, the public and the environment from receiving radiation doses in excess of regulatory limits.

(5) Environmental protection should be assured by minimising the release of radioisotopes.

(6) Fuel retrievability must always be available.

2.2. Wet storage

As already discussed, wet storage is implemented in AR and AFR storage facilities.

AR facilities are essentially storage pools in which spent fuel is kept under water following discharge from the reactor. Most AR storage pools have been built at the same time as the reactor and are fully integrated with the reactor operation. Thus experience with AR wet storage is available for more than 30 years and is not described in this section.

There is a variety of AFR wet storage facilities in use. Some provide extended operational capacity to reactors once their AR pool is full of spent fuel, and may or may not be built at reactor site.

A typical AFR wet storage facility may have the following features:

- Cask reception, decontamination, unloading, maintenance and dispatch;
- Underwater spent fuel storage (pool);
- Auxiliary services (radiation monitoring, water cooling and purification, solid radioactive waste handling, ventilation, power supply etc.).

Spent fuel is received (either wet or dry) at the ARF facility contained in a transport cask. Fuel may be removed either assembly by assembly or in a multi-element canister. Two types of cask unloading method are in operation: wet and dry. The wet unloading, being the initially developed type for LWR spent fuel, is performed under water. A hot cell type facility is used for dry unloading.

The storage pool is a reinforced concrete structure usually built above ground or at least at ground elevation, however, one wholly underground facility is in operation. Some early pools were open to the atmosphere, but operational experience and the need to control pool water purity has resulted in all pools now being covered. The reinforced concrete structure of the pool, including the covering building, needs to be seismically qualified depending upon national requirements.

Most pools are stainless steel lined, some are coated with epoxy resin based paint. However, there has been experience with degradation of the latter after a number of years. A further option is for the pond to be unlined and untreated. In some situations the pool may be stainless steel lined or epoxy treated only at the water line or at other locations.

Regarding unlined and untreated pools, properly selected and applied concrete proved to have negligible corrosive ion leaching and permeability to water.

The pools are filled with deionized water with or without additive addition depending on the type of fuel to be stored and the adopted method of treatment. The water is either a fixed quantity or a once through pond purge. Water activity levels are maintained ALARA (as low as reasonably achievable) by either in-pool or external ion exchange systems or by limiting activity release to the bulk pool water.

Leakage from the pool is monitored, either by means of an integrated leakage collection system or via the interspace in pools with two walls. In both cases any recovered pool water may be cleaned up and returned to the main pool.

In addition to the control of activity by ion exchange or purge, some pools are operated with an imposed chemical regime. This is for pH control, maintaining boron levels for criticality control where necessary, and the maintenance of acceptably low levels of aggressive anions such as chloride and sulphate to minimise fuel degradation. Maintenance of good water chemistry provides good water clarity and usually prevents the occurrence of micro-biological organisms. If these do occur, they are treated with specific chemical dosing.

There are also two methods in regular use allowing fuel to be isolated from the bulk pool water; namely by using single or multi-element bottles, or storage containers.

Subcriticality was originally maintained for LWR spent fuel (assumed to be fresh) by spacing within the storage racks or baskets. However with the need to store greater quantities of fuel, higher storage density has been achieved by the introduction of neutron absorbing materials in storage racks and baskets such as boronated stainless steel, boral or boraflex.

The period of time that spent fuel resides in a pool varies between pools (AR and AFR) and the requirements of the overall spent fuel management system. Some Zircaloy clad fuel has been wet stored satisfactorily for over 40 years.

The survey results of the AFR wet storage experience are given in Table I. The number of facilities and total design capacities are given along with the approximate current inventories as of 1997.

TABLE I. SUMMARY OF WORLDWIDE AWAY-FROM-REACTOR (AFR) WET SPENT FUEL STORAGE

Member State	AFR pools in operation		
	Number of facilities	Design capacity t HM	Current inventory t HM
Argentina	1	1100	766
Belgium	1	1000	35
Bulgaria	1	600	356
Finland	2	1450	700
France	4	14 500	9159
Germany	1	560	526
India	1	27	27
Japan	3	4300	3500
Russian Federation	6	12 960	6046
Slovakia	1	600	523
Sweden	1	5000	2703
Ukraine	1	2000	1695
United Kingdom	4	10 350	7031
United States of America	1	780	700
TOTAL	28	55 227	33 767

2.3. Dry storage

Development work and progress on a variety of dry storage technologies has been intensive over the last decade. For practical and economic reasons, various dry spent fuel storage technologies were developed to meet specific requirements of different reactor fuels; e.g. maximum allowable cladding temperature, cover gas environment (air, CO_2, or helium). Dry storage facilities operating or under construction in the Member States are listed in Table II, as of end of 1997.

Initially dry storage were single purpose systems. They only provided AFR (RS) storage (with one exception represented by Wylfa Dry Stores, which is also an AR facility) without the capability or authorisation for eventual transport off site (without rehandling and reloading the fuel into transport casks). Vaults, silos and non-transportable casks are single purpose systems. With continuing development of dry storage technology, it was recognised that casks and containers for encapsulating the fuel could perform multiple functions. Dual purpose casks were developed (e.g. CASTOR cask in Germany, TN 24 in Belgium and the NAC-STC in USA) which allowed storage and transport to and from a storage facility without rehandling of fuel assemblies. The fuel containers of some storage systems may be used for transport and/or final disposal. These are often referred to as dual- or multi-purpose systems, respectively.

TABLE II. SUMMARY OF WORLDWIDE DRY SPENT FUEL STORAGE

Member State	Number of facilities	Design capacity t HM	Current inventory t HM
Argentina	1	200	64
Belgium	1	800	142
Canada			
Operating	7	8567	1930
Construction	1	14 500	-
Czech Republic	1	600	232
France	1	180	180
Germany			
Operating	3	7768	58
Construction	1	585	-
Hungary	1	162[1]	54
Japan	1	73	73
Republic of Korea			
Operating	1	609	609
Construction	1	812	0
Lithuania	1	419	0
Ukraine	1	50	0
United Kingdom	1	958	680
USA			
operating	10	4700	1270
construction	6	2155	
TOTAL	39	43 138	5292

2.3.1. Vaults

Vaults consist of above- or below-ground reinforced concrete buildings containing arrays of storage cavities suitable for containment of one or more fuel units. Shielding is provided by the exterior structure. Heat removal is normally accomplished by forced or natural convection of air or gas over the exterior of the fuel containing units or storage cavities, and subsequently exhausting this air directly to the outside atmosphere or dissipating the heat via a secondary heat removal system.

Typical features of vaults are their modularity, which facilitates incremental capacity extension, separated shielding and containment functions, capability for containment monitoring, and a vertical fuel loading methodology.

[1] Phase 1.

Spent fuel is received (either dry or wet) at a vault facility using transfer or transportation casks. Spent fuel is removed from the transfer or transportation casks, prepared for storage if needed, and placed in a metal storage tube (single fuel element) or a storage cylinder (single or multi-element canister) which is housed within a concrete storage cavity in the vault structure. The storage tubes or storage cylinders are sealed and may be backfilled with an inert gas to improve heat transfer from the fuel and prevent oxidation of spent fuel while in storage. They are usually fitted with connections to a continuous or periodic monitoring system.

In vaults using metal storage tubes the transfer of uncontainerised fuel assemblies is carried out, following drying if required, one by one directly into their storage location. Typical components of this type of storage facility are the vault modules, the fuel handling machine operating in the charge hall, the cask receiving area and the auxiliary facilities (areas for plant control, maintenance, services, offices etc.). Examples are the MVDS facility at Paks in Hungary and the Magnox Dry Storage Facility at the Wylfa reactor in the UK.

Vaults using storage cylinders receive the fuel already sealed in containers (the MACSTOR system CANSTOR application at Gentilly 2 NPP in Canada, the CASCAD facility in France, or Fort St. Vrain MVDS in the USA). These types of vault facilities use a transfer cask handled by crane. The container transfer into the storage cylinder is either performed remotely (CASCAD) or with operator assistance (Fort St. Vrain and Gentilly 2).

2.3.2. Container (cask and silo) systems

A container is a receptacle to hold spent fuel to facilitate movement and storage or eventual disposal, according to the IAEA glossary of spent fuel terms [3]. Metal casks, concrete casks and silos are variations of the container storage systems. There is a large variety of container system designs used for storage of spent fuel.

The following features are common to all cask and silo designs:

Casks or silos are modular in nature. These systems are sealed systems with no radioactive release from the casks or silos during storage. A storage cask or silo provides shielding and containment of the spent fuel by physical barriers which may include the metal or concrete body and metal liner or metal canister and lids. They are usually circular in cross-section, with the long axis being either vertical or horizontal. Fuel position is maintained inside a storage basket which may or may not be an integral part of the container. Heat is removed from the stored fuel by conduction or natural convection to the surrounding environment. Casks or silos may be enclosed in buildings or stored in an open area.

A cask or silo storage facility may include cask handling equipment, fuel handling equipment, decontamination equipment, radiation protection, and leak tightness monitoring equipment. Cask or silo storage facilities may not be independent of reactor services and may depend on cask handling, fuel handling and decontamination equipment from the reactor.

Some features that may vary between the technologies are structural material, transportability (dual or multi-purpose), fuel loading orientation, storage orientation (horizontal or vertical). Individual systems may or may not be monitored for leak tightness.

2.3.2.1. Metal casks

Metal casks are massive containers used in transport, storage and eventual disposal of spent fuel. The structural materials for metal casks may be forged steel, nodular cast iron, or a steel/lead sandwich structure. They are fitted with an internal basket or sealed metal canister which provides structural strength as well as assures subcriticality. Metal casks usually have a double lid closure system that may be bolted or seal welded and may be monitored for leak tightness.

Metal casks are usually transferred directly from the fuel loading area to the storage site. Some metal casks are licensed for both storage and off-site transportation. Fuel is loaded vertically into the casks which are usually stored in a vertical position.

Metal casks used in a number of countries such as Germany, the USA, the Czech Republic and Switzerland; Transnucléaire's TN-40 metal casks used in the USA; Westinghouse MC-10 cask used in the USA; and Nuclear Assurance Corporation's metal cask designs used in the USA and Spain.

2.3.2.2. Concrete casks

Concrete casks are moveable structures with one storage cavity. They are used in storage, and in some cases, transport of spent fuel. Structural strength and radiological shielding are provided by reinforced regular or high density concrete.

Concrete cask systems may use sealed metal canisters housed inside the concrete storage cask to contain spent fuel. The metal canister may be cooled by natural convection of the ambient air and use a double lid closure system.

Sealed metal canisters may be contained in an on-site transfer cask for loading spent fuel from the fuel loading station and for transfer to the concrete storage cask.

Spent fuel may also be loaded directly into a concrete cask in the fuel loading station and the concrete cask would be transferred directly to the storage site. Some sealed metal canisters may be licensed for transportation as part of an off-site transportation package.

Alternatively, concrete cask systems may use a metal liner in the cask cavity to contain spent fuel and a single lid closure system. Heat transfer may take place solely by conduction through the concrete structure.

Concrete casks that rely on conductive heat transfer have more thermal limitations than those using natural convection air passages.

Fuel is loaded vertically into the concrete casks and the concrete cask systems are stored in a vertical orientation.

Concrete casks use single or double lid closure systems, are welded closed, and tested for leak tightness. Concrete cask systems may or may not be monitored for leak tightness.

Examples of vertical concrete casks include Sierra Nuclear's VSC cask; and Ontario Hydro's Pickering concrete dry storage container which is also designed for off site transport.

2.3.2.3. Silos

Silo systems are monolithic or modular concrete reinforced structures. The concrete provides shielding while containment is provided by either an integral inner metal vessel (liner), which can be sealed after fuel loading, or by a separate sealed metal canister. In silos, spent fuel may be stored in vertical or horizontal orientation. Fuel loading into silos always takes place at the storage site.

A typical example of a silo system is AECL's concrete canister, which is built on-site using regular reinforced concrete and is fitted with a steel inner liner. Spent fuel is transferred in increments within sealed baskets using a shielded transfer cask and loaded vertically. Once loading operations are complete, a closure shield plug is placed and welded to the inner liner to provide additional containment.

The NUHOMS storage system is an example of a horizontal concrete silo system. Fuel is loaded vertically into metal canisters which are stored in a horizontal orientation inside concrete storage modules. The sealed metal canister is contained in an on-site transfer cask for loading spent fuel from the fuel loading station and for transfer to the horizontal concrete storage module. The metal canisters are fitted with a double lid closure system, which following welding is tested for leak tightness. Some sealed metal canisters may be licensed for transportation as part of a transportation package. The system is not monitored for leak tightness.

3. EXPERIENCE WITH WET STORAGE OF SPENT FUEL

3.1. Introduction

This section outlines and documents the experience on wet storage.

Storage pool experience exists for both AR and AFR technologies. While AR pool storage is common to all reactors in order to provide cooling following discharge from the reactor, AFR pool storage is an option for additional spent fuel storage prior to disposal or reprocessing. The information on AR pools is not complete but some representative examples from some Member States have been included. The quantity of fuel storage in AR pools is difficult to determine because the inventory varies with reactor refuelling cycles and the amount transferred to AFR storage and reprocessing. In general, AR pools are never operated to full design capacity because of a need to provide some buffer storage capacity for operational reasons. Since the last survey completed in 1988, approximately 40 power reactors with related AR storage pools have been commissioned. The variety of solutions for AFR pool storage gives a wide range of experience. AFR pool facilities are subdivided into pools in operation, under licensing and construction.

Positive experience on the storage of spent fuel in pools has been collected over more than 30 years. It can now be predicted that Zircaloy clad fuel integrity will be maintained even after 50 years of wet storage. Monitoring and surveillance have confirmed that adherence to the specified pool water chemistry is essential to prevent fuel cladding degradation during pool storage for all types of spent fuel. Even if the fuel assembly contains defects incurred during irradiation, it can be stored in pools for extended periods. It may even be that a pool component could, in some cases, be more life limiting than the fuel assembly itself.

In conclusion it can be stated, that wet storage of spent fuel is a proven technology, which can meet all storage requirements through proper engineering. The experience, which has been reported using different facilities, is described in this section.

3.2. At-reactor (AR) storage pools

At-reactor spent fuel storage pools are either within the reactor building or in an adjacent spent fuel building which is linked to the reactor by a transfer tunnel. Access to the fuel in the storage pool is usually by means of immersing a cask in the pool, loading it with fuel and then removing the cask for lid closure, decontamination and transport. A recent development, unique to France, is a cask loading concept with bottom access ports from the pool for fuel transfer into the cask. The advantages of this design are that contamination of the external surface of the flask by immersion in the pool is avoided, and also the requirement to lift the flask (empty and loaded) between the inlet/outlet location and the pool and a heavy duty crane is no longer needed. There are some cases, for example at gas cooled reactors and at Sellafield in the UK, where spent fuel is loaded into casks in a dry shielded cave and the cask is never immersed in water.

The capacity of AR wet storage pools varies between countries and is a function of the overall fuel management strategy at the time the facility was built. The extremes are modest storage capacity for short term buffer storage before transport off-site, to capacity sufficient to store a significant proportion of the reactor lifetime arisings. The latter is generally the result of the deferral by a country on decisions for reprocessing or disposal. In addition there will be a requirement to reserve space for full or part core inventory. This capacity for whole core discharge would be separately identified as part of plant operations and is not considered part of AR interim spent fuel storage. In addition, new fuel or partly utilised fuel could be temporarily stored in the pool as part of plant operating inventory and would reduce the net capacity available for AR storage.

All AR storage pools require some form of water purity and chemical control to minimise the effects of corrosion and the build up of activity in the water. This is potentially important for long periods of storage and would be augmented by data from research and inspection. The majority of fuel in wet storage is from water cooled reactors and is clad in zirconium based alloy. The experience has been good and potential mechanisms for corrosion or degradation are understood. With water reactor fuel, removal from the transport flask or other container can sometimes result in release of active particulate material (crud) into the pool water. This depends largely on the fuel history in the reactor.

AR wet storage summarised in Table III.

3.2.1. Canada

Experience with wet storage of spent fuel goes back to the early 1950s. Canadian in-pool wet storage technology was initially developed at Chalk River Laboratories. The same technology is applied to store fuel from CANDU prototype and power reactors.

In Canada neither recycling nor reprocessing are planned for spent CANDU fuel. A permanent disposal system is currently being developed. Consequently, AR interim wet storage facilities are expected to remain operational until fuel shipment to the disposal centre is complete (around 2035).

CANDU reactors have a variety of pool designs and storage capacity. Single unit stations are usually provided with a single pool. The storage capacity is based on 10 years of reactor operation.

Ontario Hydro's multi-unit stations usually have primary and secondary storage pools. The water filled, reinforced concrete pools are built in and out of ground and are fitted with epoxy or stainless steel liners.

Spent fuel bundles are horizontally stored in the pool in receptacles of different designs. Storage trays accommodate up to 24 bundles in a single layer. Trays are stacked approximately 19 high in groups of two to four. Each group of stacks is provided with a cover that is held in place by vertical rods that retain the stacks together to resist seismic loads and for safeguards reasons.

At Ontario Hydro's Pickering and Darlington reactor sites, spent fuel is stored in rectangular modules containing 96 fuel bundles. The modules are equipped with wire mesh along the sides and are stored in frames for seismic restraint and safeguards purposes.

TABLE III. INTERNATIONAL AR WET STORAGE EXPERIENCE

Country	Type of reactors	Number of pools	Capacity, t HM	Inventory, t HM	Operating periods
Argentina	PHWR	2	1450	1200	1975 -
Bulgaria	WWER-440	4	480	121	1974 -
	WWER-1000	2	520	266	1988 -
Canada	CANDU	10	31 407	22 555	1971 -
China	PWR	3		177	1991 -
Czech Rep.	WWER	4	480	306	1985 -
Finland	BWR/WWER	4	666	251	1978 -
France	900 MW PWR	34	5870	4187	1979 -
	1300 MW PWR	20	5420	1608	1985 -
Germany	Operating PWR	13	3176	2011	1975 -
	Operating BWR	6	1385	821	1977 -
	Shut down	8	526	-	1968 -
Hungary	WWER	4	480	350	1982 -
Italy	LWR	3	253	253	1981 -
Japan	PWR	20	6460	2070	1970 -
	BWR	23	8410	3050	1970 -
	Others	2	280	120	1966 -
Korea, Rep.	PWR/PHWR	12	5875	3072	1978 -
Lithuania	RBMK	2	2093	1380	1984 -
Mexico	BWR	2	984	80	1991 -
Romania	CANDU	1	940	100	1996 -
Russian Federation	WWER-440	6	480	320	1966 -
	WWER-1000	7	1200	460	1978 -
	RBMK	11	3560	2700	1975 -
Slovakia	WWER	4	480	150	1981 -
Slovenia	PWR	1	410	205	1984 -
South Africa	PWR	2	670	392	1984 -
Spain	PWR/BWR	9	3820	2000	1969 -
Sweden	PWR/BWR	12	1500	730	1973 -
Switzerland	PWR/BWR	5	705	150	1970 -
Ukraine	WWER-440	2	240	92	1980 -
	WWER-1000	11	2170	1156	1982 -
	RBMK	3	600	380	1977 -
UK	Magnox	20	1500	330	1956 -
	AGR	14	230	154	1976 -
	PWR	1	936	30	1995 -
USA	Operating LWR	110	59 000	38 343	1957 -
	Shutdown LWR	8	1700	957	1957 -

Fuel handling is currently a manual operation in most instances. Fuel loading into the storage modules is performed remotely underwater. Special tools are used to manipulate bundles and trays from a travelling bridge over the pool.

Three CANDU prototype reactors are decommissioned including the pool facilities. At Douglas Point, the stainless steel lined pool has been completely decontaminated. All auxiliary systems are kept operational. At Gentilly-1, the epoxy lined pool is completely clean following drainage and removal of contaminated concrete surfaces. The entire area is converted into office space. The NPD reactor pool (stainless steel lined) is drained, partially decontaminated and kept under surveillance.

3.2.2. France

The back end of fuel cycle policy implemented in France (based on reprocessing, plutonium and uranium recycling through MOX and RepU fuels), has resulted in the French utility EDF establishing a management practice to reprocess the UO_2 fuels first (after a suitable cooling period) while storing the MOX and RepU spent fuels for a period of time not defined yet.

AR storage capacities are needed at each reactor site in order to secure a cooling period for discharged fuel awaiting transportation to the reprocessing plant.

3.2.3. Germany

The German spent fuel management policy was primarily based on reprocessing until 1994. Reprocessing was mandatory by German atomic law. Exceptions were permitted if reprocessing was not available or not economically feasible e.g. in the case of the HTR pebble bed spent fuel.

A law was passed in 1994 by parliament which allowed direct disposal as an equivalent option. The choice is left to the utilities operating the NPPs.

All NPPs are equipped with AR storage pools. The technical design is in accordance with proven international standards. The capacity and geometry vary from plant to plant. More recent plants tend to have larger storage capacity in order to improve the flexibility of spent fuel management.

3.2.4. Japan

Most of the spent fuel in Japan is stored in AR pools and amounts to 5200 t HM. This is only about 1/3 of the total AR design capacity. Some of the fuel, amounting to over 6800 t HM including PWR, BWR and Magnox, has been sent for reprocessing in the UK and France. 1000 t HM has been sent to the Tokai facility. A small amount has been put into a new cask storage at Fukushima and amounts to 73 t HM. Some AR facilities currently have very small quantities of fuel in storage or none.

Experience with wet storage of spent fuel has been good and extends over about 31 years (1966–1997). No defected fuel has been reported nor any serious incidents with storage facilities.

Breeder reactor fuel has also been stored since 1996 and no problems have been reported. Currently 88 t HM of fast reactor fuel is in AR storage.

3.2.5. *Russian Federation*

Following is a brief description of standard AR facility constructions and operation.

The WWER-440 AR storage period is normally up to 3 years. The storage pool is situated in the main hall of the reactor unit in the vicinity of the reactor.

The storage capacity of standard AR pools at WWER-440 reactors is designed for 2 full cores. One half (about 350 assemblies) was originally designed for normal reloads and the upper racks are used for emergency discharge from the reactor. Fuel is stored in racks at a spacing of 225 mm in a triangular arrangement. (Some WWER-440 pools in other countries went through a reracking which resulted in doubling the capacity).

The construction of the AR storage pool for WWER-1000 fuel is somewhat different than for WWER-440 reactors. The storage pool with a total volume of 1100 m^3 consists of 3 bays. The first bay and one half of the second bay are occupied by the rack for spent fuel, while the other half of the second bay is used for storing new (unirradiated) fuel. The third bay is a reserve for emergency core discharge. The total capacity of the pool is designed on the requirement to accommodate 2.5 full cores (three yearly discharges in a 2 year fuel cycle plus one emergency core discharge totalling 165 t HM). Fuel is stored in racks with a spacing of 400 mm in a triangular arrangement.

The AR storage pool for RBMK-1000 fuel is situated in the main reactor hall in the vicinity of the reactor. The pool consists of 2 independent bays, each having the volume of 750 m^3. The design capacity of each bay is for 850 fuel assemblies stored in separate cans filed with demineralised water. Reloading operations are performed by a special reloading machine at the operating reactor. Spent fuel placement in a storage position is by means of a 1t hoist which has a restricted lifting height to ensure that the fuel remains under a shielding water layer at all times. The loaded cans are hung between beams spaced at 250 mm at the level of the metal deck of the pool hall. Fuel assemblies are spaced at 160 mm.

The BN-600 fuel is also stored in water pools. Reloading operations are performed at the shut - down reactor during planned maintenance and repair works. A dry reloading mode is used, with the reloading equipment located in the reactor vessel and in reloading boxes or containers. Inert gas atmosphere in the containers provides safe reloading of fuel with traces of sodium coolant.

3.2.6. United Kingdom

In the UK no problems have been experienced with interim storage of AGR stainless steel clad fuel in station spent fuel storage pools. Fuel is stored in open topped skips and as it is currently all committed to reprocessing, the storage period is not long usually less than a year but cooled for about 120 days before transport. The pools have reserve capacity for a whole core discharge. The pools have the usual capability for recirculation, cooling and filtration. Magnox fuel storage in AR pools is also satisfactory with the fuel elements stored in open topped skips. Magnox cladding cannot dwell in water for long periods and the fuel is usually shipped for reprocessing after a cooling period of about 120 days.

As with its American counter parts of more recent design, Sizewell B has been designed to minimise the stations dependency on the back end of the nuclear fuel cycle. Initially designed to accommodate up to a thousand fuel assemblies approximately 18 years of operation, capacity is currently being reviewed by investigation of fuel densification systems. Sizewell B was commissioned in 1995 and has discharged its first fuel to the AR pool.

3.2.7. USA

The majority of spent nuclear fuel arisings in the USA are stored in at-reactor spent fuel storage pools. At the end of 1997, 110 operating and 9 shutdown reactors had approximately 35 500 MTU of spent nuclear fuel in storage in operating reactor AR pools and 1000 MTU in shutdown reactor pools. Approximately 1300 MTU of spent fuel is stored in dry storage facilities.

The current licensed AR wet storage capacity in the USA is approximately 210 000 spent fuel assemblies, corresponding to approximately 61 000 MTU. However, the excess of total maximum capacity over current total inventory does not reflect the shortage of pool storage capacity that occurs in individual reactor cases. For example, shutdown reactor pools had a capacity of 5800 assemblies or approximately 1700 MTU. The majority of reactor spent fuel storage pools have been reracked once, and some several times, to increase in-pool storage capacity. Reracking of spent fuel storage pools is now only available to a small remaining number of US reactors as a means of increasing storage capacity [4].

Currently, 14 reactors have exhausted AR pool capacity and have had to construct dry storage facilities. Of the 110 operating reactors in the USA, approximately 27 reactors are projected to run out of in-pool spent fuel storage capacity by 1998.

3.3. Away-from-reactor (AFR) storage pools

Away-from-reactor pools constitute the largest volume of interim spent fuel storage. They are divided into pools at the reactor site (RS) and pools away from the reactor site or off site (OS). The distinction between the RS and OS categories is clear but this is not always as clear in classifying At-reactor and Away-from-reactor storage pools. True AFR(RS) pools are independent of the reactor and all its services and can continue to operate after the reactor has been finally shut down and decommissioned. There are pools, however, that are truly AFR types but rely extensively on reactor services such as cooling water and water treatment, ventilation and electrical supplies (e.g. Loviisa, Pickering). In fact, nearly all AFR(RS) pools are dependent on the reactor systems to some extent and certainly for staff and operating management. When reactors are shut down, special arrangements will have to be taken because it could be impractical or uneconomic to continue to operate costly reactor derived services if the fuel must remain in storage for long periods. Many of the AFR(RS) facilities have been provided at older power plants because these AR pools are often not large nor sized for lifetime arisings.

AFR(OS) interim storage facilities on the other hand are most often associated with reprocessing plants (La Hague, Sellafield, Cheljabinsk and Rokkasho Mura in the future) but sometimes for direct disposal (e.g. CLAB in Sweden).

3.3.1. Bulgaria

Bulgaria has one AFR(RS) facility located at Kozloduy NPP.

Proposed in 1974 as an alternative to spent fuel transportation to the USSR, construction of Kozloduy AFR(RS) facility did not began until 1982. The first fuel receipts to this facility were made on the 28^{th} February 1990.

The facility was the first of a proposed common design for an AFR at the Soviet built reactors to store WWER fuel and it comprises of fuel receipt, unloading and storage areas. The current design is slightly different from the other facilities in that respect that this was meant for the long-term storage of 168 baskets (4920 assemblies, ~600 t HM) of spent fuel from the sites four WWER-440 and two WWER-1000 reactors; to be loaded over a period of ten years.

After cooling for 3 years in the AR storage pools, the assemblies are transported to the AFR(RS) by an on-site transport container and a specialised trailer unit. Yearly receipts are at the rate of 25 transport baskets comprised of 4 baskets or 120 fuel assemblies per WWER-440 reactor and 9 baskets or 108 fuel assemblies from the two WWER-1000 units.

The storage area is made up of three operational water bays and a contingency bay to allow for preventive maintenance/provision against major in-bay failure. To afford this storage bays can be isolated from the one another by hydraulic seals/gates, and leak monitoring equipment is provided at the pool lining inter space. All pools are doubled lined with carbon and stainless steel.

Spent fuel from the WWER-440 reactors is stored in transport baskets (containing 30 fuel assemblies (FA) with intact fuel cladding or 18 bottled fuel assemblies where the cladding is leaking). WWER-1000 spent fuel is stored in transport baskets. The capacity of the baskets is: 12 intact fuel assemblies, or 6 bottles of failed fuel.

Storage temperature is maintained below 45°C in the spent fuel compartments which are provided with automatic continuous monitoring of feedwater, overflow, and permissible high and low water levels.

3.3.2. Finland

Finland has two AFR(RS) facilities located at Loviisa and Olkiluoto NPPs.

3.3.2.1. Loviisa AFR(RS)

Phase 1 of the Loviisa AFR(RS) was brought into operation in 1980 increasing the storage capacity of the unit 1 NPP to take account of a need for increased fuel cooling from 3–5 years prior to transport/reprocessing in the Soviet Union. The AFR was later extended to 1984 (phase 2) to provide additional storage capacity for unit 2 of the NPP (see Fig. 1).

The two phases of the AFR were built alongside one another three metres below ground. The services for each phase are provided by the associated unit of the NPP.

Phase 1 comprises two parallel storage bays, a loading bay, a decontamination well for casks, a dry burial ground for control rods, and a lid deck under which the cask transport vehicles are located. The storage bays are connected to the loading bay by gates and each bay has a capacity for up to eight fuel baskets. A fuel basket can accommodate 30 fuel assemblies with a hexagonal spacing of 225 mm. Thus the total storage capacity is 480 assemblies (57.6 Mg U).

Phase 2 comprises three storage bays in a row, a loading bay, a decontamination well for the cask and lid deck under which the cask transporter vehicle is located. The storage regime in phase 2 differs from phase 1 in that each bay accommodates four fuel racks of 130 assembly capacity (total 187.2 Mg U).

The storage bays in both phases are connected with gates and covered by lids when there are no fuel handling operations.

3.3.2.2. TVO - KPA AFR(RS) (Olkiluoto)

A cross-section and detailed description of the KPA Store at Olkiluoto Power Plant is given on page 107 of Ref. [2] and will not be repeated here.

3.3.2.2.1. Operational experience

Long stored fuel undergoes a programme of condition surveillance, this includes visual inspections and oxide layer thickness measurements. Over the past five to ten years of monitoring no abnormal events have been observed.

The time required to transfer and place fuel into storage is 4–5 days. Collective dose for each fuel loading is not separately registered, but estimated to be about 0.06 mSv. The collective dose during storage maintenance and operation is about 1 mSv/a. Dose rate at site boundary is not directly measurable but is less than the background level of the site:0.15 μSv/h. Abnormal occurrences have not been reported.

