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Design Requirements of A Consolidating Dry Storage Module for CANDU Spent Fuels

Kyung Ho Lee, Jeong Hyoun Yoon, Ke-Hyung Yang, Byung Il Choi,
Heung Young Lee, and Gyuseong Cho*

KHNP/NETEC, *KAIST
DukJin 150 Yusong, Daejeon

ABSTRACT

This paper presents a technical description of design requirement document covers the requirements of the MACSTOR/KN-400 module, which is under development to densely accommodate CANDU spent fuels with more efficient way. The Design Requirement is for the module that will be constructed within a dry storage site after successfully licensed by the regulatory body. This temporary outdoor spent fuel dry storage facility provides for safe storage of spent nuclear fuel after it has been removed from the plant's storage pool after being allowed to decay for a period of at least 6 years. The MACSTOR/KN-400 module is being designed to the envelope of site environmental conditions encountered at the Wolsong station. The design requirements of MACSTOR/KN-400 module meets the requirements of the appropriate Codes and Standards for dry storage of spent fuel from nuclear power reactors such as 10CFR72, and Korea Atomic Energy Act and relevant technical standard.

1. INTRODUCTION

Since 1983, KHNP is operating the Wolsong-1 CANDU6 NPP and the similar Wolsong 2-3-4 units respectively since 1997, 1998 and 1999. Since 1991, the extra fuel from Wolsong 1 has been stored at the Wolsong 1 dry storage facility that uses concrete canisters each holding 540 standard CANDU 6 fuel bundles. The basic storage density offered by concrete canisters is of approximately 30 bundles per m^2. This density is sufficient at certain storage sites having a single reactor, but is now too low for a site like Wolsong, that now has four CANDU 6 NPP' s. For their supplementary fuel storage needs, two CANDU 6 stations use a larger and denser structure, the MACSTOR 200 storage module. The MACSTOR 200 module is used since 1995 at Gentilly 2 and is constructed at Cernavoda for loading in 2003. These modules hold 12,000 fuel bundles in 200 fuel baskets each holding 60 bundles. The fuel baskets are stacked 10 high in each of 20 vertical storage cylinders, that are arranged in a 2 by 10 rectangular array. To further increase the storage density, a larger module holding 40 vertical storage cylinders arranged in a 4 by 10 rectangular array is planned for the Wolsong site. This large module is named the MACSTOR/KN-400 storage module. The design of the MACSTOR/KN-400 storage module shall aim at the following objectives 1) to reuse the design features of the MACSTOR 200 storage module whenever practical and economical, 2) to minimize changes from the existing MACSTOR 200 design 3) to maintain compatibility with existing fuel basket, fuel basket loading equipment, storage cylinder monitoring system, storage site and storage site services 4) to implement structural configurations that enhance thermal and mechanical performance and minimize stresses in the structure during normal, off-normal and postulated Design Basis Events. In this paper, overall design requirements to fulfil the both functional and safety aspects in the above are introduced.

2. GENERAL DESCRIPTION OF DESIGN REQUIREMENTS

As functional aspects following requirements shall be addressed for the MACSTOR/KN-400 module ;

1. Store CANDU 6 fuel baskets containing reference fuel bundles
2. Passively dissipate heat generated by the stored fuel, to maintain fuel bundles and storage module at acceptable temperatures
3. Provide sufficient shielding to attenuate gamma and neutron radiation below acceptable values
4. Provide confinement to the storage basket
5. Provide adequate structural integrity during construction, normal and abnormal operation and during Design Basis Events
6. Provide capability for periodic sampling of each storage cylinder cavity
7. Provide a basic intrusion resistance against removal of fissile material and provide receptacles for installation of Safeguards monitoring equipment by the IAEA

The MACSTOR/KN-400 shall be designed to the general performance requirements listed in Table 1. These performance requirements have been derived from the previous performance requirements of the MACSTOR 200 module or from capacity commitments.