3.3.3. France

France has 6 AFR(OS) facilities operated by COGEMA at La Hague in support of reprocessing activities (See Table IV).

TABLE IV. FRENCH AFR STORAGE FACILITIES AT LA HAGUE

Storage pools			Nominal capacity t HM	Inventory t HM	Commissioning date
UP2 pools	800	Storage HAO	400	184	1976
		NPH	2 000	1 133	1981
		Pool C	3 600	2 417	1984
UP3		Pool D	3 500	2 196	1986
		Pool E	4 900	3 256	1988
Total			14 400	9 159	–

3.3.3.1. TO

The TO dry unloading facility commissioned in 1986 has a design throughput of 800 t HM/a processes individual dry casks. The internal arrangement of the facility is based on a cross, the points of the cross making up process areas, i.e. cask receipt/export, preparation, unloading and decontamination. Each cell is isolated form one another by shield doors.

On receipt the cask is placed on a trolley which is remotely moved around the facility, cask preparation includes the fitting of the special collar for making a seal with the unloading hot cell. Fuel unloading involves engaging the cask into the base of the hot cell by hydraulically raising the cask. Once a seal is attained, the hot cell shield plug is removed, the cask lid is removed and individual fuel transfers can take place. Prior to loading the fuel into the storage fuel basket, located on a ramp at one end of the hot cell, the fuel is checked for integrity using a krypton monitor and then cooled to pool water temperature in a water circulating pit.

Spent fuel receipt and storage at La Hague is achieved by a collection of independent facilities served by a common fuel shipping cask storage pad. Fuel storage facilities are interconnected to achieve optimum availability of nuclear materials for reprocessing.

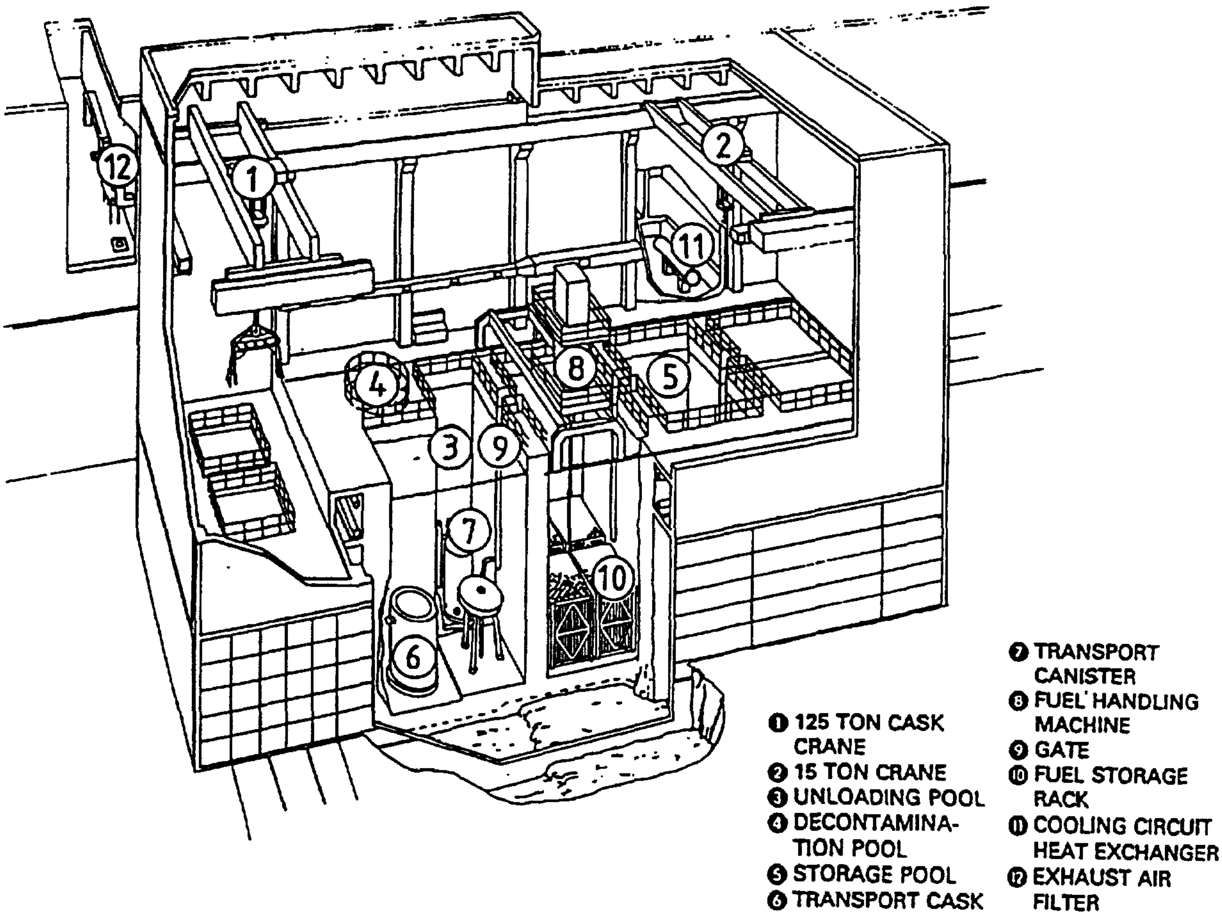

FIG 1. Loviisa pool.

3.3.3.2. HAO (High Activity Oxide) Nord

Commissioned in 1976 the HAO facility has a cask unloading throughput of 400 t HM/a is connected to a pool with a storage capacity of 400 t HM. It is designed as a fuel storage buffer to the UP2 400 plant until its reprocessing capacity is doubled by commissioning new units which will make it the UP2 800 plant. The HAO Nord facility will then cease to operate.

3.3.3.3. NPH (New pools Hague)

NPH facility commissioned in 1981 comprises of a single cask wet unloading line with a design throughput of 800 t HM/a. The line which is capable of handling all types of shipping casks (standard, non-standard, dry or wet) is connected to a pool with a storage capacity of 2000 t HM and is currently used to supply spent fuel to the UP2 800 reprocessing plant.

3.3.3.4. Storage facilities

In addition to the facilities mentioned above, the underwater storage capacity at La Hague plant is ensured by a set of three other facilities. Pool C was commissioned in 1984, its storage capacity is 3600 t HM. Pool D was commissioned in 1986 along with the TO facility, its storage capacity is 3500 t HM and is used to supply the UP3 plant. Pool E facility was commissioned in 1988, its storage capacity is 4900 t HM.

Spent fuel is stored in 9 compartment PWR and 16 compartment BWR baskets equipped with locked lids to prevent accidental modification of the fuel arrangement. Where spent fuel of greater than 3.75% U235 initial enrichment is received the fuel burnup is measured using a system "PYTHON" to allow storage at the same capacity.

Pool temperature is maintained below 40°C and water activity below about 5×10^{-4} Ci/m^3 (18.5 MBq/m^3) during normal operation.

One feature which differs from most AFR pools are the deployment of in-pond heat exchanger/ion exchange units (NYMPHEA) in pools C, D and E. This design has the advantage of precluding the siting of radioactive portions of the cooling network outside the pool. Movement of fuel between pools is performed by conveyors between pools C, D, and E, and a dry transfer corridor between pool C and NPH.

3.3.4. Germany

Germany has limited AFR wet storage facilities located at Greifswald NPP.

The Greifswald power plant now shut down consisted of five Russian WWER-440 units each with associated AR pools and a central AFR pool of standard design for WWER plants. It is similar in design and capacity to the AFR pool at Kozloduy (see section on Bulgarian AFR pools).

All pools are currently being cleared of fuel to allow decommissioning activities to commence. Some of the fuel of low burnup was sent to the Paks power plant in Hungary (for re-irradiation), but the remainder is planned eventually to go into dry cask storage.

3.3.5. India

India has a single AFR(RS) facility located at Tarapur.

3.3.5.1. Tarapur

The 280 t HM (2000 assemblies) Tarapur AFR(RS) facility, which was commissioned in 1991 with a 25 year design life, was provided to service the two Tarapur BWR reactors whilst the back-end policy was derived. The facility now also accommodates fuel from the Rajasthan PHWR NPP (Kota) as an interim measure whilst additional storage facilities are being provided at that plant.

The seismically designed facility measures 73 m × 35.5 m × 22.3 m high and comprises of spent fuel, services and waste management buildings. A more detailed description of the facility is provided in Ref. [5].

Receipts into the facility are made in a storage cask, originally intended for dry storage at other locations, with a capacity for 37 fuel assemblies (5.2 t HM) and is normally loaded with 10 year cooled fuel.

The pool is stainless steel lined, measures 9 m × 13 m × 13 m deep, is built partly below ground and has 1.5 m thick walls. Fuel is loaded into high density fuel racks of 12 × 12 array by using a 1 t bridge crane. Fuel racks are designed to meet both criticality and seismic requirements.

Because the equilibrium temperature of the long cooled fuel has been calculated not to exceed 60°C (when the facility is fully loaded) no emergency cooling system is provided. However, a heat exchanger has been provided to keep water temperature below 42°C under normal operating conditions.

3.3.5.1.1. Operational experience

The facility has operated satisfactorily since it was commissioned in 1991. Visibility, pond water activity and temperatures are all well within limits. Radiation levels over the ponds is also well within limits.

3.3.6. Japan

Japan has three AFR wet storage facilities, two AFR(OS) facilities at the reprocessing sites of Tokai Mura and Rokkasho Mura, and a new AFR(RS) located at the Fukushima Daiichi NPP.

3.3.6.1. Tokai Mura

This relatively small 100 t HM capacity AFR(OS) facility acts as a buffer for the Tokai Mura prototype 0.7 t HM/day capacity reprocessing plant. The facility comprises of casks receipt/preparation areas, unloading pool, storage pool and intermediate pool for fuel feeding to the head end of the reprocessing plant. Fuel is stored in baskets.

3.3.6.2. Rokkasho Mura

The facility consists of 3 bays each having 3 compartments. The compartments at one end communicate with the other bays by means of a transfer channel and an under water transfer trolley for baskets. There is a spent fuel handling machine provided for each bay. An outline of the facility is shown in Figure 2.

The total capacity of the Rokkasho Mura pool is 3 000 t HM distributed as follows:

- 1000 t HM for BWR fuel
- 1000 t HM for PWR fuel
- 1000 t HM shared between BWR & PWR.

Although the storage pool was filled with water at the end of 1996, a decision is still awaited with respect to the licence to operate. When operable storage capacity, however, will be limited to 60% of the total capacity until reprocessing is available.

3.3.6.3. Fukushima Daiichi

The AFR(RS) facility, completed October 1997, has been added to the Fukushima Daiichi reactor site to overcome a short-fall in on-site storage capacity.

The facility comprises of a 29 m × 11 m pool with a storage capacity of around 1200 t HM equivalent to about 6 800 fuel assemblies.

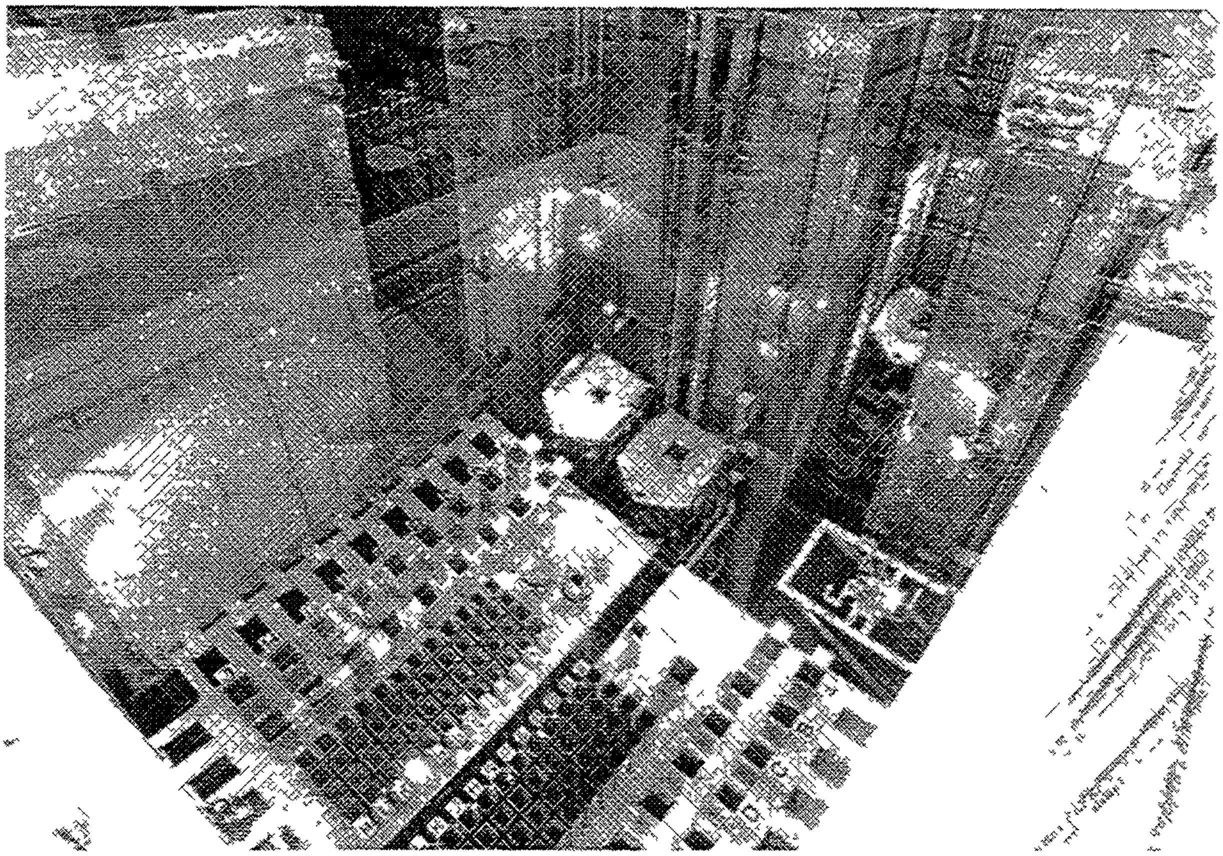

FIG. 2. Storage pool at Rokkasho reprocessing plant.

3.3.7. Russian Federation

The Russian Federation has 6 AFR facilities as detailed in Table V The development/design criteria for Russian AFR facilities is given in detail in Annex B of Ref. [6].

Twenty years operational experience of spent fuel storage in water pools has demonstrated high corrosion resistance of intact fuel during long term storage In addition, no serious deterioration of defective fuel occurred after several years of storage in water pools. Wet storage in The Russian Federation is proven technology. However, continued improvement of wet storage technology is sought through the continued study of the behaviour of spent fuel during long-term storage (damaged fuel in particular) and through reracking in the storage pools in the operating plant.

Following are typical examples of Russian RMBK and WWER AFR facilities.

3.3.7.1. Leningrad

Located at the Leningrad NPP site the AFR (RS) storage facility was designed to hold 2000 t HM of RMBK spent fuel. The storage area consists of five water pools (one is a reserve) designed for storing spent fuel in cans, each pool can accommodate up to 4380 cans. The capacity of each can is one spent fuel assembly.

RMBK spent fuel storage differs from the norm in that individual fuel assemblies are sealed into cans which are stored suspended just above the pool floor in a fixed slot, at a spacing of 110 × 230 mm, in a metal beam placed across the pool This design of storage provides a fixed storage layout to ensure sub criticality is maintained The beams also provide the necessary support for the pool lids to minimise water evaporation, and operator access for manual fuel placement operations.

TABLE V. AFR STORAGE FACILITIES IN THE RUSSIAN FEDERATION

Location of the facility	Fuel stored	Design capacity (t HM)	Current inventory (t HM)	Operating period
Leningrad NPP	RBMK-1000[a]	2000	2500 (with the stand-by bay)	1984 to present
Smolenskaya NPP	RBMK-1000	2000	400	1996 to present
Kurskaya NPP	RBMK-1000	2000	1700	1986 to present
Novo-Voronezh NPP	WWER-1000[b]	400	11	1986 to present
Krasnoyarsk Mining and Chemical Plant	WWER-1000	6000	2000	1984 to present
Association Mayak	WWER-440 BN-600	560	435	1975 to present

[a] Burnup 25 MS d/t HM; 2.4% enrichment; maximum cladding temperature 50°C; 3 years ageing prior to storage.

[b] Burnup 50 MW d/t HM; 4.4% enrichment; maximum cladding temperature 50oC; 3 years ageing prior to storage.

A typical fuel receipt involves a loaded TK-8 cask which after preparation has been placed into the unloading pool. The transport basket with 9 fuel assemblies is then removed from the cask and set on a intermediate shelf in the unloading pool. These operations are performed by using a 15 t cable trolley with a 5 t capstan and are remotely controlled from the operators' room.

A 20/5 t bridge crane transfers the transport basket to the deep section of the unloading pool where individual fuel assemblies are removed and placed in cans. The loaded can is transferred to the main pool hall where it is initially parked at the end of a channel where the pool cover has been removed

Fuel handling/placement in storage is performed by a 1 t-hoist which is height limited and controlled from the pool hall deck. Once the loaded cans have been suspended on the beams of the metal deck of the pool hall the opened portion in the deck is covered again to prevent water evaporation.

3.3.7.2. Operating Experience

The time required to transfer and place fuel into storage is approximately 12–18 hours. This includes the return of the TK-8 container from the AFR(RS) to the reactor unit, loading TK-8 with fuel, transport to the storage building and basket unloading from TK-8. About 8 hours are required for all fuel unloading from the transport basket (with 9 fuel assemblies) into cans and placing the cans into storage. The collective dose for each fuel loading operation is approximately 1.9 mSv (as was predicted). The collective dose during maintenance and operation is no more than 50 μSv/a (a specified value). The pool water activity is very low at 3.3 Bq/kg.

3.3.7.3. Krasnoyarsk AFR (OS) storage facility

The storage facility is located at Krasnoyarsk RT-2 reprocessing plant site. The facility was designed to hold up to 6000 t(U) of spent WWER-1000 nuclear fuel in baskets in readiness for fuel reprocessing in the RT-2 reprocessing plant; yet to be commissioned (Fig. 3.).

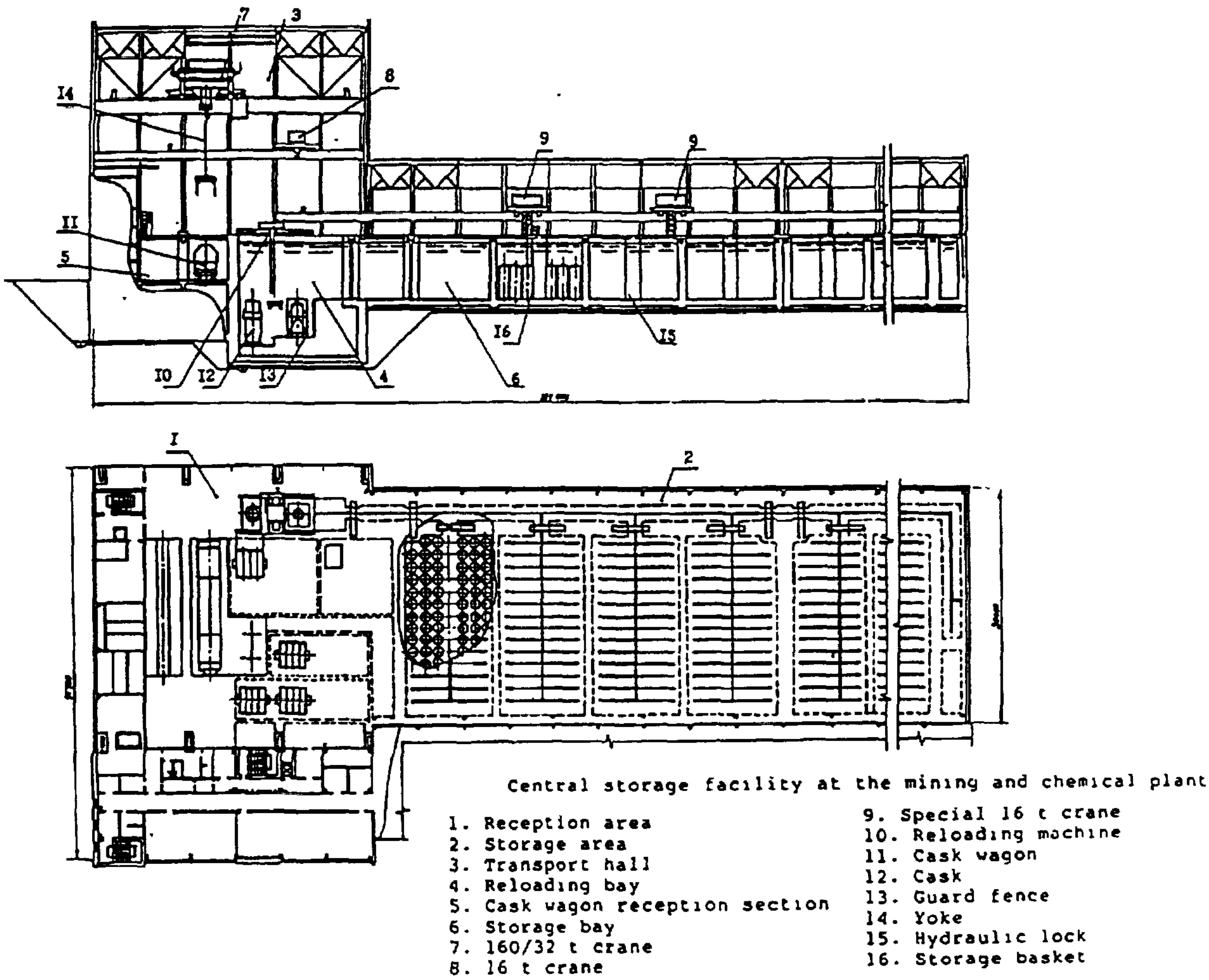

FIG. 3. RT-2 pool.

The facility comprises a reception, storage, and process engineering areas.

Transport cask receipt is not more than two casks per day and can be either TK-10's or TK-13's of 6 or 12 assembly capacity.

The storage pool consists of 15 bays, with one reserve bay. The bays are connected with one another and with the unloading pool via a transport corridor. Each section can be separated by a removable hydraulic lock and emptied independently for maintenance and repair. Baskets with fuel assemblies are placed on the pool floor. The pool is a rectangular shaped structure measuring 11 300 × 3450 × 8400 mm and lined with stainless steel. It is separated from the transport hall by a metal deck with slots which are closed with flap covers. The slot openings facilitate the work of operating personnel and affords a fixed pitch for rows of baskets since the basket is carried on a rod by a 16-t crane along the open slot in the deck. The fixed pitch is 1600 × 1600 × 1600 mm and, with a basket diameter of 1460 mm, prevents the possible collision of baskets. The pool can accommodate between 69 to 84 baskets, however, capacity can be increased if the central transport channel is also filled up.

Pool water temperature is maintained at 40°C by an automatic water cooling system and activity levels controlled by a water purification system which is usually operated once a week per pool.

Operating experience

Time required for unloading a cask of spent fuel is 4 hrs. The time for the basket loading and placing into storage is 12 hrs. Permissible occupational dose limit does not exceed the specified value of 50 μSv/a.

3.3.7.4. Novo-Voronezh NPP

The AFR (RS) WWER-1000 facility is located at the Novo-Voronezh NPP site. The design capacity is 400 t HM. Fuel assemblies are stored in racks at a space of 400 mm in a triangular arrangement under the shielding water.

The storage bays are located in a row on either side of the cask reception room. The decontamination area accommodates a facility for cask decontamination and painting. The cask reception room has a stepwise configuration with two locations. In the upper location the cask lid is removed and in the lower location the cask is unloaded. The storage bays communicate with each other through openings with sluice gates. The storage bays are rectangular ferro-concrete structures with dimensions of 6200 × 4400 × 16 400 mm with double lining and leakage collection from behind the liner.

Fuel arrives by rail in TK-10 transport casks (capacity: 2.6 t HM or 6 WWER-1000 fuel assemblies) and CASTOR casks (capacity 5.2 t HM or 12 WWER-1000 fuel assemblies). Transport operations with casks are performed by a 160/32 t crane in the main hall. Cask loading/unloading operations are performed by a special fuel handling machine. The facility is in operation for loading/unloading operations 24 hours per day for 20 days per year.

The facility is equipped with cladding leak testing and gamma scanning for burnup determination.

- The cooling system is brought into operation when the pool water temperature rises to 45–50°C. The cleaning system operates periodically; on average 24 hours/week/bay.
- The water quality is controlled to the following specifications:
- pH - no more than 4.3;
- H_3BO_3 concentration - no more than 13 g/kg;
- Cl - ion content - no more than 150 mg/kg;
- NH_4 - content - no more than 50 mg/kg;
- The water activity is controlled and does not exceed 10 Bq/kg.

The AFR (OS) storage facility at Mayak

The interim AFR(OS) wet storage facility is located at the site of the Mayak Reprocessing Plant. This facility reprocesses WWER-440 and research reactor (submarine) fuel.

The facility comprises a reception, storage, and process engineering areas. Fuel is stored in baskets. A cross-section of the reception area is shown in Fig. 4.

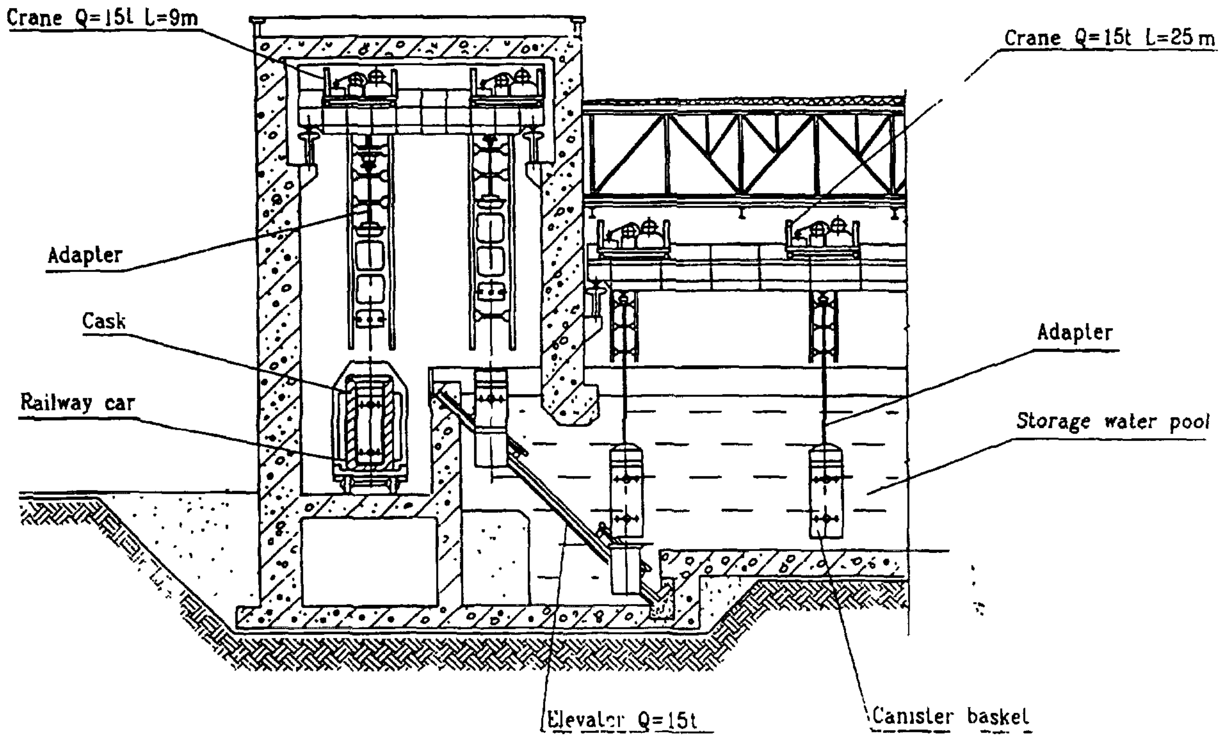

FIG. 4. Mayak reception pool.

3.3.8. Slovakia

The interim AFR(RS) wet storage facility in Slovakia is located at the site of the Jaslovske Bohunice NPP.

3.3.8.1. Bohunice

In 1983 construction started on an interim AFR(RS) storage pool at Bohunice NPP and it was commissioned in 1987. The design capacity of the facility is 600 t HM (5000 fuel assemblies). It is expected that the storage will be completely full by the end of 1998.

The facility consists of three working bays and one reserve bay all interconnected by a water channel. The structure including all the service areas occupies a space of about 45 m × 66 m. The pools are located at ground level and there is a substantial sized reception bay for transport containers. An overhead crane of 125/20 t capacity lifts the casks into an unloading well and the fuel is removed by a 15 t bridge crane into an assembly washing area before transferring to the storage bays.

The facility is of standard USSR WWER design (see Kozloduy, Bulgaria), and stores WWER-440 fuel only.

Operating experience

Although the design maximum water temperature is 50 °C, under normal operating conditions observed water temperatures have been in the 20–30 °C range. The facility only stores non-leakers. The fuel is stored in open baskets, 30 assemblies per basket. No abnormal occurrences have been observed. The specified limits on water activity and temperature were not exceeded. No water leakage has been observed.

Other relevant information

The official policy is not to commit any further fuel for reprocessing. Preparation is being made to extend the existing storage capacity (600 t HM) and to consider higher density racking. This approach would replace the existing 30 fuel assembly baskets with baskets containing approximately 50 assemblies. Analysis is being made of the pool floor pad loading and the cooling capability for higher density racking. The additional space could extend the storage capacity to 2005.

An alternative is to investigate the dry storage option in the event that the extended pool capacity is not achieved. There will also be a need for storage capacity for the second NPP at Mochovce which is expected to start up in 1998.

3.3.9. Sweden

Sweden has a single AFR (OS) interim storage facility (CLAB) located on the Simpevarp peninsula near the Oskarshamn nuclear power plant. The facility differs from any other AFR in that the storage pool is entirely located underground in rock to overcome safety issues such as impact from aircraft.

CLAB

CLAB (first operation 1985) with a planned operational life of around 60 years comprises one above ground (site services, cask handling and fuel preparation operations) and one underground section (fuel storage). A detailed description of the facility including technical data and design criteria is given in Annex A of Ref. [6].

The receipt building has three receiving pool lines, two of which are specially equipped for receiving the TN17 Mk2 cask. The third pool which accommodates fuel leakage detection equipment is primarily provided for receipt of casks other than TN17 Mk2. The receipt pools are arranged so that cask immersion is into non-contaminated water prior to fuel transfer operations into high density fuel canisters; capacity 25 BWR or 9 PWR fuel assemblies.

The conversion to higher density fuel canisters has increased the total storage capacity for the facility from 3000 t HM (as given in Reference 6) to 5000 t HM.

Transfer of individual storage canisters to the underground storage complex is by a fuel elevator containing a water filled cage; the whole process being controlled remotely. On passing from the pools of the receiving section to the elevator shaft, the elevator cage goes through a water trap. The elevator shaft itself is not water-filled.

The storage complex is in a rock cavern 25–30 metres below the surface. It is 120 metres long, 21 metres wide and 27 metres high. It contains four storage pools and one smaller central pool connected to a transport channel. Each storage pool can hold up to 1250 t HM of spent nuclear fuel, giving a total storage capacity for the facility of 5000 t HM.

The storage pools have very thick concrete walls with extremely strong reinforcement. Loss of water from the pools can only occur by evaporation in case of total loss of electricity supply and cooling. The pool water will heat up to close to 100°C. in about one week. If no feedwater is supplied, the water level will drop to the top at the fuel after about one month.

The fuel transport cask cooling system, where the greatest accumulation of radioactivity could be expected, has been equipped with a comprehensive system permitting remote removal of components by means of shielded casks.

In order to reduce the impact of possible airborne contamination in the receiving hall, the normal air change rate is as high as five times per hour in the floor zone where the operators work. If necessary, this air exchange rate can be extended to the total volume of the receiving hall by use of an extra ventilation system.

Operational experience

To August 1997 CLAB had received approximately 900 transport casks, 840 containing fuel and the remainder highly active core components (control rods etc.). The fuel inventory corresponds to around 2 700 t HM comprised of:

— BWR fuel assemblies
— PWR fuel assemblies
— MOX fuel assemblies
— Ågesta fuel assemblies (PHWR)
— Canisters with fuel debris.

Part of the fuel assemblies have been reloaded from the original storage canisters to the new high density storage canister.

Uncertainties such as crud release during dry cask cooling operations have been found to be 50–100 times less than was assumed in the Final Safety Analysis Report (FSAR). This fact may to a great extent be attributed to the good water chemistry in the Swedish reactors and the corrosion resistant material in the turbine and feedwater systems resulting in relatively small quantities of crud.

During the first month of operation problems with the slot filter and backwash filter arose. By developing a new backwash filter and changing the slot filter to a sintered metal filter the problem was resolved.

A surprising fact is that the activity release to the storage pool water is more than 95% ionic. In the Final Safety Report, the opposite was assumed predicting 90% to be in particulate form. The activity released is 90–95% ^{60}Co, the remainder being mainly ^{54}Mn. Less than 1% is ^{137}Caesium.

The activity concentration at 2000 t HM is low, 7 MBq/m^3, which however is higher than expected. The reason for this is the above mentioned high proportion of ionic release. Particles would have settled down on the pool bottom and would not have been observed in the water samples taken from the pools. Instead the activity now remains in the water.

The influence of pool water temperature on activity release rate was measured in 1988 by allowing the pool temperature to rise from 28°C to 36°C. The resultant effect was a 2.1 fold increase in activity concentration.

3.3.9.1. Radiation doses

During the years 1986–1993, the collective dose to CLAB staff and contractors was between 65 and 135 person mSv, which was about 25% of expected values in the FSAR. In the years

1993–1994, the yearly dose was 100–115 person mSv. The rising tendency can be explained by a build-up of activity in plant systems, increased maintenance work and more staff members passing the dose detection limit. The development is closely watched and measures are being taken and planned to break the tendency.

3.3.10. United Kingdom

The UK has four operational AFR(OS) facilities all located at the Sellafield reprocessing site. Pool operation differs from the world wide practice in that the pools are purged by a once-through water flow with discharge to the sea; after conditioning. A summary of the AFR storage facilities in the UK is given in Table VI.

TABLE VI. SUMMARY OF CURRENT AFR FUEL HOLDINGS IN UK [8]

Facility	Fuel type	Design capacity t HM	Inventory t HM	Commissioned/ first operation
OFSP	LWR	2300	1119	1964
ABSP	AGR	1445	1445	1981
FHP	Magnox/AGR	2650	944	1985
TR&S	LWR/AGR	3800	2969	1988/9

OFSP: oxide fuel storage pool
ABSP: AGR buffer storage pool
FHP: Fuel handling pool
TR&S: Thorp receipt and storage

3.3.10.1. Oxide fuel storage pool (OFSP)

This is now the oldest of the operational storage pools at Sellafield and dates from 1964 when it comprised a wet receipt building and four open topped storage bays. The facility was extended to meet business needs in the late 1970s, with the addition of a new receipt building and a fifth storage bay (1980).

Early receipts were in basketed wet and dry transport flasks where the fuel was transferred upon receipt into open topped pond storage skips.

Owing to problems associated with 'crud' migration during storage and within transport flasks, which in turn led to excessive radiation doses being detected at pool and flask surfaces, methods of fuel containment have been developed. These ultimately led to the introduction of multi-element bottles (MEBs) for transport and storage. (For details see Appendix A.)

LWR fuel has now been stored in this facility for in excess of 20 years. Monitoring of long stored fuel has concluded it to be in good condition.

3.3.10.2. AGR buffer storage pool (ABSP)

This store was built as a buffer for AGR fuel whilst the THORP reprocessing facilities were being built. It was the last of the open topped storage ponds to be built at Sellafield and became operational in 1981. The facility has a single dry receipt cell where fuel housed in a transport/storage skip is transferred from a shielded wet transport flask into a pool storage container. Containers are stored flooded stacked up to three high in the single pool with a capacity for up to 600 containers.

Major operational changes since commissioning of this pond have been the receipt of dismantled fuel, increasing storage capacity from 500 t HM to around 1500 t HM, and the introduction of the fuel cladding corrosion inhibitor sodium hydroxide by dosing the pool water to pH11.5. The susceptibility of AGR fuel to cladding corrosion has been reported as part of the Co-ordinated Research Programme on Behaviour of spent fuel during long-term storage (BEFAST) [7].

Since the introduction of corrosion inhibitors and stringent control of water chemistry, no further pin perforations have been discovered over a thirteen year period.

3.3.10.3. Fuel handling plant (FHP)

Commissioned in 1985, the facility comprises three dry receipt caves, three main storage ponds for the storage of Magnox and AGR fuels, three sub ponds, decanning cells for Magnox fuel and AGR dismantling lines. All ponds and sub ponds are interconnected in a building 150 metres long by 25 metres wide raised above ground level.

Fuel receipt and storage is similar to the ABSP, the main differences are that the pool storage containers are predosed in the receipt cell to (pH13, (Cl^- + SO_4^{2-}) < 0.5ppm). AGR fuel is received from reactor stations in fifteen element fuel skips. Magnox containers are sealed and ullaged with nitrogen gas prior to storage to minimise the release of activity and cladding corrosion products to the bulk pond water.

Pool water within the facility is predosed to pH11.4 and cooled to 15 °C by refrigeration units to minimise activity leach rates.

Magnox fuel is stored for up to 18 months. Prior to reprocessing, Magnox containers are transferred to a sub pond containing a skip washer. Here, the container is purged to remove soluble activity, and tumble washed to remove cladding corrosion products. Effluents from these processes are directed to the Site Ion Exchange Effluent Plant (SIXEP). The fuel is then decanned (cladding removed) before cask transfer to the Magnox Reprocessing Plant.

Unlike Magnox receipts, AGR containers are stored flooded for up to 180 days to allow for heat decay to meet the fuel dismantler heat loading limits. A 3:1 fuel consolidation is achieved by dismantling, the rods being placed into 285 mm diameter by 1 metre stainless steel slotted cans. (A more detailed description of the rod consolidation process at BNFL is given in Appendix B.) The cans are transferred into twenty compartment skips and either returned to storage in FHP, transferred to the ABSP or transferred directly to THORP receipt and storage for reprocessing.

3.3.10.4. THORP receipt and storage (TR&S)

Commissioned in 1988, THORP Receipt and Storage (TR&S) is the latest AFR to be built at Sellafield. Constructed to the latest international building standards the design of the facility is based around BNFL's practice of fuel containerisation for both transport and storage.

TR&S is primarily used for the receipt and intermediate storage of LWR fuel prior to reprocessing, but it is also used to store a reprocessing buffer, up to 166 containers, of AGR fuel. The facility comprises two main buildings, the receipt building and the pond hall building. The two buildings are interconnected by an access channel, and since 1995 the Pond Hall Building has been connected to THORP Feed Pond, by a further access channel, where the fuel is taken for reprocessing after a minimum cooling period of 5 years (for LWR fuel).

The receipt building stands some 36 m high with an operating floor at the 11 m level. New receipts of LWR fuel are brought into the facility by rail at the base of the building and lifted to the operating floor through one of two hoist wells using a 150 t crane.

Flask preparation is undertaken in one of three preparation bays and flask decontamination in one of a further three decontamination bays. Provision is made to undertake all flask preparation operations automatically, this is routinely practised for venting and flushing operations, whilst automatic unbolting is now only likely to be used for high burnup fuel receipts. All decontamination operations are manual, although there are facilities for auto cask washing.

The inlet pool is on two levels and has a deep section of 14.6 m for the removal of LWR fuel MEBs and a shallower section of 9 m depth for the removal of the much shorter AGR fuel skips. For in-pond operations, the inlet pond is serviced by the inlet pond handler (effectively a travelling bridge with a heavy duty tooled hoist for the movement of fuel-baring containers) which is controlled remotely from a shielded console located at the side of the inlet pond in the clean area. The inlet pond can also be isolated from the main pond by an electrically operated sluice gate which forms a water tight seal allowing inlet pond draining for maintenance and decontamination.

The Pool Hall Building stands 35 m high with an operating floor at the 10 m level. The hall comprises two enclosed interconnecting 72 m long by 36 m wide by 9 m deep reinforced concrete pools. The pools, built above ground, are multi skinned with leak detection equipment located at the interspace/drainage channel of the two skins and stainless steel clad at the water line.

Two storage systems are in operation: multi-element bottles (MEBs) stored in pairs in a rack for the storage of LWR fuel, and AGR containers stacked up to three high for the storage of AGR fuel.

The two pools are serviced by a main pool handler (MPH) for movements within the pools, a rack transfer machine (RTM) for movements between buildings, and recirculating cooling water system to maintain pond water temperature below 30°C. Both the MPH and RTM are remotely controlled from the receipt building operational control room.

Since 1988 TR&S has processed some 3650 t HM of fuel without a single incident. Dose uptake to operators has been maintained well below 1 mSv/a c.f. the design criteria for the facility of 5 mSv/a. The effectiveness of containerising fuel is supported by the very low pool water activity levels being maintained at around 4 MBq/m^3

3.3.11. Ukraine

Ukraine has one wet AFR facility located at the Chernobyl NPP site. The design and storage technology of this facility is the standard for AFRs used for storing spent fuel from RMBK - 1000 reactors. A description can be obtained from the section on the Leningrad NPP in the Russian section above.

3.3.12. USA

The USA has a single wet AFR(OS) facility located at Morris [1].

3.3.12.1. Morris

Operational since 1972 the Morris AFR(OS) facility consists of cask receiving area, decontamination area, cask unloading pool, fuel storage pools 1 and 2, low level radioactive waste evaporator, control room, and pool water cleanup and cooling system.

The facility was designed to receive one year cooled spent UO_2 nuclear fuel up to 5% ^{235}U and maximum burnup of 44 GW d/t HM from PWRs and BWRs. By 1976, the fuel storage capacity of the facility was increased from 100 t HM to 750 t HM by the installation of higher density fuel storage racks and through changes in fuel handling and support systems.

On receipt a 125 ton crane lifts the cask from the trailer or rail car and sets it upright on the decontamination area pad. The interior of the cask is flushed with pool water, which is then sampled and analysed for radioactive contamination as a means of detecting defective fuel. If defective fuel is suspected, special procedures are employed for opening and unloading the cask.

Fuel is unloaded from the cask submerged in the unloading pool using a 5 ton fuel handling crane. The unloading and storage pools are served by the pool crane — a manual control bridge crane of 7.5 ton capacity. The pool crane has a platform on the north side of the bridge that provides a work station for the fuel handling operator. An underwater closed-circuit television system is available to support fuel handling operations.

3.3.12.1.1. Operating experience

There has been no significant fuel leakage (as determined by measurement of pool water activity), indicating that the fuel is a stable, inert material while in the storage pool environment. Effective control of water quality, radioactive material concentration in the water, cask contamination, and airborne radioactive material has been demonstrated.

4. EXPERIENCE WITH DRY STORAGE OF SPENT FUEL

4.1. Introduction

This section provides a survey of dry spent fuel storage facilities including those in operation and those being licensed and built. The number and types of dry storage facilities in operation and under construction has significantly increased during the past ten years. In addition to the basic storage only technologies (vaults, casks, and silos), some cask and silo technologies are also being used or developed for dual-purpose (storage and transport) or multi-purpose (storage, transport and disposal) applications. Dry storage facilities generally remove decay heat by passive cooling and have low operating costs. They also provides the advantage of incremental storage capacity expansion by allowing additional storage capacity to be constructed on an as-needed basis. The majority of dry storage facilities have been constructed at reactor sites. For purposes of this report, these facilities are classified as AFR (RS) facilities. Facilities at Surry, H.B. Robinson, Fort St. Vrain, Pickering, and Gentilly 2 are examples of AFR (RS) facilities. In addition, several AFR dry storage facilities have been commissioned that are AFR (OS) facilities, e.g. Gorleben, Ahaus.

Container systems, which include casks and silos, comprise the majority of the dry storage technologies in use. Descriptions of commonly used container systems are provided in Appendix C.

Spent nuclear fuel has been handled and stored for short periods under dry conditions since the 1940s. The use of continuous dry storage of spent fuel began in the early 1960s. In the late 1970s, several countries concluded that there are advantages to storing spent fuel under dry conditions and started development programmes, which have culminated in the operation of licensed dry storage facilities in several countries.

The storage of zirconium alloy clad spent LWR fuel in an inert gas atmosphere is a proven technology up to temperatures of about 450°C. Dry storage of that fuel is licensed in Germany for temperatures <410°C and in the USA for temperatures <380 °C in an inert atmosphere. Dry storage of spent CANDU fuel in air at temperatures up to 160°C has been licensed in Canada. Dry storage of Magnox type fuel has been licensed in the United Kingdom in air or inert atmosphere. Degradation of fuel during dry storage is unlikely and no significant fuel degradation in storage has been observed. Tables summarising dry storage experience for each dry storage type are provided in this section.

4.2. Vault facilities

Vault facilities have been constructed in Canada, France, Hungary, the United Kingdom and the USA using a variety of vault dry storage technologies. Table VII summarises international experience with dry storage in vault facilities.

4.2.1. Canada

Hydro Quebec's Interim Spent Fuel Dry Storage (ISFDS) facility went into operation in September 1995 after its first storage module was completed. It was licensed by Atomic Energy Control Board (AECB) to store spent fuel from the operating 680 MW(e) Gentilly 2 CANDU power reactor.

This is the first application of the MACSTOR concept to store spent fuel from a CANDU reactor which evolved from AECL's (formerly Atomic Energy of Canada) silo based technology. Its advantages are superior thermal performance, a more compact storage site, as well as overall economical and operational benefits. One concrete module stores the same quantity of spent fuel as 22 stand alone silos (concrete canisters) used at Pt. Lepreau reactor site.

TABLE VII. SUMMARY OF DRY STORAGE IN VAULT FACILITIES

Country/facility	Fuel type	Design capacity t(HM)	Current inventory t(HM)	Operating period
Canada				
Gentilly 2	CANDU	3648	20	1995 to present
France				
CASCAD	HWR	180	180	1990 to present
Hungary				
Paks	WWER-440	162	54	1997 to present
UK				
Wylfa	Magnox	958	680	1971 to present
USA				
Fort St. Vrain	HTGR	15.4	15.4	1991 to present

4.2.1.1. *Facilities for dry spent fuel storage*

The storage site, which is approximately 90 m wide and 200 m long, is located on-site in the vicinity of the spent fuel bay. It allows space for the construction of 15 additional storage modules to take care of the lifetime spent fuel arisings of the station. The foundation for the storage modules was prepared through continuous concrete pouring from the rock (6 m below the ground) up to the ground level.

The service building around the spent fuel bay was modified and an extension was built to accommodate the fuel handling facilities needed for dry storage. A two-transfer cask method is used in conjunction with a new cask handling crane installed in the building extension. The new facilities are essentially the same as used for dry spent fuel storage by Gentilly 2's sister CANDU reactors at Pt. Lepreau (Canada) and Wolsong 1 (Republic of Korea).

4.2.1.2. *Fuel handling operations*

Figure 5. depicts the fuel handling operations. The spent fuel bundles are first manually loaded underwater into storage baskets. The Shielded Work Station (SWS) is installed in the service building extension adjacent to the storage bay. The chute, to guide and shield the storage basket, is installed over the edge of the bay. The transfer cask positioned over the chute hoists the basket out of the bay. After the basket is drained, the cask is rolled out on rails to the SWS. The 30 ton crane positions the cask over the SWS and the basket is lowered, dried and seal welded thus forming the primary containment. The basket is then lifted into a second transfer cask and brought to the storage site by the trailer. The 30 ton site crane lifts the transfer cask atop the concrete storage monolith, called the CANSTOR module, where the loading platform guides it into position. The storage basket is then lowered into the storage cylinder. Once filled with 10 baskets, the shield plug is placed and seal welded to the top of the storage cylinder. Thus the secondary containment is established. Monitoring of the air space in the storage cylinder allows for verification of the leak tightness of both containment boundaries.

A rail mounted gantry crane of 30 ton capacity is installed. It has a span of 30 m and is capable of reaching any of the 20 storage cavities in the storage module.

4.2.1.3. *CANSTOR module description*

The CANSTOR module is a monolith, built outdoors using regular reinforced concrete, and contains 20 storage cavities. Each cavity is fitted with a storage cylinder which is sealed after loading of 10 storage baskets. Each basket contains 60 standard CANDU fuel bundles with 102 mm diameter and 495 mm length. The module's labyrinth arrangement for air passage allows for heat removal by natural convection (see Table VIII).

In spite of the excellent heat rejection capability of the CANSTOR module, the AECB requested that the cladding temperature of the stored fuel be verified. To this effect, the module was instrumented to allow for measuring and recording internal concrete and storage cylinder surface temperatures. It is expected that the interpretation of the results would indicate that there is a wide margin between the maximum allowable and derived fuel cladding temperature. Therefore spent fuel with a shorter cooling period than 7 years will be permitted to be stored in subsequently built modules.

TABLE VIII. CANSTOR DESIGN PARAMETERS

Module height	8.1 m
Module width	7.5 m
Module length	21.6 m
Storage capacity of module	228 t HM (12 000 bundles)
Storage cylinder material	carbon steel
Storage basket material	stainless steel
Fuel operating temperature	<150 °C

4.2.2. France

CASCAD (CASemate CADarache), located on the Cadarache site, is intended for the dry storage of exotic fuels which cannot be economically reprocessed because of their special properties. This facility , which has been operated since 1990, is planned for a storage period of 50 years, after which the fuel will be rehandled, according to the final decision about its fate.

Fuels to be stored arise from the CEA (Comissariat à l'énergie atomique) research reactors and in particular from the Brennilis EL4 heavy water reactor.

The major operating and safety principles include: (1) spent fuel canisterization and helium pressurisation in order to maintain the containment barrier in case of fuel cladding deterioration, and (2) spent fuel cooling with a passive convection system. It has to be noted that for the EL4 fuel, the canistering operation is performed at the Brennilis reactor site.

4.2.2.1. Facility description

The CASCAD vault facility consists of a shipping cask receiving zone and a storage area.

The facility is mainly composed of:

(1) A storage vault enclosing 319 storage wells. The main components of the storage wells are :

— A leaktight cover, located in the upper section of the well, equipped with a system for sampling the internal atmosphere of the well;
— A biological shielding plug;
— The walls of the well which constitute a containment barrier; and
— A guide tube at the bottom of the well.

(2) A handling cell which enables the transfer of fuel from the transport cask to the well. The shielded slab ensures the support of the wells as well as the biological shielding of the operating team.

(3) Equipment rooms which enable the reception and preparation of the casks and contain all the facility's equipment (control, ventilation, electricity).

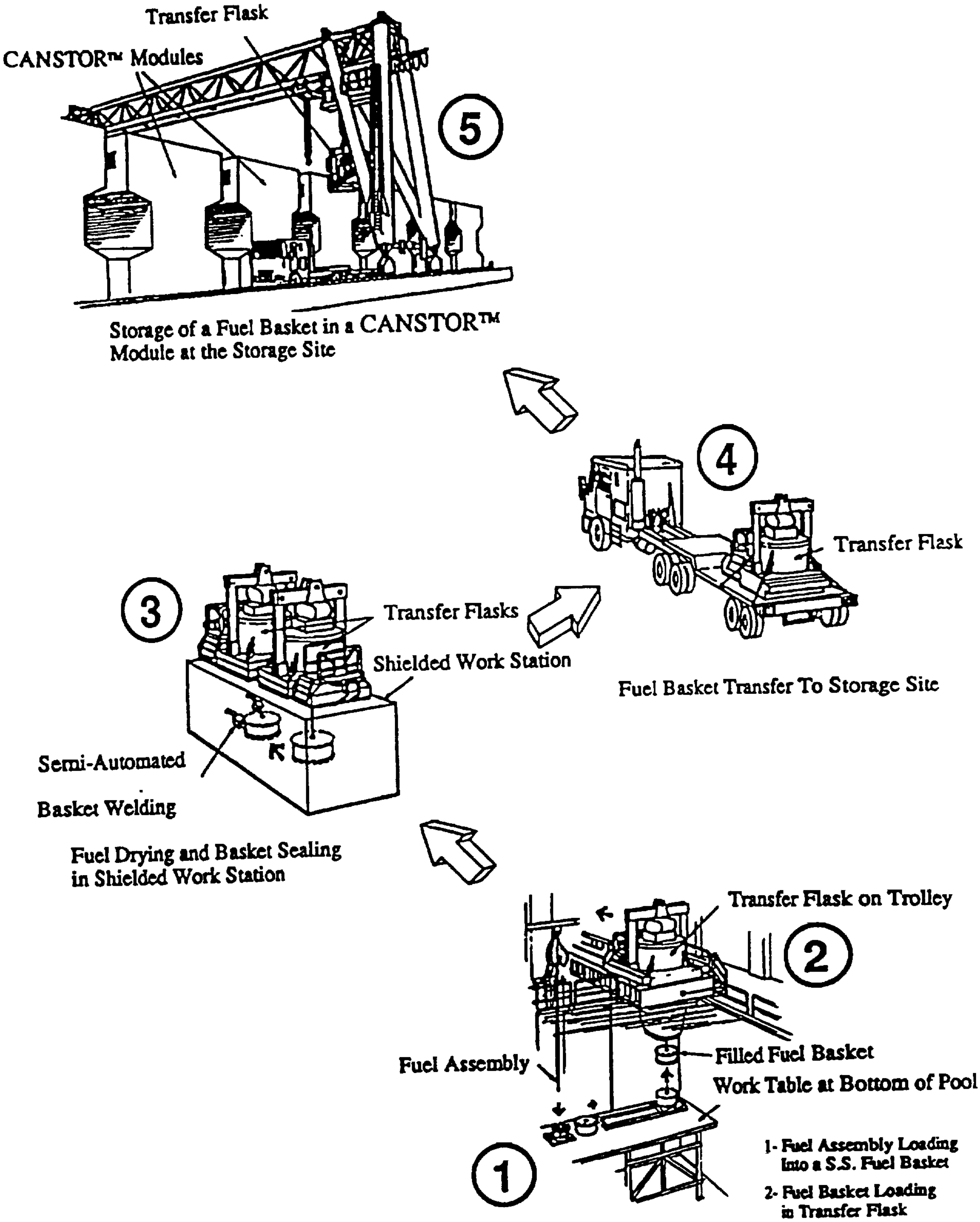

FIG. 5. Fuel handling at Gentilly 2.

4.2.2.1.1. Storage vault

The storage vault consists of a concrete structure which provides biological shielding for both handling operations and storage. The lower part of the structure contains an array of storage tubes into the canisters are placed. The storage tubes are cooled by air circulation achieved by natural convection. Cooling air is introduced through the lower part, then heated as it passes the storage tubes. The heated air is released through a stack. The EL4 Canister external dimensions: Ø = 104 mm H = 1100 mm

Two operators are required to perform unloading and storage operations. The individual dose rate for the entire staff ranges between 0.35 mSv/a and 5.25 mSv/a. The dose rate measured outside the building is less than 10^{-5} mSv/a.

4.2.3. Hungary

In order to ensure the continuous operation of the Paks NPP, an interim spent fuel storage system has been chosen and licensed, and the construction of the storage building has commenced. During the years 1991 and 1992 following an evaluation of the different spent fuel storage systems, the GEC ALSTHOM ESL Modular Vault Dry Store (MVDS) System has been selected.

The licensing process took place during the years 1993 and 1994. The Construction License has already been issued for construction of the first three phases (11 Vault modules; 4950 assemblies). The operation of the Phase 1 is (3 Vaults, 900 assemblies) has started in late 1997. A pictorial representation of the MVDS is shown in Fig. 6.

4.2.3.1. General description of installation

The vault module is a reinforced concrete structure which is covered by a structural steel building to form a charge hall. The buoyancy driven air cooling flow inlet and outlet ducts are an integral part of the vault modules.

The transfer cask reception building is a separate facility adjacent to the vault module. It houses the equipment necessary to handle and position the transfer cask prior to fuel assembly removal/drying operations. The transfer cask reception building also houses service and plant rooms, ventilation systems and provides health physics facilities for operating staff and monitoring equipment.

Arrangement of major structures and equipment

The MVDS provides for vertical dry storage of irradiated fuel assemblies in a concrete vault module. The principal components are a concrete and structural steel vault module housing an array of steel fuel storage tubes each with a removable steel shield plug. Each fuel storage tube houses a single fuel assembly. A fuel handling machine moves the fuel assembly from a water filled transfer cask to the fuel storage tube via a drying tube. The fuel handling machine operates in an enclosed volume above the fuel storage tubes referred to as the charge hall. To permit the transfer cask to be prepared for fuel assembly removal by the fuel handling machine, the storage facility is provided with a transfer cask reception building. The equipment required to load and transfer the fuel assemblies at the nuclear power plant is presently licensed for use and is outside the design scope of the MVDS.

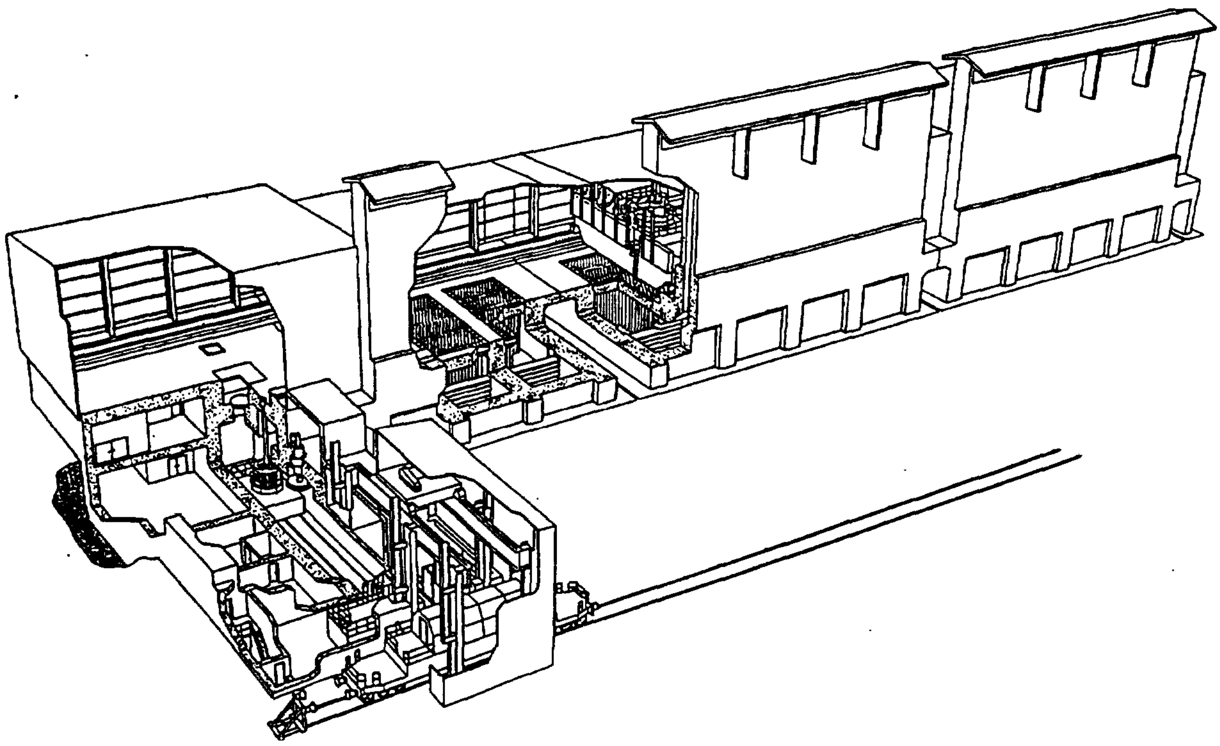

FIG. 6. Paks MVDS.

Safety features

The principal safety features of the MVDS are as follows:

(1) Confinement provided by the fuel storage tube and gas services system;

(2) The use of a nitrogen cover gas within the fuel storage tube providing a non oxidising environment for the fuel assembly; and

(3) A temperature level sufficiently low to prevent degradation and gross rupture of the fuel cladding.

The principal design features that characterise the MVDS are similar to the buffer dry stores at Wylfa described elsewhere (Appendix B of Ref. [2]).

Monitoring and surveillance

The condition of the fuel assemblies over long periods in storage can be monitored in the MVDS system. The MVDS provides opportunity to monitor visually the condition of individual fuel assemblies during storage. This can be achieved by raising the fuel assemblies into the fuel handling machine and using TV systems. The ability to monitor the fuel condition is an inherent part of the waste management function. Not only may the visual condition of the fuel assembly have to be checked, but also the storage environment. The method of loading the fuel assemblies into the MVDS provides opportunity to check the condition of the fuel assembly as received and to remove them for periodic inspection [2].

4.2.4. United Kingdom

The Wylfa Power Station has two types of dry storage facilities in commercial operation. Operated by Nuclear Electric plc, Wylfa reactor site comprises two 550 MW Magnox reactors, three 86 t(U) carbon dioxide cooled short duration dry stores (DSC 1–3), and two 350 t(U) air cooled buffer dry stores (DSC 4 and 5).

4.2.4.1. Short duration dry stores

The primary dry store cells were licensed for operation in December 1970 and the first irradiated fuel loaded in March 1971. The first air cooled dry store was licensed for operation in September 1979 when the first spent fuel element was loaded. The store was full (28 922 elements, approximately 350 t HM) by September 1981. The second air cooled dry store was licensed for operation in May 1982 and is used for storage as and when required.

Fuel to be buffer stored is pre-cooled in one of the three carbon dioxide cooled dry stores until decay heat, determined by gamma monitoring, is found to be less than 60 watts or temperatures fall to 150°C. Up to 64 assemblies are transferred at a time to one of the two buffer stores which are kept at slightly below atmospheric pressure to ensure any leaks are inward. The stores are designed so that relative humidity is maintained below 50% by drier units, ambient temperature is maintained by heat exchangers, and exhaust gases are discharged to the atmosphere via a series of absolute filters.

Each cell contains 588 steel tubes arranged concentrically in eleven rings. The tubes are approximately 15 m long and each can hold 12 elements loaded on top of one another. The tubes contain CO_2 at a pressure of 1200 mbar, the purity being maintained at better than 0.1% air concentration. Station operating procedures ensure that maintenance work which could affect the purity is not started until a specified time has elapsed from the loading of the last fuel element. No forced cooling means are provided, the tubes being cooled by a flow of air in an open cycle system. The heat output of an element going into storage is 1 kW, with a cladding temperature of 365°C.

4.2.4.2. Buffer dry stores

The second type of storage facility is a closed cycle air cooled dry store with two vaults. Each is a reinforced concrete chamber about 60 m long, 11 m wide and 4.5 m high, with 2 m thick shield walls. The chamber contains 150 skips, 6 row with 25 skips in each row, plus 1 spare skip required for moving the skips about the storage area. Each skip consists of 16 rows of 12 element tubes, making 192 in all. The skips are located on conveyor chains for longitudinal and transverse movement within the store. Cooling air passes through the bottom of the skip and around the outside of the tubes. The fuel in each skip draws cooling air according to its needs. The higher the heat output from the fuel, the greater the buoyancy head and hence the greater the cooling flow. The bulk heated air is removed by a conventional fan and heat exchanger system. The air atmosphere in the store is subatmospheric (12 to 25 mbar depression) so that any leakage is always inward and not outwards from the store. The storage skips are chain driven to the fuel transfer machine via locating rails for loading.

Generally, operational experience of the five dry stores has been very good. The notable exception is the widely reported water ingress into DSC4 due to a roofing fault. Discovered in 1990, 45 fuel elements have suffered some degree of cladding corrosion as a result of water getting into the store. The leakage highlighted inadequacies in the degree of humidity and activity monitoring equipment. This has now been addressed by the provision of additional equipment.

4.2.5. *USA*

Public Service Company of Colorado was granted an independent spent fuel storage installation (ISFSI) license by the US Nuclear Regulatory Commission (NRC) for the shut down Fort St. Vrain high-temperature gas-cooled reactor (HTGR) in November 1991 using the modular vault dry store (MVDS) system designed by FW Energy, based on the GEC-Alsthom design. A total of 1464 HTGR spent fuel assemblies (15.4 t HM) are stored in the MVDS. The twenty year license authorises storage in the ISFSI of up to 1482 spent fuel elements, 37 reflector control rod elements, and 6 neutron source elements.

Fort St. Vrain spent fuel elements are graphite elements in hexagonal arrays with a 36.0 cm maximum cross section and 79.3 cm in length. The fuel characteristics for the ISFSI design included 600 day cooled, highly enriched uranium/thorium carbide fuel, maximum heat output of 150 watts per assembly and an average heat output of 85 watts per assembly.

The MVDS consists of a six concrete vault modules, two standby and one neutron source storage wells, and a transfer cask reception bay. Each vault module consists of a matrix of 45 storage positions. Each storage position holds 6 fuel elements or 12 reflector elements in a fuel storage container (FSC). The loaded FSC is brought to the MVDS in a transfer cask (TC) from the reactor building and is received in the transfer cask reception bay (TCRB). The TC is lifted from the TC trailer by the MVDS crane, and positioned vertically in the cask load/unload port. The FSC is then removed by the container handling machine (CHM) and moved by crane over the charge face structure of the storage vault. When the CHM reaches its position, the crane lowers the CHM to the CFS in the vault module.

4.2.5.1. *Civil structure*

The MVDS civil structure consists of vault modules, the transfer cask reception bay, the charge face structures, foundation structure, and standby and neutron source storage wells. The foundation for the vault modules is a reinforced concrete slab which extends approximately 3 m (10 ft.) beyond each side of the storage facility. Each vault module is shielded by a 1.07 m concrete wall.

Ambient air flows into the vault modules through an inlet duct and passes around the outside of the FSCs. The air exits through a reinforced concrete exhaust stack, which projects above the MVDS and is covered by a steel canopy. The charge face structure forms a roof over the vault modules and is made of carbon steel and filled with non-structural concrete for shielding purposes. The air outlet stack forms one wall of the charge hall and the other three sides are made of reinforced concrete up to 10 m above ground level. The remainder of the walls and the roof are made of steel sheathing supported by steel framework. The transfer cask reception bay is part of the MVDS civil structure. It allows the transfer cask to be moved laterally by the MVDS crane into the cask load/unload port through an opening above the bay at the FSC level.

4.2.5.2. *Transfer cask reception bay*

The TCRB provides an opening at the charge face level through which the TC can be lifted and moved laterally by the MVDS crane and seated on the cask load/unload port. The cask load/unload port consists of a seating ring and adapter plate with a shield ring to provide a place for the transfer cask to be secured for unloading the FSC. The flanged top of the TC rests in a recessed seating ring so that the MVDS crane may position an adapter plate, shield ring, and isolation valve.

4.2.5.3. Fuel storage containers

The FSC consists of a cylindrical carbon steel tube body with an exterior aluminium spray coating, double metal O ring seals, and a bolted lid. The FSC can hold 6 fuel elements or 12 reflector elements. It is supported axially by a support stool fixed to the floor of the vault module at its lower end. The top of the FSC is shielded by a depleted uranium shield plug during transport, and by a shied plug placed above the FSC in the FSC during storage. The FSC provides secondary confinement for irradiated fuel, the first confinement barrier being provided by the particle coating. The fuel elements are stored in an air environment.

4.2.5.4. Handling equipment

The MVDS crane is an overhead gantry crane which can access the entire charge hall. It lifts the TC, the container handling machine, and the cask load/unload adapter plate, the isolation valves, and the shield plug handling devices.

The container handling machine is used to raise and lower FSCs from the transfer cask and vault storage locations. It is moved over the charge face structure by the MVDS and is fully shielded. The container handling machine consists of a main shield tube, a single failure proof raise/lower mechanism, and a FSC grapple. An isolation valve on the bottom of the container handling machine provides radiation shielding.

An interlock system ensures that all operations are carried out in a safe manner. The following operations are controlled by interlocks: (1) the container handling machine cannot be lifted unless the isolation valves are closed; (2) the isolation valves cannot be closed unless the FSC raise/lower mechanism is fully up; (3) the FSC raise/lower mechanism cannot lower unless the isolation valves are open; and (4) the FSC raise/lower mechanism cannot lower if the load sensing cell indicates that the load is less than the grapple weight.

4.2.5.5. Fuel handling and storage operations

A vault module storage position is selected and prepared prior to loading an FSC. The fuel elements are loaded into an FSC, which has been placed in the TC in the reactor building, and the TC is lowered back onto the trailer. The TC is received in the MVDS in the transfer cask reception bay. The TC is raised by the MVDS crane and positioned in the cask load/unload port.

To unload the FSC, the TC outer closure is removed and the cask shield ring is positioned. The cask load/unload port isolation valve is positioned above the TC. The depleted uranium shield is removed and the shielded container handling machine is positioned on the cask load/unload isolation valve. The FSC is raised into the container handling machine. The container handling machine is positioned by the crane on the charge face isolation valve and the FSC is lowered into the vault storage position. The container handling machine is removed and the charge face shield plug is replaced [9].

4.3. Cask facilities

Dry storage cask facilities have been constructed in Belgium, Canada, the Czech Republic, Germany, India, Japan, and the USA using a variety of dry storage technologies, including metal and concrete casks. Cask facilities are under licensing and construction in Canada, Germany, Lithuania and the USA. Table IX summarises international use of dry storage in casks.

4.3.1. Cask facilities in operation

4.3.1.1. Belgium

Doel units 3 and 4

Seven nuclear reactors are in operation in Belgium. In order to maintain flexibility in the management of its spent nuclear fuel, Electrabel wished to have available additional means for spent fuel storage. Following a survey of the alternatives for interim storage, Belgatom, the engineering and consulting firm, and Synatom, the Belgium nuclear fuel management organisation, decided to build an at-reactor storage facility for each nuclear power plant when needed. Dual purpose dry storage casks, located in a separate building, are being used at the Doel power plant since September 1995.

The Transnucléaire TN-24 family of casks was selected for the dry storage facility at the Doel power plant. Doel Unit 3, a PWR 900, will use the TN-24 D. Doel Unit 4, a PWR 1000, will use the TN-24 XL. The TN-24 D has a capacity of 28 assemblies with an active length of 12 feet, while the TN-24 XL has a capacity of 24 assemblies with an active length of 14 feet.

A description of the TN cask family is provided in Appendix C. The two cask versions selected for the Doel power similar design features and differ mostly by their overall height of 4.7 m and 5.6 m for Doel 3 and 4, respectively.

Licensing conditions were defined by Synatom and the Belgian regulatory authority at the start of the project. The TN-24 is a transportable storage cask; therefore, a transport license was obtained first since its requirements would cover most of the licensing issues. Another set of conditions had to be met to comply with the storage requirements.

In addition to the safety features expected from all interim storage systems, the Belgian regulatory authority required that the interim storage system be able to withstand the crash of a military aeroplane. This could have been achieved by constructing an air crash proof building, but it was determined to be less costly to design the casks to withstand an aeroplane crash. The loaded cask was designed to withstand the impact of an F16 military fighter with a total weight of 14 600 kg and a speed at impact of 150 m/s [10].

4.3.1.2. Canada

Phase I, stage I of the Pickering Dry Storage Facility (DSF), located at the Pickering Nuclear Generating Station in Ontario (8 × 550 MWe CANDU), was commissioned in 1995. The dry storage facility consists of a building which houses an operations area (workshops, services, utilities, offices, etc.) and a storage area with capacity for 185 dry storage containers (DSCs), each containing 10 tonnes of CANDU spent fuel. The DSCs are described in detail in Appendix C.

TABLE IX. SUMMARY OF DRY STORAGE IN CASKS

Country/facility	Fuel type	Design capacity, t HM	Inventory t HM	Operating period
Belgium	PWR	800	142	1995 to present
Canada				
Pickering, Ph1	CANDU	1421	460	1995 to present
Pickering, Ph2	CANDU	5376	0	Planned
Czech Republic				
Dukovany	WWER	600	232	1996 to present
Germany				
Ahaus	LWR, HTR, MTR	3960	15	1992 to present
Gorleben	LWR	3800	38	1995 to present
Juelich	LWR/HTR	8	5	1993 to present
Greifswald	WWER	585	0	Planned 1998
India				
Tarapur	BWR	27	27	1990 to present
Japan				
Fukushima	BWR	73	73	1995 to present
USA				
Arkansas Nucl.	PWR	150	44	1996 to present
Dresden 1	BWR	70	0	Planned 1998
North Anna	PWR	840	0	Planned 1998
Palisades	PWR	233	102	1993 to present
Point Beach	PWR	447	19	1995 to present
Prairie Island	PWR	724	60	1995 to present
Surry	PWR	808	347	1986 to present
Trojan	PWR	358.9	0	Planned 1999

Operations area

New containers are received at a designated workshop area where equipment is provided for the DSC commissioning operations. A laydown area is available to place the commissioned DSCs for later transfer to the irradiated fuel bays.

The DSCs are loaded with irradiated fuel in the fuel bays and then transported to the welding and decontamination area of the workshop for final sealing, decontamination and painting prior to storage. The casks are welded using automatic welding equipment. The welds are inspected by X ray, and helium leak tested to 1×10^{-5} at cm^3/s. Active drainage, a fume hood, and an active ventilation system are provided to control radiological emissions to the environment. Facilities for painting the weld area of the DSC around the lid and the drain and vent ports are also provided. An 80 ton overhead crane servicing the entire workshop and a lifting beam are provided to handle the DSCs.

Storage Area

In the storage area, the containers are stored in rows that are 0.63 m apart with 0.23 m spacing between containers in a row. This provides sufficient space for air circulation and cooling. Concrete peripheral walls of 0.2 m thickness limit the radiation dose rate at the exterior surface of the wall to less than 2.5 μSv/h. The storage building is ventilated by natural convection flow through openings in the peripheral walls and ceiling of the storage building. The design maximum facility air temperature is 38°C.

Drainage from the welding and decontamination area is treated as active liquid waste. Under normal conditions no liquid wastes are expected to arise in the container storage area. For contingencies, however, floor drainage is directed to two underground active-liquid stainless steel lined sumps and transferred via sump pumps to two stainless steel holding tanks.

After monitoring, the contents of the holding tanks are periodically transferred for routine treatment by pumping their contents, via underground nuclear class stainless steel piping, to the existing active liquid waste treatment system at Pickering NGS.

The on-site transporter is a specially designed multi-wheeled vehicle for transport of the DSCs to storage and for retrieval of the seal-welded DSCs. The transporter is self-loading and self-powered, not requiring the assistance of a crane. It is propelled by hydraulic hub motors, with the hydraulics powered by a diesel engine.

The first DSC was loaded with fuel in August 1995 and 460 t HM have been placed in dry storage. Stage II of the Pickering DSF will consist of an outdoor storage yard, adjacent to the stage I building, which is designed to hold an additional 500 DSCs. Stage II is currently in the planning and licensing stage. Phase II, which will store all of the remaining fuel generated over the life of the eight Pickering reactors is planned for operation in the future.

4.3.1.3. Czech Republic

Dukovany Nuclear Power Plant

The Czech Republic has constructed an interim dry storage facility at the Dukovany Nuclear Power Plant, operated by CEZ. The storage capacity is 600 t HM. The site can be accessed by road and rail. Facility licensing took place from February 1992 through March 1994. Facility construction began in June 1994 and was completed in October 1995. The first CASTOR 440/84 cask was loaded at Dukovany in November 1995.

The Dukovany Interim Spent Fuel Storage facility uses the CASTOR 440/84 storage and transport cask, which is described in Appendix C. The facility is designed to store up to 60 CASTOR 440/84 casks. The capacity of each cask is 84 assemblies or approximately 10 t HM. Spent fuel characteristics for the CASTOR 440/84 include: storage of WWER 440 spent fuel; 35 000 MW d/t HM burnup; 3.5% ^{235}U enrichment; a minimum fuel age of 5 years prior to storage; no damaged assemblies may be stored; maximum cladding temperature of 350 °C.

The principle of the storage concept is the safe containment of the irradiated fuel assemblies in CASTOR 440/84 casks. All safety related functions are accomplished by the casks themselves. The intermediate storage building serves primarily for the optimisation of the operational procedures and protection against weather conditions, and provides additional radiation protection to the environment. The removal of the decay-heat is achieved by natural convection through openings in the side walls and the roof of the storage building.

Storage building

The storage building has a cask receiving area which is separated from the storage area by a concrete shielding wall. This wall is approximately 40 cm thick and 6 m high except for a centre 4.5 m high section over which the cask is lifted when being moved from the receiving area to storage area. The floor of the storage building is a reinforced concrete plate. The building has one hall with columns and a light steel roof. The columns support an overhead rail for the 130 ton crane. The external walls of the storage building were constructed with light concrete and brick wall panels. The storage part of the building is surrounded by a precast concrete shield wall that is 5 m high. This building and a fence around the receiving area fulfil the physical protection requirements.

The handling and maintenance of the casks is performed in the receiving area. All casks are moved within the storage building using a crane that covers the receiving and storage areas. Facility operating steps include: raising, lowering and tilting of the cask from or onto the rail wagon; and transport of the cask between the receiving area and storage position within the storage area. The storage building is ventilated by natural convection through openings in the walls and ceiling.

Loading of the cask

Loading the CASTOR 440 is similar to loading a transport cask. The differences result from requirements for drying of the cask cavity in accordance with long-term storage specifications; and the use metallic seals for the two lids. After loading of the cask, it is shipped by a special wagon to the storage facility, where the cask is attached to the lifting yoke of the storage building crane. If the cask is ready for storage, it is transported to its storage position, otherwise the cask is transported by the crane into the maintenance room, where it is prepared for storage and tested.

Storage preparation includes filling the interlid space between primary and secondary lids with inert helium gas, installation of the inner lid pressure monitor and seal testing with a helium leak detector. The cask is then transported to its storage position in the storage building, the pressure monitoring system of cask is electrically connected, and the protection plate is fixed on the cask.

The important equipment includes: special lifting yoke for tilting the cask on the wagon, the transport of the cask from the reactor area into the loading pool and back; adapter for positioning; water pump with equipment for removing the water over the primary lid and from the cask (self-priming pump with an output of 10 m^3/h); vacuum drying equipment; equipment for leaktightness testing and gas filling system (vacuum pumps etc.); and work platforms, special parts and equipment for cask dispatching, etc.

The main maintenance and repair work requirements include: (1) exchange of defective seals. (2) By a failure of the secondary lid seal, this seal is exchanged without opening the cask. If the primary lid seal fails, then the cask must be transported back to the NPP. (3) Inspection and, if necessary, replacement of the pressure gage. (4) Replacement of the trunnions.

4.3.1.4. Germany

General

In accordance with the German spent fuel management policy, in the early 1980s utilities determined that AFR-interim storage would be necessary. During the review of options for interim storage, it was recognised that spent fuel could be stored safely in transport casks. A new German cask storage technology was developed that used nodular cast iron as the cask body material. The development of the cask storage concept was performed in parallel with this new cask technology.

After an extended time period for design and licensing, two centralised cask storage facilities were built — one in Ahaus (close to the Netherlands border) and one in Gorleben (close to the border of the former GDR). Both facilities are basically of the same design and originally had a capacity of 1500 t HM each. Since 1996, Gorleben has extended its license to 3800 t HM, while Ahaus has been licensed for 3960 t HM. Both extensions are based on the use of more advanced higher capacity cask designs without increasing the size of the storage buildings.

The Gorleben plant is owned and operated by "Brennelementlager Gorleben GmbH" (BLG), a 100% subsidiary of "Gesellschaft für Nuklearservice mbH" (GNS). Ahaus is owned and operated by "Brennelement-Zwischenlager Ahaus GmbH" (BZA), a joint venture of GNS (55%) and "STEAG Kernenergie GmbH" (45%). Both facilities are an investment of all German utilities operating NPPs. They hold fixed fractions of the capacities.

Technical description

The main features of the German AFR cask storage concept are:

— Fulfilment of all safety requirements by the casks
— Natural convection heat dissipation without active systems
— No handling of open casks at the dry storage facility
— Flexibility by modularity
— Easy operation
— Easy decommissioning
— Practically no secondary wastes or contamination
— No release of radioactivity to the environment.

Both the Ahaus and the Gorleben facilities have a storage building of about 200 m length, 38 m width and 20 m height. The buildings provide a well defined controlled area for radiation and security protection measures and contribute to shielding of direct and skyshine radiation, which is essential as the sites are close to densely populated areas. The buildings also allow better working conditions for the staff and protect the technical equipment against moist weather conditions.

The storage buildings contain a cask reception area where the casks, after radiation and security checks, are lifted from the railway or road car. A bridge crane with a capacity of 140 t can move the casks to all handling and storage positions. The storage buildings also contain a maintenance area where the casks are prepared for storage and reshipment and where repairs can be performed. The buildings are equipped with air inlet openings in the side walls and outlets in the roof to enable natural convection heat removal.

The German AFR cask storage facilities provide for continuous monitoring of the leaktightness of each cask during the total storage period. As described in Appendix C, the CASTOR casks are pressurised with inert gas in the space between the primary and secondary lids. The interlid pressure is monitored with a pressure switch connected to an electronic monitoring system. The monitoring system provided at the Ahaus and Gorleben storage buildings will alarm if the interlid pressure drops below its specified set point.

The facilities are centralised and independent of other nuclear facilities and have all infrastructure buildings and technical equipment as well as personnel needed for a safe operation and administration.

The Jülich interim storage facility is based on the same technical cask storage concept. The facility is used to store spent fuel of the HTR pilot pebble bed reactor AVR, which has been under decommissioning for several years. The design capacity of the interim storage facility is 154 CASTOR casks which can store 3 t HM (U+TH) each. The reactor and the storage building are located on the site of the Jülich nuclear research centre. The transfer of the fuel into CASTOR casks and into the storage facility was started in 1993. At the end of 1997, 96 casks were loaded into the storage building.

Operation

The Ahaus and Gorleben storage facilities are centralised plants that are connected to heavy load public transport routes. Both facilities have a cask reception, cask handling and cask storage preparation area. The spent fuel assemblies are loaded into transport/storage casks within the delivering NPP. The primary lid is bolted to the cask body and checked for leak tightness at the NPP, while the secondary lid is only preliminarily mounted prior to shipment. The cask and the loading documents will become part of the documentation of the storage operator. The spent fuel is shipped within the casks to the storage facility.

When the casks arrive at the storage facility, site security and radiation protection checks are performed. The cask is unloaded from the car and transferred to the maintenance area. There the cask is prepared for storage by:

- fitting the secondary lid to the cask body,
- measuring leaktightness of the secondary lid and its penetrations,
- fitting and function testing of the pressure gauge,
- pressurising the interlid space with 6 bar helium
- connecting the leaktightness monitoring system.

The cask is transferred to its final position in the storage area and attached to the leaktightness monitoring system.

During the storage period, no active steps are necessary. In the case of an alarm of the leaktightness monitoring system, the cask is transferred from its position to the maintenance area. There leaktightness measurements of the secondary lid are performed. If it is not in accordance with the specification, it can be repaired by replacing the lid gaskets. If it is in accordance with the specification, it is concluded that the leaktightness of the primary lid decreased. Due to the design requirement of not handling open casks at the storage facility, the primary lid is not opened. Instead, a third lid is welded to the cask body and equipped with a pressure gauge. After pressurising the space between the secondary and the third lid, the cask again has a monitored double lid system and can be further stored in line with all safety requirements.

A total of 305 CASTOR casks with HTR fuel was accepted in the Ahaus facility from 1992 until the end of 1996. Thus, this facility has the wide experience with the cask storage concept including handling the casks, preparing them for storage and storing them in the facility. No major problems have occurred and it can be concluded that this technology can be considered safe and feasible (see Fig. 7).

FIG. 7. Ahaus storage facility.

4.3.1.5. India

Tarapur Atomic Power Station

Construction of an AFR spent fuel storage facility began at the Tarapur station in 1986, a BWR station. However, additional spent fuel storage capacity was needed prior to the AFR pool being commissioned. Spent fuel was stored in lead shielded dry storage casks as an interim measure. The facility was licensed in 1990, constructed during 1985 to 1990, and began operating in 1990. The facility has a design maximum fuel burnup of 15 000 MW d/t HM with a maximum enrichment of 2.4% ^{235}U and a minimum cooling time of 10 years.

Four casks were constructed, each with a capacity of 37 BWR fuel assemblies. The spent fuel basket used to hold spent fuel inside the storage cask is made of 3.2 mm stainless steel tubes in square arrays. The centre-to-centre spacing between storage tubes is 152.4 mm. The loaded casks are stored in a fenced area on concrete pads within the Tarapur plant boundary.

Rajasthan Atomic Power Station

The Rajasthan station dry storage project was constructed during 1994 and 1995. The facility was commissioned and began operation in 1995. The concrete dry storage casks contain PHWR spent fuel from RAPS 1 and 2. RAPS 1 and 2 use natural uranium fuel and the maximum burnup is 6900 MW d/t HM. Spent fuel must be cooled for 10 years prior to loading into the storage casks.

A dry storage cask made of concrete with a stainless steel cavity and a carbon steel outer liner was designed. The minimum concrete thickness is 750 mm. The cask lid is a concrete lined with steel plates, and a sealing plate is kept over the top lid and seal welded for containment. The casks are stored on a separate area within the site boundary. The area is designed to hold up to 224 casks.

4.3.1.6. Japan

Tokyo Electric Power, Fukushima 1

Tokyo Electric Power (TEPCO) has constructed a dry cask storage facility for the Fukushima 1 reactor. The facility consists of a seismically-designed storage building, the Cask Custody Building, in which dry storage casks are stored horizontally. The facility was licensed over the period 1992 through 1994. Construction began in 1994 and facility operation in 1995. The storage facility has a planned operating life of 40 years.

At the end of 1997, there were nine casks in the facility storing 408 fuel assemblies (73 t HM). Five large casks, containing 52 spent fuel assemblies, and four medium casks, containing 37 fuel assemblies, are stored in the Cask Custody Building. The facility is designed to store BWR fuel (8 × 8, 8 × 8RJ, 8 × 8BJ) with a maximum initial enrichment of 3.0%, a maximum burnup of 40 000 MW d/t HM, and a cooling time of four years.

4.3.1.7. USA

Virginia Power, Surry Units 1 and 2

In 1986, Virginia Power received a license for a dry storage facility located at the site of the Surry NPP. This facility is licensed to store spent fuel in metal dry storage casks of various designs. As of December 1997, 34 casks have been loaded at the Surry ISFSI; 25 GNSI CASTOR V/21s, one Westinghouse MC-10, two NAC International, Inc. NAC-I28/ST, one GNSI CASTOR X/33 and five TN-32s. These cask designs are described in detail in Appendix C.

Facility description

The Surry dry storage facility is designed to accommodate up to 84 storage casks on up to three concrete pads and is licensed to store up to 1764 spent fuel assemblies. The cask storage pads are constructed of reinforced concrete nominally 32 feet × 236 feet × 3 feet thick with a 20 foot ramp on each end for vehicle access. Each pad is designed to hold 28 casks arranged in two rows, nominally 16 feet apart centre to centre. The casks are stored in a vertical position.

Cask loading operations

The Surry storage facility uses five metal cask designs that are similar but which may have certain unique loading steps that are not included in this description. Metal casks arrive at the Surry site, are removed from the transport trailer and rotated to a vertical position by the spent fuel handling crane at the NPP. The empty cask is prepared for fuel loading including : lid(s) removal; cleaning of sealing surfaces; installation of sealing surface protectors; inspection of fuel basket; and replacement of metallic O ring seals. The cask primary lid is attached to a hoist and lifted. A lifting yoke is attached to the storage cask and the cask is lifted and transferred to the fuel building and positioned over the spent fuel storage pool.

The cask is then lowered to the bottom of the pool and the lift yoke is removed. Spent fuel assemblies, which have been verified to meet the fuel selection criteria of the cask being loaded, are transferred from spent fuel storage racks and placed in the storage cask. After the spent fuel assemblies have been loaded into the storage cask, the primary lid is installed. The cask is moved to a work area and its outer surface is decontaminated. The cask is vacuum dried and cask cavity dryness and primary lid seal leak tightness are tested. The cask cavity is backfilled with helium, the secondary lid is placed on the cask is tested for leak tightness. The interlid space is pressurised, the pressure monitor is installed, and the loaded cask is transferred to the storage facility.

Fuel selection parameters

The Surry dry storage facility is not designed to store spent fuel assemblies with known or suspected structural defects sufficiently severe to adversely affect fuel handling and transfer. Fuel selected must meet cask design specific fuel selection parameters that limit the maximum enrichment, maximum burnup, minimum cooling time and maximum decay heat. The cask specific limits range from enrichments of 1.9 to 3.7%, maximum burnup of 35 000 to 40 000 MW d/t HM, minimum cooling time 5 to 10 years, maximum decay heat 0.3 to 1.0 kW per fuel assembly.

Northern States Power Company, Prairie Island 1 and 2

In October 1993, Northern States Power Company (NSP) received a license from the NRC for an dry spent fuel storage facility using TN-40 metal storage casks at the Prairie Island site. NSP loaded its first TN-40 cask in 1995. The facility is licensed to store 48 TN-40 storage casks totalling 1920 spent fuel assemblies and is located within the boundaries of the Prairie Island site.

ISFSI description

The Prairie Island storage facility consists of two concrete pads which are designed to hold two parallel rows of twelve casks per row on each concrete pad. Both concrete pads were constructed prior to initial facility operation. An earthen berm was constructed facility to provide additional radiological shielding. A detailed description of the TN-40 cask is provided in Appendix C.

Cask loading operations

Fuel loading operations are similar to those for loading the metal casks described in the section on Virginia Power's Surry facility.

Fuel selection parameters

The following fuel assembly characteristics represent the limiting parameters for storage of spent fuel assemblies in the Prairie Island ISFSI: initial enrichment of 3.85 weight per cent ^{235}U; maximum fuel burnup of 45 000 MW d/t HM; minimum decay time of 10 years; intact fuel assemblies with no known cladding defects or physical defects which would inhibit insertion or removal of fuel from the cask basket. The Prairie Island fuel is a 14 × 14 PWR fuel design [11].

Consumers Power Company, Palisades

Consumers Power Company's Palisades dry storage facility was the first to store spent fuel in a certified cask under a general license in accordance with the US Code of Federal Regulations. In May 1993, Consumers Power loaded its first VSC-24 concrete storage cask. Presently a total of 11 VSC-24 storage casks are loaded with 264 spent fuel assemblies.

The VSC-24 system was issued a Certificate of Compliance in 1993, following completion of a Safety Evaluation Report by the US NRC and completion of a rulemaking process to add the VSC-24 system to the list of casks approved by the US NRC for use under a general license.

System description

The VSC-24 system is a vertical concrete cask system composed of a multi-assembly sealed basket (MSB) and a ventilated concrete cask (VCC). The welded MSB provides confinement and criticality control for the storage and transfer of spent nuclear fuel. The VCC provides radiation shielding while allowing cooling of the MSB and fuel by natural convection during storage. A description of the VSC-24 storage system is provided in Appendix C.

Cask loading

The VSC-24 system is loaded in the spent fuel pool in a manner similar to that of the NUHOMS system described previously. During VSC-24 system loading, the transfer cask containing an empty MSB is positioned in the spent fuel pool. A shielded ring is placed on the MSB and the transfer cask is used to remove the MSB from the spent fuel pool. The MSB, contained in the transfer cask, is drained, vacuum dried, seal welded, and backfilled with helium. The seal welds are leak tested. The MSB, in the transfer cask, is then positioned vertically over the VCC. The MSB is lowered into the VCC and the shield ring is placed over the MSB/VCC gap and the weather cover is installed. The VCC is then transferred to a concrete storage pad and is positioned on the storage pad using a hydraulic roller skid.

Spent fuel selection parameters

The VSC-24 system is designed to store only intact, unconsolidated PWR fuel assemblies meeting the specifications of the cask Certificate of Compliance. The fuel characteristics that apply to the VSC-24 system are presented in the description of the VSC-24 system in Appendix C.

Wisconsin Electric Power Company, Point Beach Units 1 and 2

Wisconsin Electric Power Company loaded its first Sierra Nuclear VSC-24 concrete cask at Point Beach Units 1 and 2 in December 1995 under a general license. The facility is designed to accommodate up to 48 VSC-24 casks.

Facility description

The facility consists of two concrete pads inside a fenced area about 400 feet long by 375 feet wide. The location is in the middle of the site to minimise off-site radiation exposure. The concrete pads are 250 feet long, 50 feet wide and three feet thick. A description of the VSC-24 system is provided in Appendix C.

Operations

The loading operation for the VSC-24 system is described in the section for the Consumers Power Company Palisades facility.

Hydrogen gas burn incident

On May 28, 1996, after loading a VSC-24 ventilated storage cask with spent fuel, an unanticipated hydrogen gas ignition occurred inside the cask during welding of the shield lid. The gas ignition displaced the shield lid upward approximately 3 inches and at a slight angle. The shield lid is approximately 9 inches thick, 5 feet in diameter, and weighs slightly less than 6400 pounds.

There was no damage to the spent fuel in the cask resulting from the gas ignition. The NRC concluded that there were no measurable releases of radioactivity from the cask, no unanticipated exposures to the staff, and no off-site radiological consequences as a result of the event.

Wisconsin Electric Power concluded that the source of the hydrogen was an electrochemical reaction between zinc in the Zinc coating used on the storage canister when in contact with the borated water in the spent fuel pool. The zinc coating was used to prevent corrosion of the multi-assembly sealed basket.

As a result of this incident, the NRC concluded that there were potential generic implications that could extend to other storage systems. NRC recommended that consideration be given to reviewing the adequacy of the chemical compatibility evaluations conducted during design reviews for all cask systems. NRC also recommended that consideration also be given to the suitability of Carbo Zinc 11 coating and similar coatings used in nuclear applications where there is the potential exposure to boric acid [12].

Energy Operations, Arkansas Nuclear One Units 1 and 2

Energy Operations uses the Sierra Nuclear VSC-24 concrete cask at Arkansas Nuclear One Units 1 and 2 under a general license. The storage facility is designed to hold 26 casks and can be expanded if necessary. At the end of 1997, the facility had four casks loaded with spent fuel. The VSC-24 design is described in Appendix C, while the loading operation is described in the section on the Consumers Power Company Palisades storage facility.

4.3.2. Cask facilities under licensing and construction

4.3.2.1. Canada

Bruce Dry Storage Facility

The Bruce Dry Storage Facility will be located at the Bruce Nuclear Power Development in Ontario, (8 × 850 MWe CANDU) and is currently under construction. Operation is expected in 1999. The facility will consist of a storage yard to hold the loaded dry storage containers (DSC). The DSCs are similar in design to the Pickering DSCs (described in Appendix C), with modifications to accommodate the different design of the Bruce fuel storage trays. Each DSC will contain 500 fuel bundles. The lid design and closure welds have also been simplified compared to the Pickering design. All welding and leak testing is done in a cask handling area adjacent to the stations' fuel bay. The sealed casks are then transported to the dry storage facility.

4.3.2.2. Germany

The Greifswald interim storage facility is based on the same technical concept as the facilities under operation described in Section 4.3.1.4 of this report. The storage is dedicated to the spent WWER fuel of the Greifswald and Rheinsberg NPPs in the former German Democratic Republic all of which have been taken out of operation. The design capacity is 80 CASTOR cask positions for about 585 t HM. The facility is located on the Greifswald reactor site. Operation is planned to start in 1998.

4.3.2.3. Lithuania

An interim spent fuel storage facility which uses dual purpose storage and transport casks has been designated for the Ignalina Nuclear Power Plant (INPP). INPP is a RBMK-1500 reactor.

The storage site is located 700 m to the south-east of Ignalina Unit 2 within the boundaries of the INPP site. The facility is planned to be constructed in several stages: (1) the first stage has a 72 cask capacity and is expecting to get its final licence in 1998; and (2) subsequent stages will be constructed as needed to provide non-stop operation of INPP until its decommissioning. The storage facility in the first stage will use the CASTOR RBMK-1500 cask design, which will store irradiated RBMK-1500 fuel in a dry environment. For the subsequent stages, licensing of a new dry concrete cask system (CONSTOR) is underway. The principal safety features that characterise the facility are:

- up to 50 year storage of spent fuel;
- the ability to ship spent fuel offsite at any time;
- 50 year design lifetime of the facility structure;
- passive heat removal;
- resistance to external events such as aeroplane crash, earthquake, tornado.

The storage site is surrounded by a reinforced concrete shielding wall and a security fence which includes an alarm system. Casks will be stored in a vertical orientation on a reinforced concrete pad. The centre-to-centre spacing between casks is 3 m. The casks will be arranged in groups on the storage pad such that the distance between cask groups is 4.1 m allowing the return of any cask to the INPP if necessary. A radiation monitoring system is provided along the perimeter of the storage facility.

The cask storage facility design also provides: a building with workshop areas, a transformer substation, checkpoint, rainwater drainage system, safeguard enclosure observation wells, and engineering service lines.

Operation

Spent fuel assemblies discharged from the reactor are cooled in the AR pool for at least one year. At this point, they may be removed from the pool for cutting in the cutting bay of the reactor building. The assemblies are cut into halves (two fuel bundles with the central rods and carrier tubes removed) and placed into 102-seat transport baskets and moved to the AR spent fuel pools for storage. Baskets with spent fuel assemblies remain in the storage pools until they are loaded into CASTOR casks to be transferred to the dry storage facility site. Failed fuel assemblies will not be stored in the dry storage facility.

There are six operational modes for the dry storage facility. These include:

(1) Mode 1: unloading of clean empty casks from the transportation vehicle at a rate of 2 casks per month.

(2) Mode 2: Storage of empty cask.

(3) Mode 3: Empty cask delivery to the power units.

(4) Mode 4: Transportation of the loaded casks to the storage facility at a rate of 3 casks per month.

(5) Mode 5: Storage of spent fuel.

(6) Mode 6: Dispatch of defective casks from the storage mode.

The facility will operate in Mode 4 for approximately 3 years from the moment of its commissioning until its capacity is fully exhausted. Mode 4 includes the operation of loaded cask transport to the storage facility, inlet dose control, and placing the cask in the storage position.

Mode 5 begins with the reception of the first loaded cask and lasts until the facility is decommissioned, but not more than 50 years. This storage mode allows for period testing of each cask for leak tightness. In highly improbable situations, such as loss of leak tightness, violation of seals, and other serious deviations from the normal conditions, Mode 6 will be used.

Design basis fuel

The design basis fuel is UO_2 fuel with initial enrichment 2.4% ^{235}U with the average burnup 20 MW d/kg for 5 year cooled spent fuel.

Cask description

The CASTOR RBMK-1500 cask design is described in Appendix C as part of the CASTOR family of casks.

4.3.2.4. USA

Commonwealth Edison, Dresden Unit 1

The Dresden station consists of three reactors. Dresden Unit 1 was permanently shutdown in 1978. In 1993, Commonwealth Edison decided to remove the fuel from the Dresden Unit 1 spent fuel pool for two reasons: (1) there was a risk of leakage of cooling water with increasing pool age; and (2) concerns regarding the corrosion of spent fuel pool rack support bolts. Following an evaluation of alternatives for emptying the Dresden 1 storage pool, Commonwealth Edison selected dry storage as the preferred approach.

Commonwealth Edison Company plans to use Holtec International's HI-STAR (**H**oltec **I**nternational **S**torage, **T**ransportation, and **R**epository) cask system at Dresden Unit 1. The HI-STAR 100 cask system is undergoing NRC review for storage and transport licensing. The Dresden 1 dry storage facility will include 11 HISTAR casks, with capacity of 68 BWR assemblies per cask.

The Holtec HI-STAR 100 cask system is described in Appendix C.

Portland General Electric, Trojan

Portland General Electric plans to use a transportable version of Sierra Nuclear's VSC-24 concrete cask system, the TranStor Storage System, at its Trojan plant, which was shut down for decommissioning in 1992. Sierra Nuclear is designing the system in conjunction with BNFL, which will be responsible for the transportation cask technology for TranStor. Construction of the storage facility began in 1997.

Facility description

The storage facility will consist of a reinforced concrete pad, supporting a maximum of 36 TranStor storage systems. It is anticipated that 35 storage canisters and concrete casks will be required. Thirty-three of the canisters will have baskets designed to store intact PWR fuel assemblies and assemblies containing damaged fuel or fuel debris. Two of the canisters will have baskets designed to store intermediate level waste.

The system is designed to permit the transfer of the canister to a shipping cask directly from the concrete cask. The TranStor shipping cask is being licensed separately from the Trojan facility by Sierra Nuclear. The shipping cask is also designed to accommodate recovery from postulated off-normal events without reliance on the spent fuel pool.

A description of the TranStor system is provided in Appendix C. The loading of the TranStor system for storage is similar to that of the VSC-24 system described earlier and will not be described again.

Spent fuel to be stored

A total of 780 fuel assemblies will be loaded — 732 of the Westinghouse 17 × 17 design and 48 of the B&W Fuel Company 17 × 17 design. Fuel assemblies may contain inserts which consist of rod cluster control assemblies or burnable poison rod assemblies, thimble plugs and sources.

The maximum burnup for 5 year cooled fuel that can be stored is 40 000 MW d/t HM and for 6 year cooled fuel it is 45 000 MW d/t HM. The corresponding initial enrichments are 3.2% ^{235}U and 3.3% ^{235}U, respectively. Decay heat is limited to 1.08 kW per assembly with a limit of 26 kW for the entire fuel canister. The fuel cladding temperature limit is 388°C.

Virginia Power, North Anna Units 1 and 2

In May 1995, Virginia Power Company submitted a license application for a dry storage facility for a site specific license at North Anna Units 1 and 2. This storage facility will initially use Transnuclear's TN-32 cask. Virginia Power plans to have a license for this facility by 1998. A sketch of the TN-32 cask is given in Figure 8.

Facility description

The facility will be located near the centre of the North Anna site. It will consist of three concrete storage pads on which the sealed storage casks will be placed. The storage pads will be built in sequence, as needed, and in an order which minimises radiation exposure. The storage pads will be surrounded by two security fences. A third fence will enclose the perimeter of the site. The facility is designed to accommodate a total of 84 storage casks and a total of 1824 spent fuel assemblies.

The loading and preparation of the storage casks will be similar to that described for the Surry facility.

Spent fuel to be stored

The design basis characteristics of the fuel to be stored include a maximum initial enrichment of 4.3% ^{235}U, a maximum burnup of 45 000 MW d/t HM, and a minimum cooling time of seven years.

4.4. Silo facilities

Silo facilities have been constructed in Argentina, Canada, and the USA using a variety of silo dry storage technologies. The AECL concrete canister system and the NUHOMS horizontal storage modules are classified as silo dry storage systems in this report. Silo facilities are under licensing and construction in the USA. These facilities are expected to begin operation between 1997 and 1999. Table X summarises international experience with dry storage in silo facilities.

4.4.1. Silo facilities in operation

4.4.1.1. Argentina

An interim dry storage facility was built at the Embalse nuclear power station prior to the pool storage capacity being exhausted in 1993. The fuel to be stored is of the CANDU 600 type, with a burnup of 7500 to 8500 MW d/t HM. The temperature of the fuel rod clad must not exceed 200°C. This requires a residence time of seven years in the spent fuel storage pool prior to the fuel being loaded into the dry storage facility. Facility construction took approximately three years [13].

The storage system design encloses the spent fuel in steel containers (baskets) that are stored in concrete canisters and stored at a dry storage facility on the Embalse reactor site. The concrete canisters have a metal liner. The steel basket holding the fuel assemblies is hermetically sealed by an automatic metal inert gas welding process.

The storage system has three separate sectors: the working area in the spent fuel pool building, the transfer building, and the storage canister yard. The system comprises two modules of 40 canisters each, accommodating spent fuel produced in ten years of operation of the power station. More modules will be constructed to store all of the spent fuel produced in the future at Embalse. The canister yard is within the site protected area and thus complies with security and radiological protection rules.

Spent nuclear fuel can be removed from the canisters when its final destination is decided. The life span of the canisters permits 50 to 100 years of safe storage. The canisters are com-

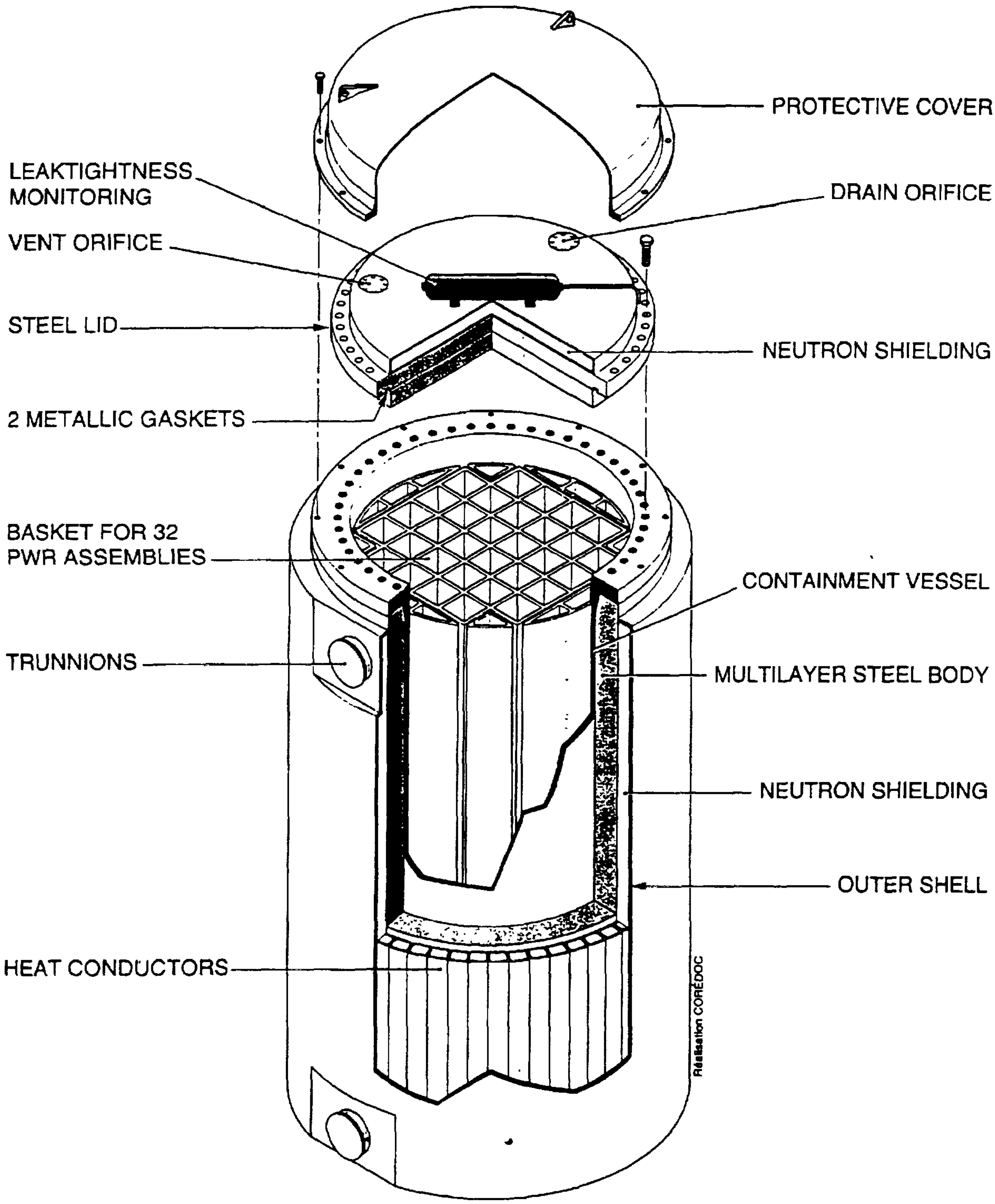

FIG. 8. TN-32 cask.

TABLE X. SUMMARY OF EXPERIENCE WITH DRY STORAGE IN SILO FACILITIES

Country/facility	Fuel type	Design capacity (t HM)	Current inventory (t HM)	Operating period
Argentina				
Embalse	CANDU	1000	–	1993 to present
Armenia				
Medzamor	WWER	73.5	0	Planned
Canada				
Whiteshell Laboratory	CANDU	25	25	1977 to present
Gentilly 1	CANDU	67	67	1985 to present
Douglas Point	CANDU	298	298	1987 to present
NPD	CANDU	75	75	1989 to present
Point Lepreau	CANDU	1 026	472	1991 to present
Gentilly	CANDU	3 648	401	1995 to present
Pickering	CANDU	1 375	381	1996 to present
Korea, Republic of				
Wolsong-1	CANDU	609	609	1992 to present
Wolsong-1	CANDU	812	0	Planned
USA				
Calvert Cliffs	PWR	1 112	154	1992 to present
Davis Besse	PWR	360	33	1995 to present
H.B. Robinson	PWR	26	26	1986 to present
Oconee	PWR	980	375	1990 to present
Oyster Creek	BWR	190	0	Planned 1998
Rancho Seco	PWR	202	0	Planned 1998
Susquehanna	BWR	343	0	Planned 1998

pletely independent of the systems of the power station, needing no maintenance once they have been loaded and sealed. Events such as earthquakes, floods and tornadoes, and the risk of explosions have been considered in the design of the storage system. The general criteria on radiological protection adopted were those of the International Commission on Radiological Protection and the regulations of the Argentine regulatory authority.

Transfer of spent fuel from the storage pool occurs by loading the grid that constitutes the base of the basket at the bottom of the pool. The loaded grid is then placed in a special shielded container and carried from the pool to the transfer building, adjacent to the fuel pool building. Once in the transfer building, the container is placed in the operations cell. There, under concrete shielding, by remote control and using automatic devices, the grid is extracted from the container, dried, covered with the upper section of the basket and welded. The loaded and sealed basket is then placed in the shielded transfer container through the transfer threshold of the cell and carried to the canister area on a transport car.

The transfer container is made of lead, covered and reinforced with steel. Its lower part, which had rested on the transfer threshold of the cell, will now rest on the upper opening of the canister. The introduction and extraction of the basket is through a manually actuated sliding gate located at the base of the container.

4.4.1.2. Armenia

Due to the unavailability of nuclear fuel reprocessing or a permanent geologic repository in Armenia, long-term storage of spent fuel assemblies has become necessary. An interim storage facility using the NUHOMS system supplied by FRAMATOME has been chosen for the Medzamor site where 2 WWER-440 reactors were constructed and one unit is operating presently. As the number of assemblies to be stored in one module is 56, the model type is designated NUHOMS®-56V.

To enable the storage of 612 assemblies, construction of 11 horizontal storage modules (HSM) has been decided. The 11 HSM are grouped together to form 2 arrays of respectively 5 and 6 HSM. The two arrays are arranged back to back.

The criticality analysis performed for the NUHOMS-56V DSC fuel does not account for fuel burnup but takes credit for soluble boron and demonstrates that fixed borated neutron absorbing material is not required in the basket assembly for criticality control.

4.4.1.3. Canada

Silo facilities have operated in Canada since 1977 at AECL's Whiteshell Laboratories (WL). Canadian Silo Facilities use the AECL designed concrete canisters (CC). They are used by AECL at WL, Gentilly 1, Douglas Point and Chalk River sites to store spent fuel from research and prototype CANDU reactors. The CCs are fitted with a carbon steel liner, and are 2.6 m in diameter and 5.4 m to 6.3 m in height. Spent fuel is mainly stored inside stainless steel baskets in an air environment. A few carbon steel baskets are also used, in which case helium cover gas is applied. Storage capacity of the CC's is approximately 6.6 t HM and heat dissipation capacity is up to 2.5 kW. The Point Lepreau Dry Irradiated Fuel Storage Facility stores spent fuel from the operating Point Lepreau 680 MW(e) CANDU reactor. The CC's diameter is 3 m and its height is 6.3 m and it contains 10 t HM spent fuel. Heat rejection capability of the CC is around 3 kW.

Each concrete canister contains nine fuel baskets each containing 60 CANDU fuel bundles (102 mm diameter and 495 mm length). The spent fuel bundles are first manually loaded underwater into the fuel baskets. The shielded work station (SWS) is installed beside the pool's edge. The equipment used is similar but larger than the one used on previous projects. The fuel baskets are then lifted out of the water and into the SWS through a chute. The basket is then drained, dried and seal welded in the SWS, forming the primary confinement seal. The fuel baskets are lifted into a transfer cask and brought by trailer to the storage site. A gantry crane is used to lift the transfer cask over the CC fitted with a loading platform. The fuel basket is lowered into the concrete canister. Once filled with 9 baskets, the liner is seal welded with the shield plug liner thus forming the secondary confinement seal. The CC cover is installed and the dry storage unit placed in operation. Yearly monitoring of the concrete canister internal cavity is made to verify leak tightness.

Whiteshell laboratories

The Whiteshell Laboratories (WL) Concrete Canister Facility began operating in 1977 and has a 50 year operating life. Its storage capacity is 24.6 t HM. The WL Concrete Canister Facility is used to store the complete fuel inventory from the decommissioned WR1 experimental reactor. The fuel is transported to WL's Shielded Facilities where it is placed into the canister storage baskets. Once a basket is full, it is seal welded closed and filled with helium. Each loaded basket is transported using the fuel basket transfer cask by truck to the canister site. A gantry is used to lift the basket from the truck onto the top of the canister. The fuel basket is then unloaded from the cask into the canister.

Once the canister is loaded with the prescribed quantity of fuel, the canister plug is seal welded in place. The weather cover is put in place and the unit placed in operation.

The facility consists of AECL concrete canisters — 15 production canisters as well as 2 experimental canisters. Each canister has a capacity of 6 baskets per canister, the capacity depending upon the fuel enrichment and fuel type. The concrete canisters are 5.4 metres high with a diameter of 2.59 metres. They are made of regular density reinforced concrete. Concrete shielding thickness is 0.89 metres. The fuel baskets and concrete canister liners are constructed of carbon steel. A total of 2263 bundle and element storage cans are stored in the concrete canisters at WL.

The facility is licensed to store ten different fuel types with 20 different enrichments. Spent fuel burnup is 10 000 MW d/t HM WR1 driver fuel (nominal). Enrichments vary from natural uranium fuel up to 95 wt.% ^{235}U. Spent fuel must be aged for a minimum of 18 months prior to loading into the canisters. Damaged fuel elements can be stored if they are enclosed in element storage cans prior to being placed in fuel baskets. The maximum cladding temperature during storage is 50°C above ambient temperature.

Gentilly 1

The Gentilly 1 Irradiated Fuel Storage Facility stores the complete inventory of the decommissioned Gentilly 1 prototype reactor. The reactor operated for only 183 effective full power days before being shut down. The inventory is contained in 11 concrete canisters that were built in-place in the turbine building. Each concrete canister contains 8 fuel baskets each containing 38 Gentilly 1 type CANDU fuel bundles (10.24 mm diameter and 500 mm length). The facility capacity is 67 t HM for a total of 3213 fuel bundles.

The spent fuel bundles were manually loaded underwater into the fuel baskets. A shielded work station (SWS) was installed besides the pool's edge. The fuel baskets were then lifted out of the water and into the SWS through a chute. The baskets were drained, dried and seal welded in the SWS, forming the primary confinement. The fuel baskets were then lifted into a transfer cask and brought by trailer to the storage site. A gantry crane was used to lift the transfer cask over the concrete canister fitted with a loading platform. The fuel baskets were then lowered into the concrete canister. Once filled with 8 baskets, the concrete canister liners were seal welded with the shield plug liner thus forming the secondary confinement seal. The concrete canister covers were installed and the dry storage unit placed in operation. Yearly monitoring of the concrete canister internal cavity is made to verify leak tightness.

The concrete canisters are 6 metres high and 2.59 metres in diameter. The canisters are made of regular density reinforced concrete, with a concrete shielding thickness of .864 metre. The fuel basket is fabricated from stainless steel and the concrete canister inner liners are constructed of carbon steel.

Maximum fuel burnup is 4683 MW d/t HM and the average burnup of fuel stored is 2225 MW d/t HM. The CANDU fuel bundles are natural uranium fuel with a 0% enrichment. Spent fuel must be stored for 7 years prior to loading into the storage containers. Only intact fuel bundles may be stored. The maximum cladding temperature is less than 52°C.

Douglas Point

The Douglas Point Dry Irradiated Fuel Storage Facility stores the complete inventory of the decommissioned Douglas Point prototype reactor. The concrete canisters are built in-place and outdoors in 4 rows of 12 for a total of 47 (46 loaded + one spare). Each concrete canister contains 9 fuel baskets each containing 54 smaller diameter CANDU fuel bundles (81.7 mm diameter and 495 mm length). The facility capacity is 294 t HM for a total of 22 256 bundles.

The spent fuel bundles were manually loaded underwater into the fuel baskets. The shielded work station (SWS) was installed beside the pool's edge. The equipment used was the same as that used for the Gentilly 1 dry spent fuel storage program two years earlier. The fuel baskets were then lifted out of the water and into the SWS through a chute. The basket was then drained, dried and seal welded in the SWS thus forming the primary confinement seal. The fuel baskets were lifted into a transfer cask and brought by trailer to the storage site. A gantry crane was used to lift the transfer cask over the concrete canister fitted with a loading platform. The fuel baskets were lowered into the concrete canister. Once filled with 9 baskets, the concrete canister liner was seal welded with the shield plug liner thus forming the secondary confinement seal. The concrete canister cover was installed and the dry storage unit placed in operation. Yearly monitoring of the concrete canister internal cavity is made to verify leak tightness.

The concrete canisters are 6.157 metres high and 2.59 metres in diameter. The canisters are made of regular density reinforced concrete, with a concrete shielding thickness of 0.864 metre. The fuel basket is fabricated from stainless steel and the concrete canister inner liners are constructed of carbon steel.

Maximum fuel burnup is 5520 MW d/t HM. The CANDU fuel bundles are natural uranium fuel with a 0% enrichment. Spent fuel must be stored for 3 years prior to loading into the storage containers if mixed with longer cooled fuel bundles. The container is designed to store intact or failed fuel assemblies. The maximum cladding temperature is less than 150°C.

NPD fuel dry storage facility

The NPD-fuel dry storage facility stores the complete inventory of the decommissioned NPD (Nuclear Power Demonstrator) prototype reactor. The facility also contains fuel bundles from operations of Chalk River reactors. The spent fuel from NPD was first transported by road over 20 km to the Chalk River NRX reactor pool. The transportation was made with the rented Pégase cask from Transnucléaire. The shielded work station (SWS) was installed besides the NRX pool's edge. The concrete canisters are located outdoors on a site located at the waste management area D, outside of the main reactor and laboratories area. The concrete canisters were built in-place in 3 sets of 4 for a total of 12 (11 loaded + one spare) and a spare pad built for 4 more concrete canisters. Each concrete canister contains up to 9 fuel baskets each containing 54 smaller diameter CANDU fuel bundles (81.7 mm diameter and 495 mm length). There are 14 baskets loaded with enriched fuel bundles from Chalk River reactors. The facility capacity is 75 t HM for a total of 4853 fuel bundles.

The spent fuel bundles were manually loaded underwater into the fuel baskets. The equipment used was the same as that used for the Gentilly 1 and Douglas Point dry spent fuel storage program 2 years earlier. The fuel baskets were then lifted out of the water and into the SWS through a chute. The baskets were drained, dried and seal welded in the SWS thus forming the primary confinement seal. The fuel baskets were lifted into a transfer cask and brought by trailer to the storage site. A gantry crane was used to lift the transfer cask over the concrete canister fitted with a loading platform. The fuel basket was lowered into the concrete canister. Once filled with 9 baskets, the concrete canister liner was seal welded with the shield plug liner, forming the secondary confinement seal. The concrete canister cover was installed and the dry storage unit placed in operation. Yearly monitoring of the concrete canister internal cavity is made to verify leak tightness.

The concrete canisters are 6.157 metres high and 2.59 metres in diameter. The canisters are made of regular density reinforced concrete, with a concrete shielding thickness of 0.864

The fuel basket is fabricated from stainless steel and the concrete canister inner liners are constructed of carbon steel.

The average burnup for natural ^{235}U fuel is 3750 MW d/t HM and for enriched fuel 5808 MW d/t HM. There are 4104 bundles with an initial enrichment of 0% ^{235}U, 94 bundles with depleted ^{235}U, and 655 bundles with 1.4% ^{235}U. Spent fuel must be stored for 2 years prior to loading into the storage containers if mixed with longer cooled fuel bundles. The container is designed to store intact or failed fuel assemblies. The maximum cladding temperature is less than 150°C for natural uranium fuel and less than 175°C for enriched uranium fuel.

Point Lepreau

The Point Lepreau Dry Irradiated Fuel Storage facility stores spent fuel from the operating Point Lepreau 680 MW(e) CANDU reactor. The facility began operating in 1991. The concrete canisters are built in-place and outdoors in 20 rows of 5 for a total of 100. Each concrete canister contains 9 fuel baskets each containing 60 normal diameter CANDU fuel bundles (102 mm diameter and 495 mm length). The design capacity is 3078 t HM, while the capacity of the facility constructed is 1026 t HM. The inventory of fuel in storage as of end of 1997 is approximately 649 t HM. In 1996, 100 concrete silos have been constructed.

The spent fuel bundles are manually loaded underwater into the fuel baskets. The shielded work station (SWS) is installed besides the pool's edge. The equipment used is similar but larger than that used on previous projects. The fuel baskets are lifted out of the water and into the SWS through a chute. The basket is drained, dried and seal welded in the SWS thus forming the primary confinement seal. The fuel baskets are then lifted into a transfer cask and brought by trailer to the storage site. A gantry crane is used to lift the transfer cask over the concrete canister fitted with a loading platform. The fuel basket is then lowered into the concrete canister. Once filled with 9 baskets, the concrete canister liner is seal welded with the shield plug liner thus forming the secondary confinement seal. The concrete canister cover is installed and the dry storage unit placed in operation. Yearly monitoring of the concrete canister internal cavity is made to verify leak tightness.

The concrete canisters are 6.325 metres high and 3.05 metres in diameter. The canisters are made of regular density reinforced concrete, with a concrete shielding thickness of .96 metre. The fuel basket is fabricated from stainless steel and the concrete canister inner liners are constructed of carbon steel.

The average burnup for natural ^{235}U fuel is 7800 MW d/t HM. The maximum burnup is 12083 MW d/t HM. Spent fuel must be cooled for 7 years prior to loading into the storage containers. Only intact fuel bundles may be stored. The maximum cladding temperature is less than 150°C for 7 year cooled spent fuel.

4.4.1.4. Republic of Korea

Wolsong

The dry spent fuel storage facility for Wolsong 1 CANDU 600 MW(e) reactor went into operation in 1992. It uses the AECL designed silo (concrete canister) system which is identical to the one operating at Pt. Lepreau station in Canada.

The spent fuel storage site is about 350 m away from the reactor. The fuel is transferred during a 6 week campaign, once a year. The stored inventory is approximately 609 t HM.

4.4.1.5. USA

Carolina Power & Light, H.B. Robinson Unit 2

Carolina Power and Light Company (CP&L) entered into a co-operative agreement with the US DOE to conduct a licensed dry storage demonstration at H.B. Robinson Unit 2 using the horizontal modular storage (NUHOMS) system.

Facility description

The NRC licensed the H.B. Robinson dry storage facility in August 1986 for the NUHOMS-07P horizontal modular concrete storage system. The facility is licensed for eight modules, which have been loaded with a total of 56 spent fuel assemblies.

The H.B. Robinson ISFSI demonstration program included the construction of three horizontal storage modules (HSM). One dry-shielded canister (DSC) is stored in each HSM. Each DSC contains seven intact PWR fuel assemblies. Descriptions of the NUHOMS-07P HSM and DSC designs are provided in Appendix C.

Transfer equipment consists of a transfer cask, hydraulic positioning system, and a horizontal hydraulic ram. The H.B. Robinson dry storage facility used an IF-300 transportation cask (modified to extend the cavity length) for transfer of the DSC from the spent fuel pool to the HSM. A hydraulic positioning system was used to align the transfer cask with the HSM for transfer of the DSC. The hydraulic ram grapple connects to the DSC for insertion and removal from the HSM.

Loading operations

The cask and DSC are prepared prior to loading. This includes exterior washdown and interior decontamination of the transfer cask and cleaning the exterior and interior of the DSC. The empty DSC is inserted into the transfer cask. The cask to DSC annulus and DSC interior are filled with deionized water. A seal is installed over the cask annulus to prevent contamination of the outer surface of the DSC. Using approved procedures, spent fuel that has been identified and verified for loading, is loaded into the DSC basket. The DSC upper end shield plug is placed inside the DSC.

The loaded cask is lifted from the spent fuel pool and placed in the decontamination area. The overhead crane is equipped with a redundant yoke during this operation. The seal is removed from the cask annulus. The water level in the DSC is drained to approximately two inches below the bottom surface of the top lead shield plug. A seal weld is applied to the interface of the DSC shell and the lead shield plug. This is the DSC primary containment seal. The remaining water is removed from the DSC interior and the interior of the DSC is vacuum dried. The DSC is backfilled with helium. The vent and drain line connectors are plugged, welded closed and checked for helium leakage. The steel cover plate is placed on the DSC and is seal welded to serve as the second containment barrier.

The cask is lifted from the decontamination area by crane with a redundant lifting yoke and is placed next to the transfer skid/trailer. The cask is lifted onto the skid and secured to the frame. The transfer trailer is towed to the HSM and is backed into position. The HSM front access cover is raised and removed. The DSC is pulled into the HSM by the hydraulic ram. After the DSC is in the HSM, the hydraulic ram is released from the DSC. The transfer trailer is pulled away and the HSM front access cover is closed. The rear access cover plate is also installed.

Duke Power, Oconee Units 1, 2, and 3

Duke Power Company received a site-specific license for a NUHOMS-24P horizontal modular concrete storage system at its Oconee site in January 1990. At the end of 1997, the Oconee ISFSI had 816 assemblies stored in 34 NUHOMS-24P modules. The site is licensed for up to 88 modules, each of which contain 24 PWR assemblies — or a maximum of 2112 spent fuel assemblies.

Facility description

The NUHOMS-24P system is similar in design and construction to the NUHOMS-07P system used at the H.B. Robinson ISFSI. The NUHOMS-24P system provides horizontal dry storage of canisterized spent fuel assemblies in a concrete horizontal storage module (HSM). The cask storage components consist of a reinforced concrete HSM and a dry storage canister (DSC) containment vessel with an internal basket assembly to hold the fuel assemblies. The NUHOMS-24P also utilises transfer equipment to move the DSCs from the plant fuel building where they are loaded with spent nuclear fuel to the ISFSI where they are stored in HSMs. The transfer system includes a transfer cask, a lifting yoke, a hydraulic ram system, a prime mover for towing, a transport trailer, a cask support skid, and a skid positioning system. This transfer system interfaces with the existing plant fuel pool and the cask handling crane. Auxiliary equipment such as a cask/canister annulus seal, a vacuum drying system, and an automated welding system are also used during DSC loading and storage preparation.

Additional information on the NUHOMS-24P HSM and DSC components is provided in Appendix C.

Spent fuel to be stored

The heat generation is limited 0.66 kW per fuel assembly. This value is based on the storage of 24 assemblies per DSC with a nominal burnup of 40 000 MW d/t HM, an initial enrichment of 4.0% ^{235}U and a nominal decay period of ten years. Other combinations of burnup, initial enrichment and cooling times may also be acceptable upon further analysis demonstrating acceptable decay heat levels [14].

Baltimore Gas and Electric Company, Calvert Cliffs 1 and 2

In November 1992, Baltimore Gas & Electric Company received a site-specific license for the Calvert Cliffs dry storage facility which uses the NUHOMS-24P storage system. At the end of 1997, the Calvert Cliffs facility had 14 NUHOMS-24P modules loaded with 336 spent fuel assemblies. The Calvert Cliffs facility is licensed to store a total of 2880 fuel assemblies in 120 storage modules, or approximately 1112 t HM.

The Calvert Cliffs facility uses the same NUHOMS-24P storage technology described for the Duke Power Oconee facility, with some revisions to accommodate a slightly different fuel assembly design. The NUHOMS-24P system is described in Appendix C. The main difference between the Calvert Cliffs DSC and the DSC design approved in the NUHOMS-24P topical report are: the addition of one spacer disk for a total of nine to accommodate the Calvert Cliffs fuel which has nine spacer grids; thinner spacer disks with wider ligaments; an additional 0.5

inches of lead in both shield plugs; and a shorter overall length accounting for the shorter fuel assembly design.

There are also differences in the HSM design details compared to those for the NUHOMS-24P system described in Appendix C. These include changes to the HSM DSC rail support beam, the HSM shear reinforcement, HSM foundation size, DSC seismic restraints, the HSM rebar design, and the shielding on the HSM door.

Spent fuel to be stored

Spent fuel assemblies to be stored in the Calvert Cliffs storage facility have a maximum decay heat of 0.66 kW per assembly. Initial enrichment must be less than 4.5% ^{235}U. Radiological source terms are calculated for the range of spent fuel to be stored in the ISFSI.

Centerior Energy (Toledo Edison), Davis Besse

During 1995, Centerior Energy loaded the first spent fuel from its Davis Besse plant into the NUHOMS-24P standardised storage system under a general license. The Davis Besse storage facility has been designed to store up to 32 concrete modules for a total capacity of 768 spent fuel assemblies. At the end of 1997, a total of 72 assemblies had been loaded into 3 NUHOMS-24P storage modules.

Davis Besse was the first to use the standardised NUHOMS system. The US NRC issued a Certificate of Compliance in January 1995 for the standardised NUHOMS system, which includes a NUHOMS-52B DSC for storage of 52 BWR fuel assemblies along with the NUHOMS-24P DSC. A description of the Standardised NUHOMS-24P/52B design is included in Appendix C.

4.4.2. Silo facilities under licensing and construction in the USA

4.4.2.1. GPU Nuclear Corporation, Oyster Creek

GPU Nuclear plans to use the NUHOMS-52B certified storage system under a general license for dry storage at its Oyster Creek plant. The facility is designed to store 1040 spent fuel assemblies in 20 concrete modules. The standardised NUHOMS-52B system design is in Appendix C.

4.4.2.2. Pennsylvania Power & Light Company, Susquehanna Units 1 and 2

Pennsylvania Power and Light Company plans to use the NUHOMS-52B certified storage system under a general license for dry storage at Susquehanna Units 1 and 2. The initial phase of the storage facility will consist of 75 to 80 storage modules on one concrete pad. The standardised NUHOMS-52B system design is described in Appendix C.

4.4.2.3. Sacramento Municipal Utility District, Rancho Seco

A site specific license application for a dry storage facility has been filed for the Sacramento Municipal Utility District's (SMUD) Rancho Seco site, which was shut down in 1989. SMUD plans to use the NUHOMS-MP187 dual purpose storage and transport system. The NRC is reviewing its design for spent fuel storage and for transportation licensing. SMUD plans to use the NUHOMS-MP187 transportation cask as a backup storage system for recovery actions to enable decommissioning of the spent fuel pool prior to the spent fuel being removed from the site. The ISFSI would include 22 concrete storage modules one of which is designed to store failed fuel assemblies. A total of 493 spent fuel assemblies will be stored in the facility.

The horizontal storage modules used with the MP187 canister for on-site spent fuel storage is the similar to that described in the Standardised NUHOMS-24P system in Appendix C. Loading operations would be the similar to the H.B. Robinson operations. Additional loading procedures would be required to transfer the NUHOMS-24P storage canister from the HSM to the NUHOMS-MP187 transportation cask.

Spent fuel to be stored

The fuel assembly characteristics for the Rancho Seco B&W 15 × 15 Mark B fuel to be stored in the MP-187 include a maximum enrichment of 3.43% and a maximum burnup of 38 268 MW d/t. The NUHOMS MP-187 design is described in detail in Appendix C. The NUHOMS-MP187 transport cask can be used in a storage mode. This would only be required for demonstration purposes at Rancho Seco or in the unlikely event that DSC leakage occurred at a time when the Rancho Seco spent fuel pool was not available for recovery actions. Under normal operations the MP-187 DSC would be stored in a concrete, horizontal storage module similar to those used at Oconee, Calvert Cliffs and Davis Besse.

5. TRANSPORTATION OF SPENT FUEL

5.1. Introduction

Transportation of spent fuel is a well established activity with a good safety record extending over 40 years. Regulations governing the safe transport of radioactive materials have been published in the IAEA Safety Standards Series No. ST-1 (1996 Edition) [15] and many Member States have established national regulations based on these recommendations. Experience with spent nuclear fuel transport is discussed in the following section.

5.2. Interim storage location

Whichever fuel cycle policy option is selected (reprocessing, direct final disposal or interim storage waiting for policy selection), spent fuel will have to be transported between reactor sites and reprocessing, storage, and final disposal sites. It is important to document the continuing safety of shipments occurring worldwide.

5.3. Recent developments

Dual purpose storage and transport systems have been in use in Europe — both casks from the TN24 cask family and the CASTOR cask family. In the USA, the NAC-STC is licensed for transport and has a US NRC approved topical report for storage. In addition, several canister-based transportable storage systems are under development and are being reviewed by the US NRC for both storage and transport requirements. Many of these systems are planned to be used for storage at reactor sites, as described in Section 4.

5.4. International experience in spent fuel transport

Since the majority of spent fuel has been transported from AR storage facilities to AFR (OS) storage facilities for either interim storage or reprocessing, it is useful to document the number of assemblies and metric tons of spent fuel shipped between these facilities to demonstrate that shipments can be made safely on a routine basis. An excellent safety record has be established while shipping over 88 000 t HM over the last 25 years by sea, road and rail [16].

Table XI summarises the spent fuel transport from countries that have substantial experience in transporting spent fuel from power reactors. Efforts were made to include only shipments of spent fuel and not empty cask shipments. The data presented indicate shipments originating in the countries shown. For example, the LWR fuels shipped by France indicates only that fuel from French AR storage pools shipped to AFR (OS) storage facilities, it does not include spent fuel shipped from other countries to France. Only fuel shipped from Japan to Europe is indicated in the data provided for Japan. In addition, on reactor site spent fuel transports (from the reactor to an AFR (RS) facility) have not been included.

TABLE XI. WORLDWIDE EXPERIENCE WITH SPENT FUEL TRANSPORTATION

	t HM		Number of casks	
	Other fuels	LWR fuels	Other fuels *	LWR fuels **
Belgium	–	630	–	350
Canada	100	–	187	–
Czech Republic	–	230	–	65
Finland	–	233	–	65
France	10 507	9006	–	1570
Germany	7	4540	305	1307
Hungary	–	258	–	72
Japan	2188	4185	200	1199
Netherlands	–	257	–	295
Russian Federation	1000	2500	100	400
Slovakia	60	320	600	100
Spain	1900	154	380	100
Sweden	–	2700	–	900
Switzerland	–	649	–	267
Ukraine	–	1300	–	300
UK	43 177	–	28 854	–
USA	9	2200	125	2300
Total:	58 948	29 162	30 751	9290
	88 110		40 041	

* Other fuels include GCR, Magnox, RBMK, CANDU, AGR and HTR fuels.
** LWR fuels include PWR, BWR and WWER fuels.

The purpose of relating this information is that while some countries may have limited spent fuel transport experience at the present time, international experience is substantial. As countries with more limited experience begin to plan transportation programs, it may be useful to look to the experience gained by countries with long-term and ongoing spent fuel transport programs.

Table XII provides an overview of the types of spent fuel transport casks used by countries with substantial spent fuel transport experience. Both wet and dry transport casks are used for spent fuel transport. Only casks currently in use for shipping spent fuel originating in the countries indicated from that country's RS storage facilities to AFR (OS) facilities are included.

TABLE XII. CASK TYPES USED FOR SPENT FUEL TRANSPORTATION

Country	Type of fuel	Cask type	Cask designation
Belgium	LWR	Dry	TN
		Wet	NTL-15
Canada	CANDU	Dry	
Czech Republic	WWER-440	Wet	TK-6, CASTOR
Finland	WWER-440	Wet/Dry	TK-6
France	LWR	Wet	NTL 3, 11, 14
		Dry	Excellox 3B, LK 100
			TN 8, 9, 10, 12, 13, 17
Germany	LWR	Dry	CASTOR
		Wet	NTL11, Excellox-6
Hungary	WWER-440	Wet/Dry	TK-6
Japan	LWR	Dry	HZ-75T, TN12, TN17
		Wet	Excellox 3A, 3B and 4
Russian Federation	BN-600	Dry	TK-11
	WWER-440	Wet/Dry	TK-6
	WWER-1000	Dry	TK-10, TK-13
Slovakia	WWER-440	Wet/Dry	TK-6, CASTOR 84
	Other		TK-15
Spain	LWR		NTL5, 7, 11
Sweden	LWR	Dry	TN-17
Switzerland	LWR	Dry	NTL-9
		Wet	Excellox-6, NTL-11
United Kingdom	Magnox		Magnox
	AGR		AGR
USA	LWR		NLI-1/2
			AAC-1
			TN-8
			TN-9
			IF-300

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APPENDICES A–C

Appendix A

MULTI-ELEMENT BOTTLES

Multi-element bottles (MEBs), are basically stainless steel cylindrical tubes with a welded base, removable lid and an internal grid for fuel location. The grid contains neutron poison material for criticality control. Integral pipework allows liquor or gas within the MEB to be purged and replaced without lid removal. MEBs are made in a variety of sizes to match the fuel to be accommodated and the transport flask, but can be split into boiling or pressurised water reactor fuel types (see Fig. 9).

The introduction of MEBs has offered several advantages over conventional forms of water reactor fuel storage and are:

- Substantial reduction in operator dose uptake from transport flasks due to prevention of 'crud' migration and exclusion of individual fuel assembly handling.
- A much quicker flask turnaround is achieved and the absence of individual fuel element transfer operations eliminates the possibility of dropping an element.
- A barrier is placed between the water surrounding the fuel and the main pond water. This has several advantages as the chemical environment of the fuel can be maintained, leaking or damaged fuel can be received as a routine operation and containment minimises the leaching of fission products and 'crud' to the bulk pond water.
- A reduction in the volume of contaminated water to be handled when the fuels are to be reprocessed, leading to smaller effluent management facilities.
- Closer packing of fuel is achieved over the original open topped storage skips.

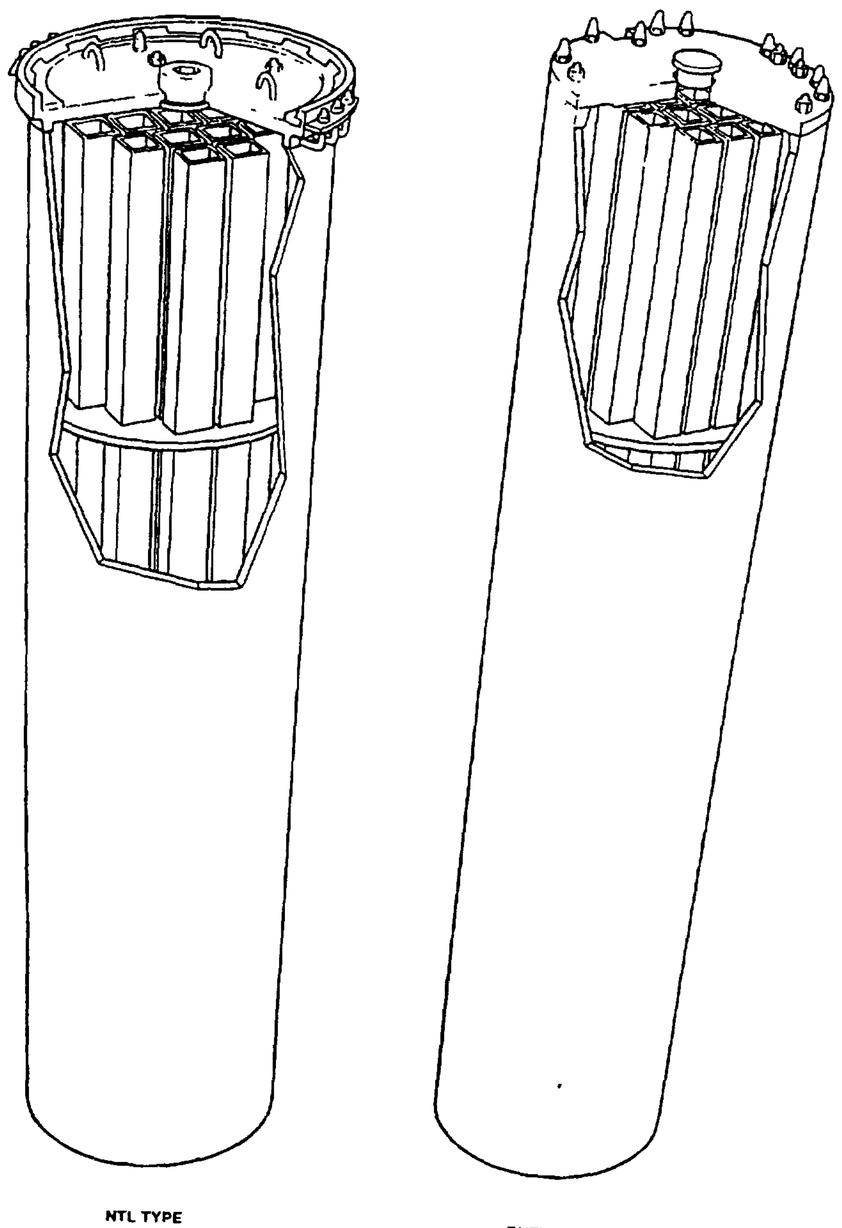

FIG. 9. Multi-element bottles.

Appendix B

ROD CONSOLIDATION AT BNFL

Although early trials of consolidating LWR fuels by in-pond techniques have not caught on, the dismantling and consolidation of AGR fuels in hot cells at BNFL's fuel handling plant (Sellafield) has been practised since 1986.

AGR DISMANTLER FUEL HANDLING PLANT (SELLAFIELD)

The AGR dismantling occupies a part of the AFR facility which also contains storage pools and hot cells for decanning Magnox fuel.

Fresh AGR fuel receipts are placed into wet storage for a minimum of 180 days before dismantling operations take place. The process involves recovering a container of fuel from the storage pool into the hot cell. Individual fuel assemblies are removed from the storage container rotated to the horizontal and fed by conveyor to one of two dismantling machines. Rods are removed by an impact punch loosening each fuel pin in turn from the supporting grid, the pin is withdrawn from the fuel assembly by a grab and allowed to roll down a ramp into a collection hopper containing a slotted stainless steel can. The assembly is then rotated so that the next pin is in line with the impact punch. The pins are withdrawn in a specific in a specific order to minimise the stresses that would otherwise distort the support grid during dismantling. When all the pins have been removed the remaining graphite sleeve and supporting grids are sized reduced, placed in drums and exported to a dedicated ILW store.

Each can accommodates three fuel assemblies and once full is transferred into a twenty compartment storage skip before returning to wet storage in a pool storage container. The process results in fuel densification from around 0.7 t(U) per container to 2.6 t(U) per container.

Since 1986 the plant has consolidated in excess of 35 000 fuel assemblies or >1.26 million pins.

Appendix C

CONTAINER DESCRIPTIONS

GNS/GNB CASTOR type casks

General description

CASTOR casks consist of a thick-walled ductile cast iron body and a lid system. The body is cast in one piece. Four trunnions are bolted on, two at the head and two at the bottom end of the body. Cooling fins are included on the outside body except on casks with low heat load. Impact limiters are attached at the top and bottom of the cask during transportation.

The ductile cast iron wall of the cask body serves as a gamma and neutron shield. For additional neutron shielding, if necessary, concentric rows of axial borings in the wall of the cask body are filled with polyethylene rods. The cask bottom and secondary lid have a slab of the same material inserted for neutron shielding.

The cask is closed with a double barrier lid system. It consists of a primary and a secondary lid installed one on top of the other. The lids are constructed of stainless steel and bolted to the cask body. The primary lid has a typical overall thickness in the range of 250 to 300 mm. It has penetrations for flushing, venting, and vacuum drying the cask cavity as well as for leak testing the lid seals. The penetrations are sealed in an equivalent way. The secondary lid has a typical overall thickness in the range of 100 mm. It has equivalently sealed penetrations for pressurising the lid interspace, monitoring this pressure, and performing the leaktightness measurements.

Both lids are equipped with multiple seals consisting of metal gaskets and elastomer O rings. The metal gaskets fulfil the long term helium leak rate requirement of a maximum leak rate of 10^{-7} mbar litre/s. During storage, the interspace between the lids is pressurised with helium to approximately 6 bar. This overpressure is continuously monitored by a pressure gauge fitted to the secondary lid. Thus, the leaktightness of the lid system is proven during the total storage period (see Fig. 10). The fuel basket accepts the spent fuel assemblies and ensures that criticality will not occur. The basket is of welded construction and is made of stainless steel and borated stainless steel sections. Its design is adapted to the particular spent nuclear fuel inventory.

The cask inner cavity has a nickel coating to prevent corrosion and enable easy decontamination. The outside of the cask body is protected by a multi-layer epoxy resin coating in the fin area and nickel coating on the head and bottom parts. The cask cavity is backfilled with helium, which serves as an internal heat transfer medium as well as inhibiting corrosion. The main characteristics of different CASTOR cask types are shown in Table XIII while pictures of various CASTOR cask can be found in previous IAEA publications [2, 5, 6].

CASTOR Cask Loading Operation

Normally the spent fuel to be stored is loaded into CASTOR casks in the reactors spent fuel storage pool. After spent fuel assemblies have been loaded, the primary lid, equipped with metal and O ring gaskets, is lowered under water in place on the cask. The cask is raised to the surface of the pool and the water is drained from the storage cask. The cask is moved to a work area and its outer surface is decontaminated. The primary lid bolts are installed and the cask is vacuum dried. The cask cavity dryness and primary lid leak tightness are measured. The cask cavity is backfilled with helium and vent and drain covers are installed and leak tested. The secondary lid is placed on the cask and its lid bolts are installed.

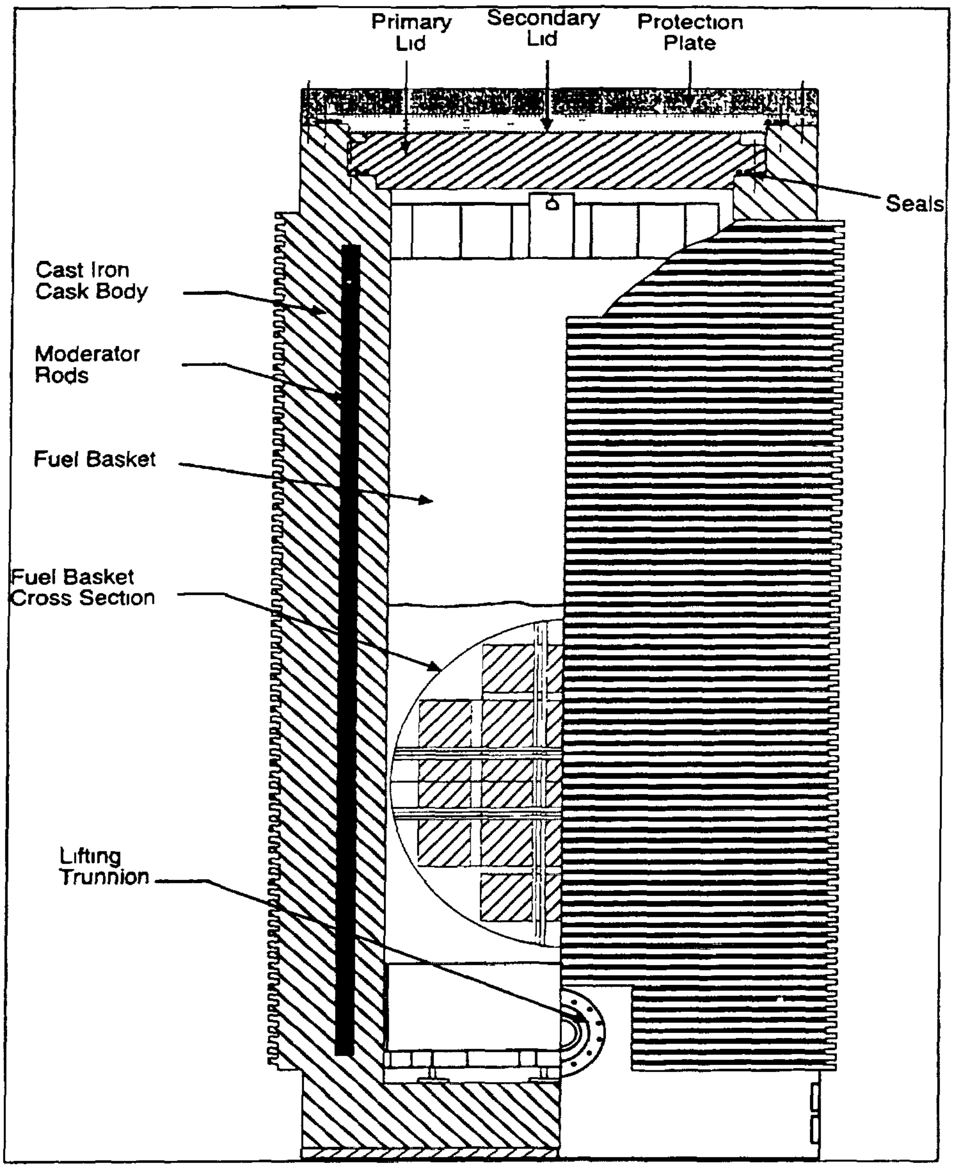

FIG. 10. CASTOR principle.

TABLE XIII. CASTOR CASK TYPES

Cask_type	Fuel type	Capacity (assembly)	Capacity (t HM)	Length (mm)	Loaded weight (t)	Use for NPP
Ia	PWR	4	2136	5980	81	Biblis
Ib	PWR	4	1432	4705	65	Stade
Ic	BWR	16	2.88	5508	88	Gundremmingn
IIa	PWR	9	4.8	6010	121	Phillipsburg
IIb	PWR	8	2.864	4707	85	Stade
V/19	PWR	19	10.203	5844	121	Neckarwesth.
V/21	PWR	21	9.765	4886	106	Surry
V/52	BWR	61	9.69	5451	121	Gundremmingn
440/84	WWER440	84	10.6	4080	120	Dukovany.
W-1000	WWER 1000	13	5.73	5505	100	Novo-Voronezh
RBMK	RBMK	102	11.2	4395	72	Ignalina
X/28 F	PWR	28	12.936	4800	104	ESCOM
X/33	PWR	33	15.345	4800	106	Surry
THTR	HTR-Spheres	2100	0.022	2784	28	THTR-300
AVR	HTR-Spheres	1900	0.020	2784	26	AVR Pilot plant
Barre	FBR	12		6230	92	Superphenix
SPX	FBR	7	1.1	6230	105	Superphenix
MTR	MTR	90		1341	12	Res. reactors
HAW 20/28	HLW	20/28	n/a	5903	100	Vitrified waste

After the primary lid is installed, the CASTOR cask, which is type B(U) licensed, can be shipped on public routes to the interim storage facility or moved to a reactor site storage facility. Depending on the arrangements with the utility, the following steps to install the secondary lid are either performed in the reactor or at the AFR storage facility. Once the secondary lid is installed, the lid interspace is pressurised, the pressure gauge is inserted and the leaktightness of the lid and its penetrations is tested. Once the cask is moved to its final position in the storage facility, the pressure gauge is connected to the electronic monitoring system.

The CASTOR HAW 20/28 CG is designed to accommodate 20 or 28 canisters of vitrified high-level waste from reprocessed spent fuel. It is used for interim storage of this material, which according to the reprocessing contracts, has to be taken back from France to the Gorleben facility. One loaded HAW-CASTOR has been shipped to Gorleben so far. The CASTOR HAW casks consist of a thick-walled cylindrical body made of ductile cast iron with radial fins machined into the cask body. A double lid system made of forged steel with metal gaskets is tightly bolted to the cask body.

GNB POLLUX cask

The POLLUX cask has been designed for final disposal of spent nuclear fuel in drifts and consists of a disposal container placed in a shielding overpack. The cask is expected to be licensed for transport and interim storage soon.

The POLLUX cask concept has been developed for direct disposal of spent fuel in salt formations and takes into account the postulated conditions of the repository. The POLLUX consists of a thick walled inner steel cask and a second outer container designed for shielding requirements during transport, interim storage and final disposal.

CONSTOR steel–concrete cask

The CONSTOR steel–concrete cask initially was developed for transport and storage of spent RBMK fuel, but further development was made to adjust the parameters to accommodate other fuel types too.

The CONSTOR RBMK cask consists of an outer and an inner shell made of steel. The space between the two liners is filled with heavy concrete for gamma and neutron shielding. Inside the concrete, steel reinforcement is arranged to improve the strength and heat removal properties. The cask bottom has the same sandwich design as the wall. At the lid end, the shells are welded to a ring made of forged steel. The trunnions for lifting and handling are attached to this ring.

The lid system is designed as a multi-barrier system. The bolted primary lid fulfils strength and shielding functions. For temporary shielding this lid is made leaktight by means of an elastomer seal. The sealing plate and the secondary lid are welded to the forged steel ring after loading and servicing of the cask. These two welded lids, together with the inner and outer shell (including their bottom plates), represent the double barrier system.

The RBMK spent fuel bundles are positioned in a basket inside the cask. The capacity of the standardised basket is 102 bundles (half length). The total mass of the CONSTOR RBMK cask including impact limiters, loaded with the 102 bundle basket is approx. 96 500 kg. The average enrichment is 2%, the average burnup is 20 GW d/t, and the minimum cooling time is 5 years, resulting in 7.65 kW heat load for a cask.

The type B(U) licensing of the CONSTOR RBMK cask was initiated in The Russian Federation in 1994 and the formal completion is expected for 1998.

HOLTEC International, Inc., HI-STAR/HI-STORM 100 System

The HOLTEC International (HOLTEC) HI-STAR 100 System (HOLTEC International Storage, Transport and Repository Cask System) consists of metal canisters (referred to as multi-purpose canisters or MPCs) designed to store spent fuel assemblies in a dry, inert environment and a metal overpack for storage and transport. The canisters are referred to as multi-purpose canisters because of the potential use of the canister with an appropriate overpack for spent fuel disposal. However, use for disposal can not be confirmed until completion of the final repository design. The HI-STAR 100 System includes three different MPC designs with different internal fuel baskets for storage of either PWR or BWR spent fuel assemblies. The spent fuel parameters for each basket are provided in Table XIV. A sketch of the HI-STAR 100 system is presented in Figure 11 [17].

Holtec has also designed a concrete and steel vertical storage overpack, the HOLTEC HI-STORM 100 Storage Overpack, that could be used for on-site spent fuel storage instead of the metal storage and transport overpack. The main structural components are provided by carbon steel and shielding is provided by concrete. The storage overpack has convective cooling ducts to allow for passive cooling of the HOLTEC HI-STAR 100 MPC. The overpack is enclosed by cylindrical steel shells, a thick steel baseplate, and a bolted-on lid. Four

TABLE XIV. HI-STAR 100 MPC SPENT FUEL PARAMETERS

Parameter	HOLTEC MPC-32	HOLTEC MPC-24	HOLTEC MPC-68
Fuel type	PWR	PWR	BWR
Initial enrichment	Limited to 1.9% PWR fuel without credit for burnup or boron	Limited to 4.2% PWR fuel without credit for burnup or boron	Limited to 3.85% BWR fuel without credit for burnup or gadolinium
MPC outer diameter (in)	68.5	68.5	68.5
MPC overall height (in)	187.25	187.25	187.25
MPC fuel cell length (in)	162	162	175
Minimum cooling time for storage (years)	5	5	5
Minimum cooling time for transport (years)	10	10	10

removable lifting lugs are attached to the top of the storage overpack for lifting the storage overpack body. The storage overpack may also be lifted from the bottom using a lifting rig.

HI-STAR 100 MPC

Each of the HI-STAR 100 MPC designs includes a fuel basket, a solid 19 mm thick bottom plate, an outer 13 mm thick canister shell, and two closure lids. The outer diameter of the HI-STAR 100 MPC is 1.7 m with a height of 4.7 m. The capacity of the three HI-STAR 100 MPCs depends on the basket configuration. There are two PWR basket designs, one which uses flux traps and one which has a higher capacity and assumes credit for burnup or an initial fuel enrichment limited to 1.9% ^{235}U. It should be noted that burnup credit has not yet been approved for storage and transportation systems in the USA.

The HI-STAR 100 MPC baskets consist of composite boxes that are seam-welded with a Boral neutron absorber panel attached to its external surfaces within a sheathing panel that is edge-welded. The composite boxes are assembled to form the honeycomb cell structure of the basket. The composite boxes are welded to the bottom plate. Composite boxes are attached to one another using connector bars. Additional braces or full-length spacers are welded to the inner surface of the canister shell. The outer shell assembly is then lowered over the fuel basket and welded to the bottom plate along the outside edge.

The HI-STAR 100 MPC includes two closure lids. The inner lid is edge-welded to the MPC outer shell and contains vent and drain ports which are used for draining, vacuum drying, and backfilling with an inert gas following loading. Adjustable spacers are used on the inside surface of the inner lid to position fuel assemblies axially in the storage basket cells. The outer closure lid is also welded to the HI-STAR 100 MPC shell.

Storage and transport overpack

The HI-STAR 100 overpack that can be used for both storage and transportation (type B) is a heavy-walled cylindrical vessel, approximately 200 inches in height with a maximum outside diameter of 96 inches. A steel shell, which is welded to a thick bottom plate, forms the main containment boundary along with a top bolted closure plate. The bolted lid configuration provides protection for the closure bolts and gaskets in the event the cask were to experience a severe impact. Metallic O rings are used to seal the main flange and the closure plate. The top closure plate has a neutron shield attached to its underside.

Additional layers of carbon steel plate placed around the inner shell form a protective barrier and provide additional gamma shielding. Steel radial connectors are vertically welded to the outside surface of the outer shell, providing additional heat conduction to the overpack outer shell surface. The outer shell of the storage cask provides neutron shielding.

The cask uses layered pressure vessels. The layer construction also provides added strength from improved ductility and elimination of potential through-wall cracks due to material flaws or impacts.

Six removable trunnions are attached to the main flange and baseplate for lifting and rotating the cask body. Four lifting trunnions are located 90° apart in the sides of the top main flange. Two rotating trunnions are 180° apart on the sides of the bottom baseplate.

NAC International, Inc., NAC S/T Casks

NAC International, Inc. has developed four variations of the NAC S/T cask: NAC S/T, NAC-C28, NAC-I28, and NAC-STC (see Table XV).

TABLE XV. SPENT FUEL TO BE STORED IN NAC CASKS

	NAC-C28	NAC-I28	NAC-STC	
Number of assemblies	56 (consolidated)	28	26	26
Initial enrichment, (%)	3.5	3.5	4.2 (W 17 × 17 OFA) 4.1	4.2 (W 17 × 17 OFA) 4.1
Burnup (MW d/t)	35 000	35 000	40 000	45 000
Decay time (years)	10	10	6.5	10
Decay heat per assembly (kW)	.357	.357	.85	.85
Decay heat per cask (kW)	20	20	22.1	22.1

The NAC S/T is a metal dry storage cask designed to vertically store 26 PWR fuel assemblies. It weighs less than 113 t when fully loaded with spent fuel, contained water and the lifting yoke.

The NAC-I28 is designed to vertically store 28 intact PWR fuel assemblies and the NAC-C28 to store consolidated fuel rods from 56 PWR fuel assemblies in 28 canisters. The NAC-STC storage and transport cask is designed to store 26 intact PWR assemblies. The NAC-S/T casks weigh less than 113 t when fully spent fuel, contained water, and the lifting yoke [18–20].

The NAC-C28/ST and the NAC-I28/ST casks were developed by the Nuclear Assurance Corporation and are approved for storage of consolidated and intact spent fuel assemblies, respectively. The NAC S/T cask is a multi-wall cylinder with a 39 mm thick inner shell and a 68 mm thick outer shell both made of stainless steel, separated by 81 mm of lead. The inner and outer shells are connected at each end by an austenitic stainless steel ring and plate. The overall dimensions of the cask are 4.6 m long and 2.4 m in diameter.

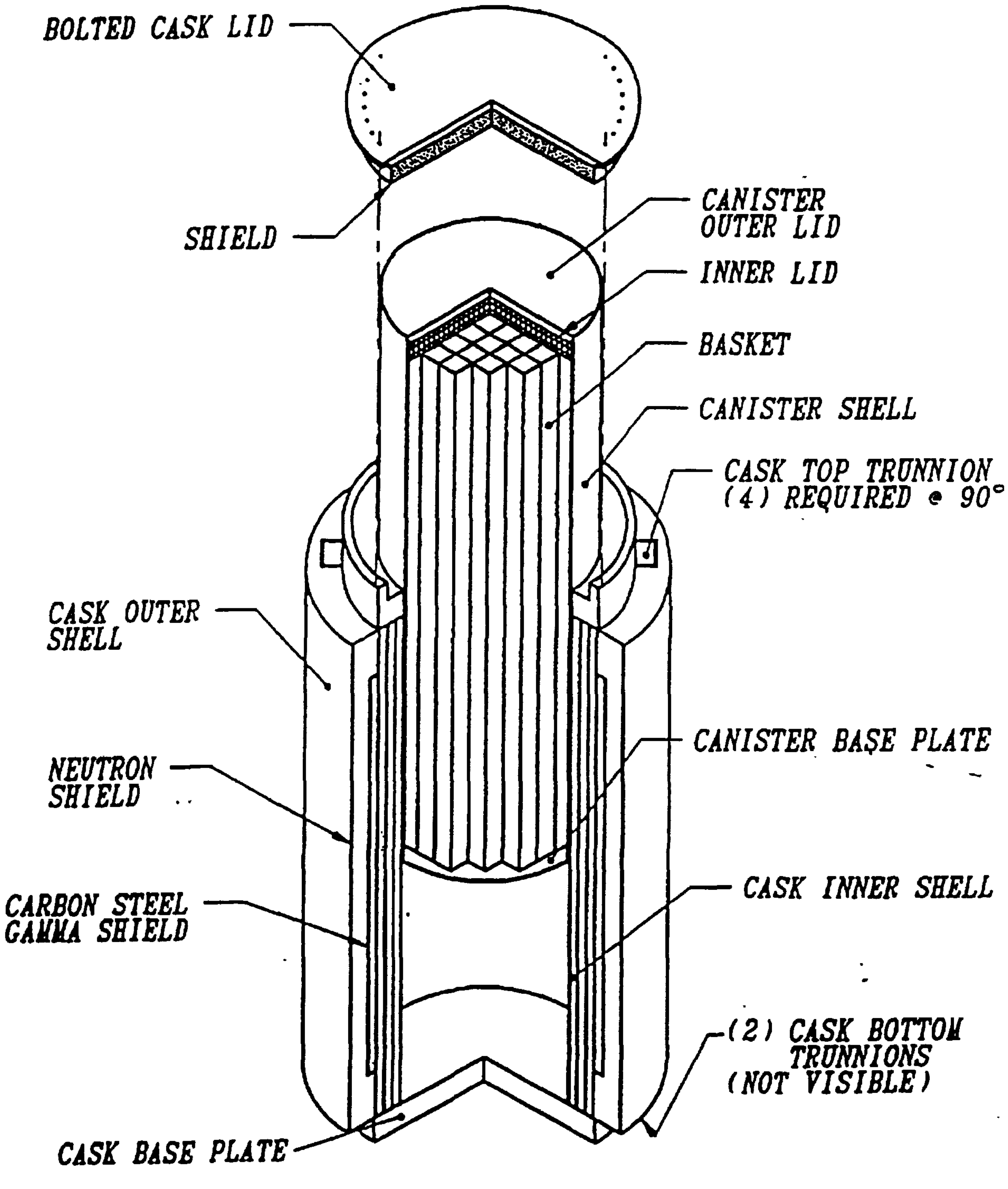

FIG. 11. HI-STAR 100.

NAC also plans to license a variation of the NAC-STC which would house a sealed metal canister for containing spent fuel in the place of the integral basket in the NAC-STC, referred to as the NAC MPC.

Cask body

The cask body for the four cask designs is similar. The range of dimensions is included in this description. The cask body consists of a cylindrical, multi-walled construction of stainless steel components. It has an approximately 38–40 mm thick inner shell and a 67 mm thick outer shell of stainless steel separated by 80–94 mm of lead.

For the NAC-C28, I28, and S/T, the inner and outer shell are connected to each other on both ends by austenitic stainless steel rings and plates. The upper end of the cask is sealed by a stainless steel bolted closure lid. The closure lid uses a double barrier seal system with two metallic O ring seals. A neutron shield cap encased in stainless steel is placed on top of the cask and may be welded to the cask body.

For the NAC-STC, the inner and outer shell are connected to each other on both ends by welded stainless steel forgings. The upper end of the cask is sealed by a stainless steel inner lid which is approximately 230 mm thick, with a 50 mm thick neutron shielding material in the centre and a 25 mm thick stainless steel cover plate. The upper end is further sealed by a 133 mm thick outer lid bolted to the top forging.

Gamma shielding is provided by the lead wall, and neutron shielding by a layer of a solid borated synthetic polymer which surrounds the outer shell along the cavity region, and is enclosed by a stainless steel shell with end plates that are welded to the outer shell.

For the NAC-C28, I28, and S/T, the bottom of the cask is sealed by a 152 mm thick stainless steel plate with a 25 mm outer closure plate, separated by 46 mm of lead gamma shielding. Twenty-four copper/stainless fins are located within the radial neutron shield to enhance heat conduction.

For the NAC-STC, the bottom of the cask is sealed by two stainless steel forgings and a stainless steel plate. Twenty-four copper/stainless steel fins are located within the radial neutron shield to enhance heat conduction.

Six trunnions can be attached to the cask for lifting and rotating the cask.

The cask has four containment penetrations: one cask cavity drain, one cask cavity vent, one inter-seal test port, and one inter-seal pressure transducer port. Each of these penetrations is in the single lid and utilises a double barrier seal containment.

The fuel basket is a right circular cylinder configuration with 26–28 aluminium fuel tubes that are separated and supported by an aluminium and stainless steel grid of spacers and tie bars, with borated neutron poison material for criticality control in the bask assembly [18–20].

Operations

The major operating systems are those required for handling and transferring the fuel from the spent fuel storage pool to the interim storage facility, and for removing fuel from the interim storage facility. The cask is loaded underwater in the spent fuel pool and the closure lid is bolted on the cask. The cask is drained, vacuum dried, decontaminated, pressurised with helium. A pressure monitoring device is installed in the double-sealed lid interspace. The neutron shield cap is installed and the cask is then transferred to the storage site and the cask is set on the concrete pad. The pressure monitoring system is externally connected. Unloading procedures are similar to loading procedures, but in reverse [18].

The cask is a totally passive system with natural cooling sufficient to maintain safe fuel cladding temperatures. The cask wall provides adequate shielding. No radioactive products are released under any credible conditions. Normal radiation survey monitoring is also performed.

NAC Universal MPC system (UMS)

NAC International, Inc. has designed a canister-based system for the storage and transport of spent nuclear fuel. The system is designated the universal MPC System — the storage component is designated the universal storage system. NAC submitted a safety analysis report for storage to the NRC in September 1997. The SAR for the universal transportation system was submitted earlier in April 1997. The canisters are referred to as multi-purpose canisters (MPCs) because of the potential use of the canister with an appropriate overpack for spent fuel disposal. However, use for disposal can not be confirmed until completion of the final repository design.

Description

The universal storage system (USS) is a spent fuel dry storage system that uses a stainless steel transportable storage canister with a welded closure and a vertical concrete cask to store intact spent fuel assemblies. The system also includes a transfer cask. The transportable storage canister is designed and fabricated to meet the requirements for transport in the universal transport cask. Figure 12 presents a diagram of the NAC UMS storage system.

The UMS storage system is designed to store 24 PWR fuel assemblies or 56 BWR fuel assemblies. PWR fuel requirements are a maximum initial enrichment of 4.2% ^{235}U, a maximum burnup of 40 000 MW d/t HM and a minimum decay time of 5 years after reactor discharge. BWR fuel requirements are a maximum initial enrichment of 3.75% ^{235}U, a maximum burnup of 40 000 MW d/t HM and a minimum decay time of 5 years after reactor discharge.

Transportable canister

The loaded canister is moved to and from the concrete cask using the transfer cask. The transfer cask provides radiation shielding while the canister is being closed and sealed and while the canister is being transferred. The canister is placed in the concrete cask by positioning the transfer cask with the loaded canister on top of the concrete cask and lowering the canister into the concrete cask.

The transportable storage canister consists of a stainless steel canister that contains the fuel basket structure and payload. The canister is defined as the confinement for the spent fuel during storage and is provided with a double-welded closure system. The canister consists of a cylindrical 16 mm thick stainless steel shell with a 44 mm thick stainless steel bottom plate and a stainless steel lid support ring. The basket assembly is placed inside the canister and provides the structural support and the primary heat transfer path for the fuel assemblies while maintaining a subcritical configuration for the spent fuel.

The shield lid assembly is a 178 mm thick stainless steel disk that is positioned on the shield lid support ring above the basket assembly. The shield lid is welded to the canister while the canister inside the transfer cask is in the work area after removal from the spent fuel pool. Two penetrations through the shield lid are provided for draining, vacuum drying, and backfilling the canister with helium. Following removal of water from the system, the system is vacuum dried and backfilled with helium and it is pressure tested and leak-tested to ensure the required leaktightness has been achieved.

The structural lid is a 76 mm stainless steel disk positioned on top of the shield lid and welded to the shell after the shield lid is welded in place and the canister is drained, dried, and backfilled with helium [21].

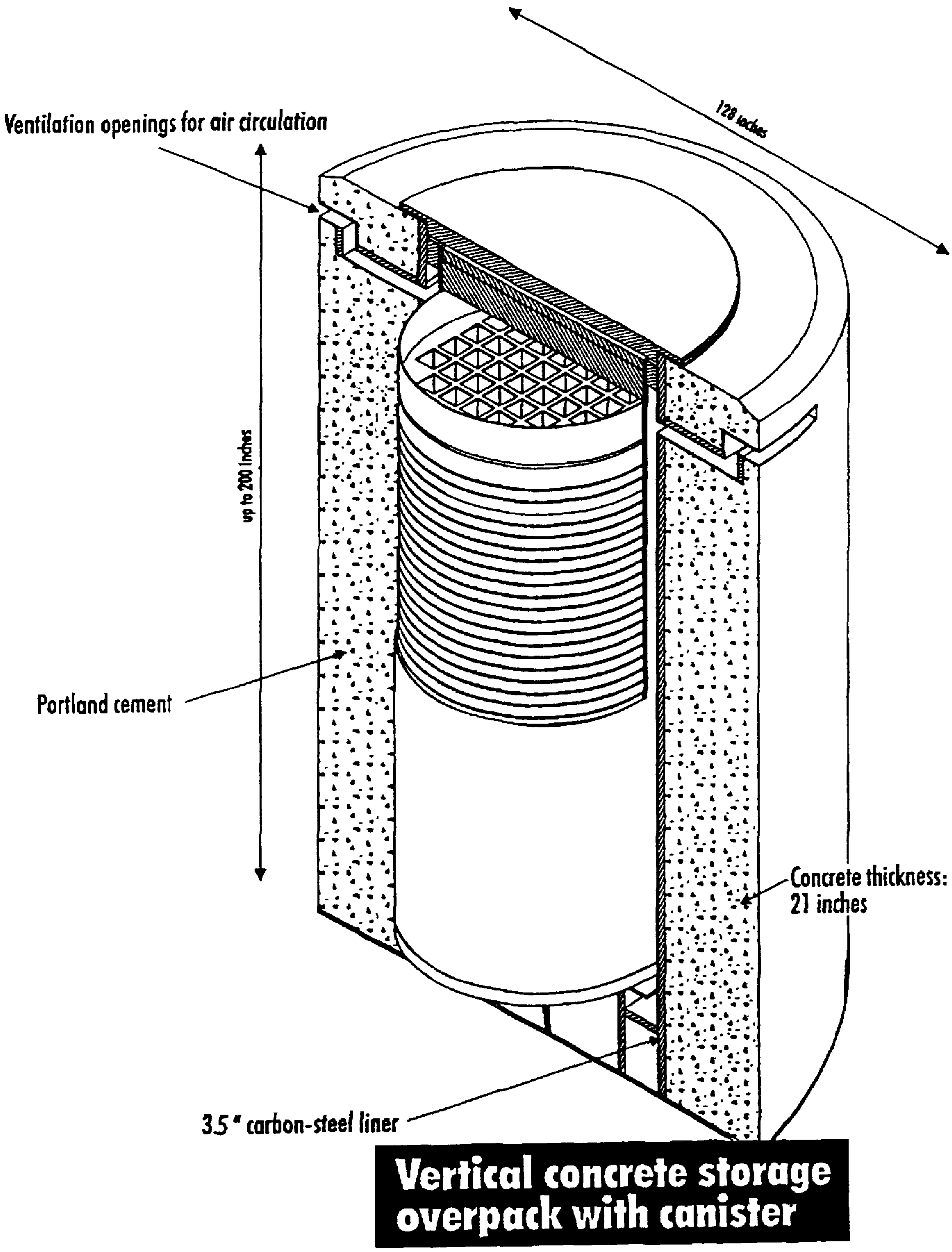

FIG. 12. NAC UMS.

Concrete storage cask

The vertical concrete cask provides structural support, shielding, protection from environmental conditions, and natural convection cooling of the canister during storage. The concrete wall and steel liner provide the neutron and gamma radiation shielding for the storage cask. Inner and outer reinforcing steel rebar assemblies are contained within the concrete. The concrete cask has an annular air passage to allow the natural circulation of air around the canister to remove the decay heat from the spent fuel stored in the transportable storage canister. The top of the concrete cask is closed by a shield plug and lid which incorporates a carbon steel plate as gamma radiation shielding and NS-4-FR as neutron radiation shielding. A carbon steel lid that provides additional gamma radiation shielding is installed above the shield lid [21].

Transfer equipment

The transfer cask is used for the vertical transfer of the canister between work stations and the concrete cask, or transport cask. The transfer cask incorporates a multi-wall design which limits the contact radiation dose to less than 3 mSv/hour. The transfer cask design also incorporates a top retaining ring, which is bolted in place, that prevents a loaded canister from being inadvertently removed through the top of the transfer cask. The transfer cask has retractable bottom shield doors to facilitate the transfer of the canister from the transfer cask into the concrete storage cask or transportation cask. Ancillary equipment needed to use the USS are: automated or manual welding equipment; an air pallet or hydraulic roller skid to move the concrete cask on and off the heavy haul trailer and to position the concrete cask on the storage pad; suction pump, vacuum drying, helium backfill and leak detection equipment; a heavy haul trailer or transporter for transport of the concrete cask to the storage pad; alignment plates and hardware to position the transfer cask with respect to the storage or transport cask; and a lifting yoke for the transfer cask and lifting slings for the canister and canister lids [21].

Ontario Hydro, Pickering dry storage container

The Pickering ***dry storage container*** (DSC) is a rectangular section container made of a double carbon-steel shell filled with reinforced high density concrete. The container design is shown in Figure 13. It measures 2.42 m × 2.12 m by 3.55 m in height. The thickness of each carbon-steel shell is 13 mm. The inner liner is the primary containment boundary. The function of the outer shell is primarily to enhance structural strength, and to facilitate decontamination. The payload chamber (cavity) is designed to hold four standard fuel storage modules (96 fuel bundles each) and measures 1.34 m × 1.05 m by 2.52 m in height. Helium is used as the cover gas in the DSC cavity. The weight of the container is approximately 53 t. The loaded DSC weighs about 63 t.

The DSC is designed with provisions for attaching safeguards seals. Two separate U-shaped 25 mm OD stainless steel tubes are embedded in the DSC walls and floor in the plane of the outer reinforcing grid. These tubes are placed so that each tube runs across the centre of the opposite container walls. Two similar tubes are embedded in the DSC lid and run diagonally across the lid. These tubes are provided for attaching IAEA COBRA seals (body and lid) and mechanical seals (lid only).

The concrete in a DSC provides radiation shielding and structural strength while maintaining adequate heat dissipation. The DSC high density reinforced concrete is composed of Portland cement, water, and high density aggregates. The thickness of the concrete wall is 520 mm.

The container closure system consists of a lid, guide pins and a closure weld around the perimeter of the container. The lid measures 2.42 × 2.12 × 0.52 m and is made of a carbon steel shell encasing a slab of reinforced heavy concrete. The lid base plate is part of the DSC containment boundary. The DSC lid is seal-welded to the container body by an automated process. All containment welds are tested and inspected to specifications.

The DSC is designed to store six year-cooled irradiated fuel with a heat load of 7.4 W per bundle. Helium is used as the cavity atmosphere.

The DSC is designed to withstand tornado winds, as well as tornado generated missile impacts, 2.8 m free drop, immersion under 200 m of water, seismic activity up to the design basis earthquake (DBE) for Pickering, and an internal overpressure of 100 kPa.

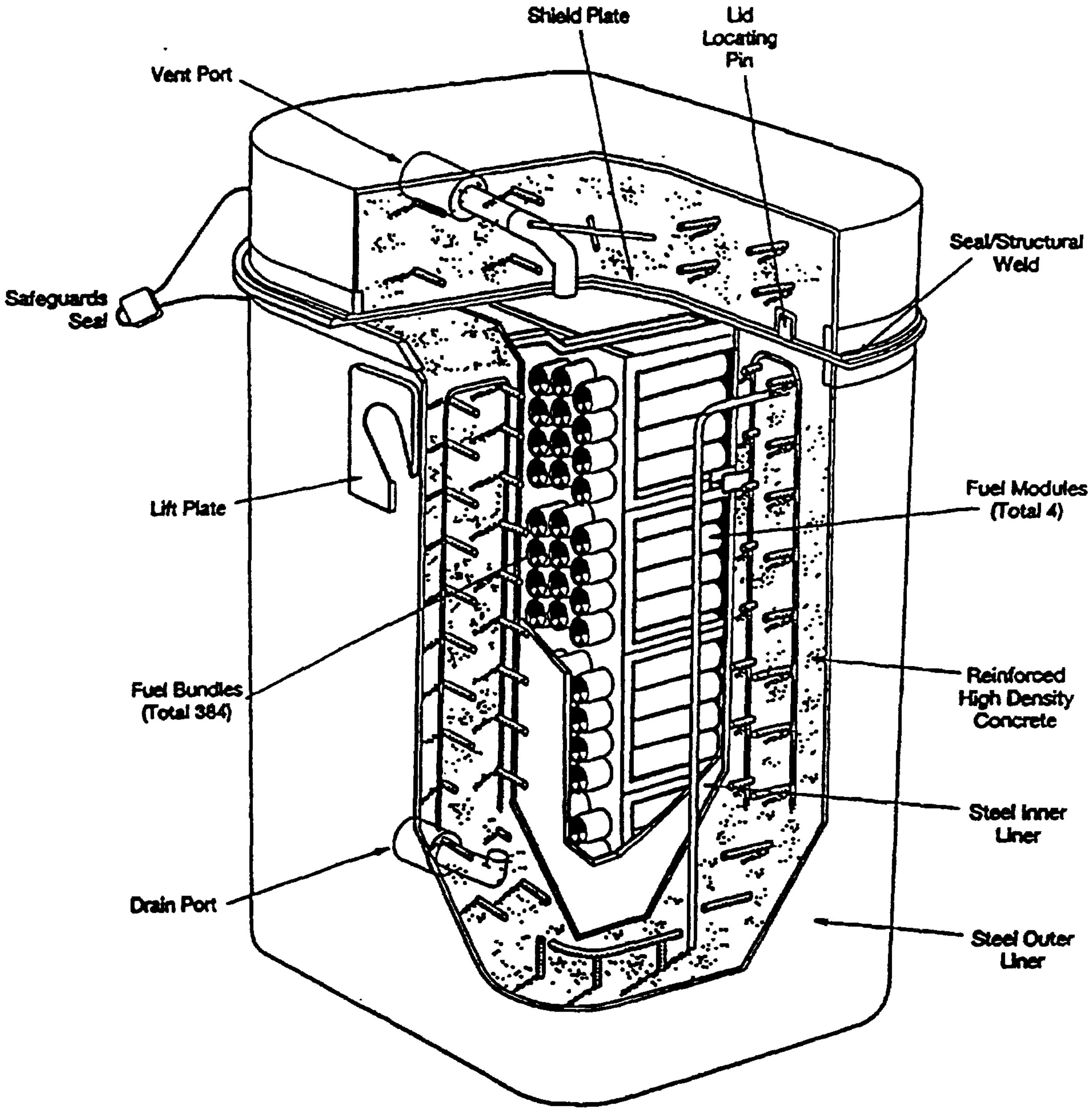

*FIG. 13. Pickering **dry storage container** (DSC).*

The container handling system consists of lifting plates, a lifting beam with trunnions and lid lifting lugs. The lugs are designed to be removable from the container. The lifting beam is dedicated to the DSC handling and is compatible with the fuel pool crane. The lifting beam, is designed to engage into the lifting plates attached on the DSC body.

The lid will be securely attached to the DSC base using an in-bay clamp during the entire operation in the bay in order to provide protection during credible accident scenarios. The in-bay clamp will be replaced by the transfer clamp in preparation to transport the container to the DSF.

Sierra Nuclear

VSC-24 and TranStor systems

The VSC-24 system is a vertical concrete cask system that stores 24 PWR spent fuel assemblies. Its components include a multi-assembly sealed basket (MSB), a ventilated concrete cask (VCC), and a MSB transfer cask (MTC). The welded MSB provides confinement for the storage and transfer of spent nuclear fuel. The VCC provides radiation shielding while allowing cooling of the MSB and fuel by natural convection during storage.

Sierra Nuclear Corporation has designed a modified version of the VSC-24 referred to as the Transtor system and has applied for licensing for storage and for transport of spent fuel.

The TranStor System includes a sealed basket containing fuel assembly sleeves, a shipping cask with impact limiters, an on-site concrete storage cask, and an on-site transfer cask. The sealed basket is used in combination with the transfer cask and the storage cask components for onsite storage of spent nuclear fuel. Offsite shipping of spent fuel is performed using the sealed basket and the shipping cask components.

VSC-24 storage system components

The MSB consists of a steel cylindrical shell with a shield plug and steel cover plates welded at each end. The shell length is fuel specific and varies from 4.1 to 4.6 m, the diameter is 1.6 m, and the shell thickness is 25 mm. An internal fuel basket is designed to hold 24 PWR spent fuel assemblies. The steel basket is a welded structure consisting of 24 square storage locations. Support in the horizontal direction is provided by curved supports located at each end and the centre of the basket assembly. The basket is coated with a CarboZinc 11 coating for corrosion protection. The MSB is installed vertically in the VCC.

The VCC is a reinforced concrete cask. The VCC has air inlets near the bottom of the concrete cask and air outlets near the top of the concrete cask. The internal cavity of the VCC as well as the air inlets and outlets are steel-lined. After the MSB is inserted in the VCC, a shield ring is placed over the MSB/VCC gap and the cask weather cover is installed.

A transfer cask is used to shield, support and protect the MSB during fuel loading and transfer to the VCC. It is a shielded lifting devise with inner and outer structural steel cylinders which house lead and solid RX-277 neutron shield cylinders.

Auxiliary equipment includes a vacuum drying system, trailer, and cask skid used during cask loading and transfer operations [18, 22].

The VSC-24 system is designed to store only intact, unconsolidated PWR fuel assemblies meeting the specifications of the cask Certificate of Compliance. The fuel characteristics that apply to the VSC-24 system are presented in Table XVI [18, 22].

TranStor system description

The PWR fuel assembly basket has 24 cells to accommodate one of the following: 24 PWR assemblies, 20 PWR assemblies and 4 special cans of failed or partial fuel or fuel debris, or any intermediate combination of PWR assemblies and special cans. The BWR fuel assembly basket has 61 cells to accommodate the following: 61 BWR assemblies with or without channels, 52 assemblies and 8 special cans of failed or partial fuel, or any intermediate combination of fuel assemblies and special cans [23].

The TranStor basket is a cylindrical steel canister designed for storage and shipping of irradiated spent fuel. Its components include a storage sleeve assembly, shell assembly, shield lid, and structural lid. The shell and lids provide containment and confinement boundaries, shielding, and lifting capability for the basket. The sleeve assembly provides support to the basket contents and is designed to accommodate intact fuel, failed fuel, fuel debris, damaged fuel, non-fuel bearing components, fuel assembly hardware, and greater-than-Class C (GTCC) low-level radioactive waste. The TranStor baskets vary in length from 114 inches to 180 inches, depending on the length of the fuel assemblies. An axial spacer, of an appropriate length is inserted between the basket and the shipping cask closure lid to maintain the basket's position during shipping.

The shell assembly consists of a cylindrical shell with a bottom plate and the shield lid support ring. The sleeve assembly is placed inside the shell and consists of square tubes which include neutron poison sheets to maintain a subcritical configuration for fresh, unirradiated fuel in unborated water. The shield lid assembly is a thick steel disk that is positioned on the shield lid support ring above the sleeve assembly after the fuel has been loaded into the basket, while the basket is in the spent fuel pool. The shield lid is welded to the basket while in the decontamination pit. Two penetrations through this shield lid are provided for draining, vacuum drying, and backfilling the basket with helium.

The structural lid is a steel disk that is positioned on top of the shield lid and welded to the basket shell after the shield lid is welded in place. The structural lid has a penetration for access to the vent and drain connections in the shield lid. The structural lid is seal welded once the helium backfield process has been completed.

The concrete cask used in the TranStor system is very similar in materials, size and construction to the concrete cask that is part of the VSC-24 storage system (see Fig. 14) [23].

Operations

During VSC-24 and TranStor system loading, the MTC containing an empty MSB is positioned in the spent fuel pool. Fuel assemblies meeting the fuel specifications are loaded into the MSB. A shield ring is placed on the MSB and the MTC is used to remove the MSB from the spent fuel pool. The MSB and MTC are drained and decontaminated. The MSB is vacuum dried, seal welded, and backfilled with helium. The seal welds are leak tested. The MSB, in the MTC, is transferred and is positioned vertically over the VCC. The MSB is lowered into the VCC and the shield ring is placed over the MSB/VCC gap and the weather cover is installed. The VCC is then transferred to the ISFSI via a truck trailer and is positioned on the storage pad using a hydraulic roller skid.

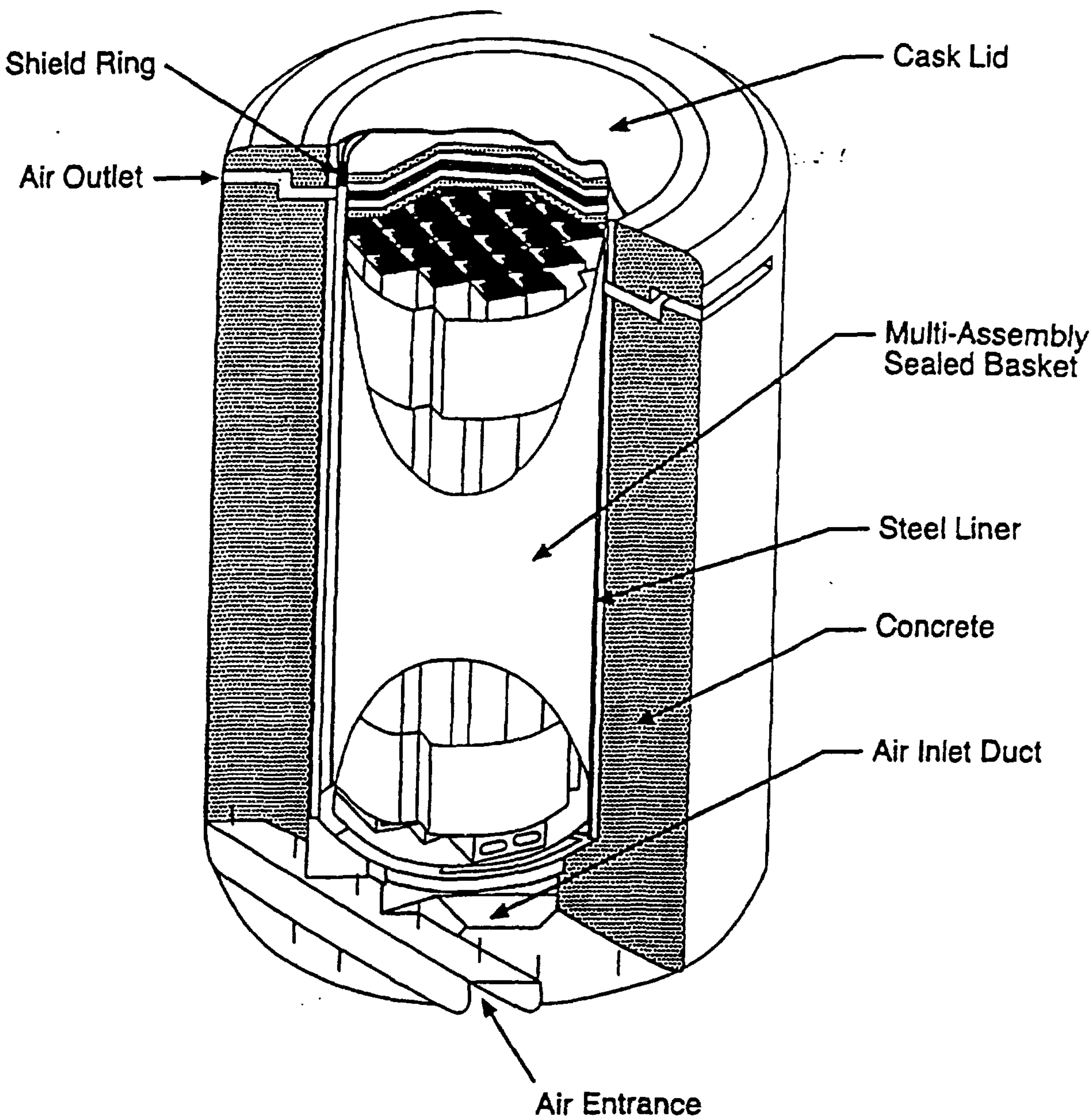

FIG. 14. TranStor system.

Transnucléaire

TN24 Transport/storage cask

The TN24 is designed as a dual purpose storage and transport cask. The TN24 cask family has been developed for the transport and storage of spent fuel assemblies with a cooling time of 5 to 10 years. Each cask version complies with the IAEA transport regulations. TN casks are also used for storage in the USA and Belgium. The main characteristics of the casks in the TN24 cask family are provided in Table XVII.

Depending on cooling time and fuel characteristics, the cask capacity varies from 24 to 32 PWR fuel assemblies, while remaining compatible in weight and size with the existing transport equipment.

TABLE XVI. CHARACTERISTICS OF SPENT FUEL TO BE STORED IN SIERRA NUCLEAR STORAGE SYSTEMS

Fuel Characteristic	VSC-24	TranStor	
Fuel class/type	PWR: B&W, Mark B, 15 × 15, CE/Siemens 15x15 CE 16 × 16, Westinghouse 14 × 14, 15 × 15, 17 × 17	BWR, NFBC, assembly hardware, GTCC LLW	PWR, NFBC, assembly hardware, GTCC LLW
Fuel cladding	Zircaloy cladding with no known or suspected gross cladding defects	Can accommodate special cans of failed fuel, or partial fuel or fuel debris	
Max decay power package	24 kW	26 kW / 24 kW for transport	
Maximum burnup	51 800 MW d/t HM [a]	40 000 MW d/t HM (6 years) 35 000 MW d/t HM (5 years)	45 000 MW d/t HM (6 years) 40 000 MW d/t HM (5 years)
Minimum decay time (years)	5	See maximum burnup	
Maximum initial enrichment (% ^{235}U)	4.2	3.7	4.2
Number of assemblies per VSC	24	61	24

[a] For casks loaded with fuel assemblies having burnups greater than 35 000 MW d/t HM, specific analyses must be performed to demonstrate that the initial fuel clad temperature criteria are not exceeded and that neutron and gamma source strengths do not exceed the specified criteria tabulated above.

Cask construction relies upon the use of a thick forged steel wall, a typical feature of the large number of spent fuel transport casks.

The following description covers several cask versions that have been developed for various fuel characteristics and operator requirements. Versions of this cask have been designed for WWER-440 and WWER-1000 fuel assemblies.

Containment

The 3 main cask containment components, a thick shell, the bottom, and the primary lid are made from forged steel. The first two components are always made of carbon steel because carbon steel combines: (1) good mechanical behaviour at low temperature needed to meet 92 AEA transport requirements, (2) good heat transfer and (3) well known manufacturing and inspection techniques.

The containment system is 220 mm to 350 mm thick in order to provide required gamma shielding which is more than the thickness required to meet mechanical design limits. A single forged steel cylinder is welded to a forged bottom plate.

A primary lid with metallic gaskets is bolted to the upper end of the cask to provide a leaktight seal. An optional secondary lid is also available. All sealing surfaces are covered with a stainless steel overlay.

The cask cavity is protected from corrosion by zinc–aluminium spray coatings.

Cask body

Outside the forged steel wall, a layer of borated resin with a thickness of 80 mm to 180 mm, provides neutron shielding. This solid material is enclosed within an external steel envelope.

Longitudinal copper plates connect the forged steel wall to the external envelope to transfer the decay heat of the fuel assemblies. The external shell is coated for corrosion protection. When needed because of high heat load, protruding fins made from aluminium profiles may be fixed to the outer shell.

The cask is handled by means of trunnions bolted to the forged steel wall. Depending on the operator's requirements, one or two pairs of trunnions at the top of the cask can be used for lifting, while one pair is fitted at the lower end to allow cask tilting to the horizontal position.

TABLE XVII. CHARACTERISTICS AND USE OF VARIOUS TN24 CASKS

	Version 1 TN24 P	Version 2 TN 24 B	Version 3 TN24D	Version 4	Version 5 TN24 XL	Version 6 TN24 G	Version 7 TN 68
Fuel assembly type	PWR 17 × 17 (900 MW)	BWR 8×8	PWR 17 × 17 (900)	PWR 17 × 17 (900)	PWR 17 × 17 (1300)	PWR 17 ×17 (900)	BWR
Number of assemblies	24	52	28	32	24	a)	
Min. cooling time (years)	5	5	8	10	8	10	10
Average burnup (MW/t HM)	33 000	33 000	36 000	37 500	36 000	42 000	40 000
^{235}U enrichment	33.5%	3.5	3.4%	3.5%	3.4%	3.8%	1143.3 %
Max thermal power (kW)	24	24	26	28	26	30	25
Loaded weight (transport conditions) t	93	95	114	115	114	125	125
Capacity (t HM)	11	10	13	15	13	>15	>12
Licensing status	US NRC licence for storage	French licence for transport	French and Belgian licences for transport Belgian licence for Storage	French licence for transport (in progress) US NRC license for storage	French and Belgian licences for transport, Belgian licence for storage (in progress	SAR under prepara-tion	Under US NRC review

a) not yet released.

Closure system

Several sealing arrangements of two independent lids have been designed to allow the flexibility needed to comply with the customer's requirements and the storage criteria imposed by its Competent Authority. Two leaktight barriers with checkable interspace are provided to meet transport requirements including accident conditions. Two leaktight metallic gaskets with continuously monitored helium pressurised interspace are provided during storage. Provisions have also been made to allow, welding of the secondary or a ternary lid.

The primary lid is equipped with a single opening to allow draining water from the cavity, venting, drying and backfilling with helium. This opening is connected to a draining tube reaching the lowest part of the cavity. Its leaktightness is also ensured by metallic gaskets and test devices are provided.

Basket

The cask cavity is fitted with a removable basket designed as a structural support for the fuel assemblies. It consists of mechanically assembled partitions in borated aluminium defining an array of cells, one for each fuel assembly. This basket technology uses borated aluminium for both neutron attenuation (Boron 10) and heat conduction (aluminium alloy).

Operations

The cask is loaded under water in the reactor spent fuel pool using procedures similar to standard transport casks. During transport, the cask is protected by shock absorbers. The cask is stored vertically on a concrete pad without the shock absorbers. Optionally, its top side can be protected from an aeroplane crash by a heavy steel cover.

The two leaktight barriers are continuously monitored during storage. Maintenance operations during the storage period are very light, mainly limited to visual inspection and repainting when needed.

Transnuclear Inc.

TN-40 cask

Cask description

The TN-40 cask consists of the following components: a basket assembly for support of the fuel assemblies; a containment vessel enclosing the basket and spent fuel; a gamma shield and a neutron shield; an outer shell; a weather cover; a pressure monitoring system; and trunnions. The TN-40 containment vessel consists of an inner shell which is a welded, carbon steel cylinder with an integrally-welded, carbon steel bottom closure; a welded flange forging; a flanged and bolted carbon-steel lid with bolts; and penetration assemblies with bolts.

The cask body consists of an inner shell which is a carbon steel cylinder with a wall thickness of 38 mm. The containment lid is 114 mm thick and is fastened to the body by 48 bolts. There are two penetrations in the lid, a drain opening and a vent. Each penetration has a double-seal mechanical closure. Double metallic O ring seals with interspace leakage monitoring are provided for the lid closure. The cask cavity is pressurised above atmospheric pressure with helium. The interspace between the metallic seals is monitored and pressurised with helium to a higher level than the cavity so that any seal leakage would be into rather than out of the cavity. A weather cover is provided above the lid.

A gamma shield is provided around the walls of the containment vessel by an independent shell of carbon steel which is welded to a bottom shield plate and to the closure flange. The gamma shield completely encloses the containment vessel inner shell and bottom closure. Neutron shielding is provided by a resin compound surrounding the body. The resin compound is enclosed in long, slender aluminium containers. The array of resin filled containers is enclosed within a smooth outer steel shell. The aluminium also provides a conduction path for heat transfer from the cask body to the outer shell. A disk of polypropylene is attached to the cask lid to provide neutron shielding during storage. Four trunnions are attached to the cask body for lifting and rotation of the cask.

The basket structure consists of an assembly of stainless steel cells joined by a fusion welding process and separated by aluminium and Boral poison plates which form a sandwich panel. The cask cavity surfaces are sprayed with metallic coating for corrosion protection. The external surfaces of the cask are painted for ease of decontamination [18, 24].

Operations

The major operating systems are those required for handling and transferring spent fuel from the storage pool to the interim storage facility. The cask is loaded underwater in the spent fuel pool and the lid is placed on the cask. The cask is lifted to the pool surface, the lid is bolted, and the cask is drained. Next, it is vacuum dried, pressurised with helium and decontaminated. The polypropylene neutron shield disk and steel cover are then installed, and a pressure monitoring devise is installed in the double-seal interspace. The cask is then transferred to the storage facility and placed on the concrete storage pad. The pressure monitoring system is externally connected and will notify the plant operators of a loss of seal integrity [18, 24].

VECTRA TECHNOLOGIES, INC.

Nuhoms storage systems

The NUHOMS family of concrete modular (silo) storage systems are designed to horizontally store PWR and BWR spent fuel assemblies. Its main components include a stainless steel dry shielded canister (DSC) with an internal fuel basket, a concrete horizontal storage module (HSM) that protects the DSC and provides radiological shielding, a transfer cask used to transport the DSC to the HSM and to provide shielding during transfer, and a hydraulic ram system (HRS) used to insert the DSC into the HSM. These components will be generally described in the following section, with specific dimensions provided in Table XVIII. A diagram of the NUHOMS-24P system can be seen in Appendix D of Ref. [6].

Horizontal storage module

The horizontal storage module (HSM) is constructed of reinforced concrete, structural steel, and stainless steel. The HSM may be constructed as a single unit or as an array of modules. The HSM provides neutron and gamma shielding for the DSC. A steel support rail structure anchored inside the HSM by the interior walls supports the DSC and extends to the access opening. Stoppers on the rails prevent horizontal movement of the DSC during a seismic event. A vertical sliding plate, consisting of thick steel and a neutron absorbing material, covers the entrance to the HSM and is tack welded closed when the DSC is in place. Cooling of spent fuel stored in the NUHOMS system is provided by a combination of radiation, conduction, and convection. Air enters shielded passages at the front of the HSM, passes around the DSC, and exits through the flow channels in the roof of the HSM. Air vents in the HSM are covered with stainless steel wire screening [18, 25–27].

Dry shielded canister

The DSC is designed to provide primary containment for spent fuel assemblies. The DSC is a stainless steel cylinder, 4.6–4.7 m in length, 0.9–1.7 m in diameter, and 13–16 mm thick. Stainless steel end plates and steel end plugs filled with lead are welded to the top and bottom of the DSC with double seal welds. The canister contains a basket assembly made of 7, 24, or 52 guide sleeves consisting of stainless steel. The NUHOMS-07P fuel basket is made of stainless steel clad borated aluminium, which serves as a neutron poison with the stainless steel as the structural material. The NUHOMS-52B basket has additional neutron-absorbing plates. The fuel basket guide sleeves are supported by circular stainless steel spacer disks [18, 25–27].

TABLE XVIII. DESIGN PARAMETERS FOR NUHOMS STORAGE SYSTEMS

Criteria or parameter	NUHOMS- 07P	NUHOM- 24P	Standardised NUHOMS	
			NUHOMS-24P	NUHOMS-52B
Initial enrichment (^{235}U)	3.5	4	4.0	4.0
Fuel burnup (MW d/t HM)	35 000	40 000	40 000	35 000
Fuel assemblies per DSC	7 PWR	24 PWR	24 PWR	52 BWR
DSC length (m)	4.6	4.7	4.7	4.7
DSC diameter (m)	0.9	1.7	1.7	1.7
DSC shell thickness (cm)	1.3	1.6	1.6	1.6
HSM length (m)	5.9	6.1	6.1	6.1
HSM height (m)	3.7	4.6	4.6	4.6
HSM width (m)	1.7	2.7	2.7	2.7
Transfer cask length (m)	4.60	4.75	4.75	4.75
Transfer cask diameter (m)	.95	1.7	1.7	1.7

Transfer cask

The transfer cask is used to transfer the DSC from the spent fuel storage pool to the HSM. It consists of three concentric cylinders with shielding material in between, connected by top and bottom steel end plates with a solid neutron shield. The bottom end plate has a removable hydraulic ram system access port plug. The transfer cask wall consists of an inner stainless steel liner, lead shield, carbon steel structural shell, solid BISCO-N3 neutron shield, and outer carbon steel shell. It is lifted by trunnions located on its sides, and mates via the transfer trailer with the access opening of the HSM for horizontal transfer of the DSC. The General Electric IF-300 shipping cask has also been approved as a transfer cask with an extension on the cask head [18, 25–27].

Hydraulic ram system (HRS)

The HRS provides the motive force for transferring the DSC between the HSM and the transfer cask. The HRS consists of a single-stage hydraulic cylinder with grapple assembly and is powered by a hydraulic power unit. The hydraulic cylinder is supported by a support frame and is designed to apply pushing and pulling forces of during canister transfer [18].

Operations

The DSC is placed in the transfer cask and is lowered into the spent fuel storage pool. After fuel is loaded into the DSC, the DSC shield plug is placed on the DSC and the transfer cask is raised out of the storage pool. The DSC and transfer cask are then decontaminated and drained. The DSC is vacuum dried, pressurised with helium, and sealed. The transfer cask lid is bolted to the cask, and the transfer cask is lowered horizontally onto a transfer trailer. The transfer cask is transferred to the storage facility and the cask is mated to the HSM. The HRS arm is inserted through the rear access port and pushes the DSC into the HSM. The transfer cask is then removed and the access steel cover plate is tack welded to seal the HSM.

The only required maintenance is the periodic inspection of the air inlet and outlet screens to ensure that they have not been blocked by debris [18].

VECTRA NUHOMS-MP/187

The horizontal storage module to be used with the NUHOMS-MP187 dry storage canister (DSC) is identical to the sandardised NUHOMS-24P HSM design described previously and will not be described again.

The DSC design under review for the NUHOMS-MP187 system is based on the sandardised NUHOMS-24P DSC design described previously, except that the MP187 DSC design includes borated neutron absorber panels in order to license the NUHOMS-MP187 for off-site transport.

There are three DSC types as part of the NUHOMS-MP187 system. The designs include: a DSC for fuel and control components; a DSC for fuel only; and a DSC for failed fuel. The DSC for fuel with control components contains up to 24 fuel assemblies with control components and has a 4.4 m internal cavity length. The DSC design for fuel only contains up to 24 fuel assemblies and the DSC for failed fuel contains up to 13 failed fuel assemblies. Both have an internal cavity length of 4.2 m [28].

Westinghouse

MC-10

Description

The MC-10 cask consists of a thick-walled forged steel cylinder and weighs approximately 103 t. The cask has a cylindrical cask cavity which holds the fuel basket. The overall length is 4.8 m and the overall diameter is 2.7 m including fins. The cask body is made of low alloy steel with forged steel walls and bottom that provide radiation (gamma) shielding and structural integrity. A low alloy steel shield cover, approximately 24 cm thick, with a metallic O ring seal, provides the initial seal and shielding following fuel loading. A carbon steel cover, with a metallic O ring seal, provides the primary containment seal. A seal lid provides a secondary containment seal. The fourth cover, containing a BISCO NS-3 neutron-absorbing material, is welded over the first two seals to provide seal redundancy. The inside surface of the cask is thermally sprayed with aluminium to provide corrosion protection. Twenty-four carbon steel heat transfer fins are welded axially along the outside of the cask wall. Carbon steel plates are welded between the fins to provide an outer protective skin approximately 6 mm in thickness situated 80 mm from the cask wall. Neutron shielding is provided by a layer of BISCO NS-3 cured in the cavity between the cask wall and outer protective skin. Four trunnions are connected to the cask body for lifting and rotating the cask.

The basket assembly consists of 24 storage locations utilising a honeycomb-type basket structure. Each of the 24 removable cell storage locations consists of an enclosure, neutron poison material, and wrappers. The upper ends of the enclosure walls are flared to facilitate fuel loading. Neutron absorbing material is attached to the enclosure walls and held in place with a stainless steel wrapper welded to the panel [18].

The MC 10 is licensed to store PWR spent fuel, cooled for ten years, with a maximum initial enrichment of 3.7% 235-U and a maximum burnup of 35 000 MW d/t HM. Maximum heat generation per assembly is 0.5625 kW per assembly [29].

Operations

The cask is loaded underwater in the spent fuel storage pool and the shield cover is placed on the cask. The loaded cask is lifted out of the spent fuel pool and the shield cover is bolted in place. The cask is drained, pressurised with helium, and decontaminated. A pressure monitoring device is mounted to the primary seal, the primary lid is bolted in place, and the cask is vacuum dried and pressurised with helium. The seal lid is then bolted to the primary lid, and the neutron shield lid is welded to the cask rim. Following decontamination of the outer surface, the cask is transferred to the storage facility and placed on the concrete pad. The pressure monitoring system is externally connected and will notify the plant operators of a loss of seal integrity [18].

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DEFINITIONS

The definitions given below may not necessarily conform to definitions adopted elsewhere for international use.

at-reactor (AR) storage. Spent fuel storage that is integral or associated with a reactor and part of the refuelling operation.

away-from-reactor on site (AFR(RS)) storage. Spent fuel storage away from and independent of the reactor(s) but still on the licensed site of the reactor(s).

away-from-reactor off site (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**. (2) A structure (various) used in **casks** with functions including heat transfer, criticality control and structural support.

buffer storage. Storage to provide flexibility between **spent fuel** receiving rate and **handling** capacity.

canister (can). A closed or sealed **container** used to isolate and contain **fuel**. It may rely on other containers (e. g. **cask**) for **shielding**.

cask. A massive **container** (various) used in the **transport**, **storage** and eventual **disposal** of **spent fuel**. It provides criticality control, **shielding**, mechanical, chemical, and radiological protection and dissipates heat from the **fuel**. Casks can be single, dual, or multi-purpose.

cladding, fuel. An external layer of material (for example of Zircaloy, stainless steel, magnesium alloys) directly surrounding **fuel** that seals and protects it from environment and protects the environment from radioactive material produced during irradiation. For HTR fuel particles, protective layers are known as coatings.

cladding defect. Through-wall penetration in **fuel cladding** caused by a manufacturing fault or by in-reactor service and/or post-irradiation **handling** and **storage**. It may lead to the release of radioactive material.

container. A general term for a receptacle designed to hold **spent fuel** 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.

degradation, fuel. Changes in the condition of the **fuel** which may adversely affect the subsequent handling, **storage** and treatment of the **fuel**, for example, **fuel** pin bowing, **cladding** failure, pellet defect and loss of structural integrity.

dry receiving. Unloading and handling of **spent fuel** in a dry environment (air or inert gas).

dry storage. Storage of **spent fuel** and related components in a gas environment such as air or inert gas. Dry **storage facilities** include **casks**, **silos** and **vaults**.

dual purpose cask. A **cask** licensed for both **transport** and **storage** of **spent fuel**.

fuel assembly. A geometrical array of **fuel rods**, pins, plates, etc., held together by structural components such as end fittings. Also called a fuel bundle, fuel cluster and fuel element.

fuel characterisation. The determination of the properties of **irradiated fuel** (assemblies, components) and involves calculation or laboratory examination.

fuel rod. A basic component of **fuel** fabricated for service in a reactor, comprising fissile and/or fertile material (oxide or metal) in a pellet form sealed in a metal tube (see **fuel cladding** and **fuel assembly**); also called fuel pin and fuel subassembly.

full-core reserve. At-reactor **storage capacity** to accommodate all **fuel assemblies** from the reactor core at any time.

interim (extended, intermediate, long term) storage. Storage of **spent fuel** until it is retrieved for further processing. The storage period ends when the **spent fuel** is reprocessed or placed in a geologic **repository**.

Irradiated fuel. See **spent fuel**.

multi-purpose canister (MPC). A canister-based system used in combination with various overpacks for the **storage**, **transport** and **disposal** of **spent fuel**. The intent of the system is to seal the **canister** after initial loading and never reopen it. The design must be acceptable for **storage**, **transport**, and **disposal**.

nuclear fuel cycle. All operations associated with the production of nuclear energy, including sequentially mining, milling and enrichment of uranium; fabrication of **fuel**; operation of nuclear reactors; **reprocessing** of **spent fuel**; recycling the products of **reprocessing** (e.g. Pu and U), decommissioning; any activity for radioactive waste management and any research or development activity related to any of the foregoing.

nuclear fuel cycle, closed. The closed fuel cycle concept involves the recycling of fissile and fertile material recovered from the **reprocessing** of **spent fuel**.

nuclear fuel cycle, one-through. The once-through fuel cycle concept involves the **disposal** of the **spent fuel** following its use in the reactor. **Interim storage** is likely to be required.

on-site transport. Transport of **spent fuel** within the boundaries of a licensed facility.

repository, fuel. A designated **site** engineered for the geologic **disposal** of **spent fuel** as a radioactive waste.

reprocessing, fuel. The operation, using separation techniques, to recover the plutonium and unused uranium in **spent fuel** for possible further use.

re-racking. Replacement of existing fuel **storage rack**s, usually to achieve denser storage of **fuel assemblies**.

rod consolidation. Removal of **fuel rod**s from a **fuel assembly** for storage in arrays which are packed more closely than the original array.

shielding. A selected material interposed between a source of radiation and personnel or equipment in order to attenuate radiation.

shield plug. A removable closure for a **silo**, **cask**, **vault** or **hot cell** which reduces radiation from stored **fuel**.

silo (caisson, concrete canister). A fixed or movable structure comprising one or more individual storage cavities. The silo affords all safety functions of a **storage facility** (i.e. structural support and radiological protection).

sipping test. A procedure to detect radioactivity escaping from failed **fuel**, usually by isolation or semi-isolation of an irradiated **assembly** in a chamber or hood, and collection and analysis of the escaping gases or radioactive species; wet or dry methods are used.

spent fuel. Irradiated fuel not intended for further use in a reactor without refabrication or **reprocessing**.

spent fuel disposal. Emplacement of **spent fuel** in a **repository** without intention of retrieval.

spent fuel inventory. The number of spent **fuel assemblies** or **elements** or their equivalent weights of heavy metal.

spent fuel management. All activities, administrative and operational, that, following **discharge**, are involved in the **handling**, treatment, **conditioning**, **transport**, **storage** and **reprocessing** of **spent fuel**, recycling of **fissile** and/or **fertile materials** and its final **disposal**.

spent fuel pool (basin, bay, pond). A water-filled facility designed and operated for storing, cooling, maintaining and **shielding** spent fuel **assemblies** or **rods**.

spent fuel storage. The process of emplacement and retention of **spent fuel** in a safe and retrievable manner. This implies an facility affording adequate environmental and physical protection. **Shielding, containment** of radionuclides, criticality control, and decay heat dissipation must be provided.

storage density. The quantity of **spent fuel** stored per unit of storage area or volume.

storage facility (system). A facility used for the **storage** of **spent fuel** and related components (see **spent fuel storage**).

storage pool. A specially designed **spent fuel pool** for **interim storage** and associated operations.

storage rack, fuel. A structure in a wet or dry **storage facility** that holds **spent fuel** assemblies or storage **container** in a configuration to control criticality, provide heat removal, facilitate **fuel** handling, and to prevent seismic damage.

storage temperature. Normally taken to mean the cladding temperature of the **fuel**. The temperature of other components and the environment may be relevant to the condition of the **fuel**.

transport. Movement of **spent fuel** from one licensed facility to another in the public domain using transport packages under prescribed conditions and regulations, in respect of which there are international guidelines.

transport cask (shipping cask, packaging). A heavy protective **container** used in the **transport** of **spent fuel**, and which dissipates heat, and provides **shielding** and **containment**, and prevents criticality. Transport cask could be wet and dry.

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.

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