Table 1. General Performance and Capacity Requirements

PARAMETER	PERFORMANCE REQUIREMENT
Reference dry storage period	50 years
Reference fuel	Standard natural Uranium CANDU 6 spent fuel bundles
Bundle integrity	Intact and non-leaktight (but mechanically sound)
Location of fuel storage site	Co-located within the Exclusion Zone Boundary of a CANDU 6 station
Location of module	Outdoor
Maximum distance to storage site fence	20 m
Minimum distance to EZB	500 m
Capacity: • Quantity of fuel bundles per module • Quantity of fuel baskets per module • Quantity of storage cylinders per module • Quantity of fuel baskets per storage cylinder • Reference number of fuel bundles per basket	 • 24,000 bundles per module • 400 fuel baskets per module • 40 storage cylinders per module • 10 fuel baskets per storage cylinder • 60 fuel bundles per fuel basket
Air cooling circuit	10 air inlets (5 on each side) 12 air outlets (6 on each side)
Monitoring	Monitoring of confinement integrity at each storage cylinder

3. ACCEPTANCE CRITERIA FOR FUEL BUNDLE IN THE MODULE

The MACSTOR/KN-400 storage module shall be designed to store fuel bundles having the following parameters listed in Table 2. Small increases/decreases in average burnups (from small variation in the initial fuel bundle Uranium mass) with respect to the specified reference average may occur as bundles mass may vary from plant to plant. These variations shall be compensated by a corresponding small site-specific increase/decrease in the reference cooling period of 6 years, as long as the average reference fuel bundles heat release is met.

Table 2. Acceptance Criteria for Fuel in Storage Module

PARAMETER	PERFORMANCE REQUIREMENT
Reference fuel cooling period	6 years for reference fuel
Fuel age spread in module	None (All bundles are conservatively assumed to have minimum cooling period)
Reference average fuel burnup	187.2 MWh/kgU (7,800 MWd/MTU)
Average bundle heat release for reference average fuel burnup	6.08 Watts
Reference maximum fuel burnup	290 MWh/kgU (12,083 MWd/MTU)
Maximum bundle heat release for reference maximum fuel burnup	9.76 Watts
Irradiation period/bundle power	325.5 days/ 452.5 MW(th) per bundle
Fuel bundle initial Uranium contents	18.9 kgU – generic 19.2 kg (Wolsong specific)
Fuel integrity	Designed for intact and non-leaktight fuel bundles
Reference average basket configuration	60 average power fuel bundles
Reference hot basket configuration	53 average power basket 7 maximum power bundles in a cluster
Fuel basket heat release: Average basket Hot basket:	 364.8 Watts 390.6 Watts
Maximum initial fuel bundle temperature *(for high burnup bundle, in a hot basket, in a hot module, with a 40°C average daily ambient air temperature)*	160°C

4. SAFETY REQUIREMENTS

The MACSTOR/KN-400 storage module shall meet the following safety requirements for normal, off-normal and Design Basis Events: Shielding, Heat dissipation, Confinement to the fuel basket and Long term structural integrity

The storage module shall be designed to safely operate under a wide set of credible events generated from naturally occurring phenomenon, from man-made hazards, from random failure of equipment and human errors. Credible but low probability events that could have severe consequences are designated as Design Basis Events (DBE) and shall have their consequences analysed. Credible DBE's are events having a probability of occurrence that are higher than 10^{-6} events per year. Events that are expected to have a probability of occurrence slightly lower than 10^{-6} events per year, (that is between 10^{-6}

and 10^{-7} events per year) must have their probability of occurrence verified to be non-credible (below 10^{-6} events per year).

The design shall specifically consider the Design Basis Events listed in Table 3. Other site specific Deign Basis Events such as the ones listed in Table 4 have to be considered using site specific parameters. Their probability of occurrence shall be evaluated and the event analyzed as necessary. The definition of postulated impacts from aircraft crashes or other acts of sabotage are site specific and specified in the design basis threat definition. Design Basis Events shall result in occupational dose to operators and in effective dose to the public at Exclusion Zone Boundary that are less than values specific in Table 5 for Design Basis Events.

For the event consisting in the drop of a fuel basket in a storage cylinder, the storage cylinder shall be designed to maintain its general structural integrity so as to allow fuel basket removal following the event. The storage cylinder need not maintain its confinement capability, as it will no longer by used following the event.

Table 3. Generic Design Basis Events Considered for MACSTOR/KN-400 Module

DESIGN BASIS EVENT	CRITERIA
Design Basis Earthquake (ground motion acceleration)	0.2g horizontal acceleration 0.133 g vertical acceleration
Wind caused by Typhoon or Hurricanes	144 km/h (Meteorological record in Korea)
Tornado winds and missiles	Per ANS-2.3
Severe air flow blockage conditions	50% of air inlet circuit (at non-floodable site) 100% of air inlet circuit (at floodable site)
Fuel basket drop in storage cylinder	From transfer flask to bottom of storage cylinder
Drop of storage cylinder shield plug	From highest handling height
Drop of flask guide mechanism	From highest handling height
Transfer flask drop on module • If commercial transfer flask hoist (having a regular reliability) is used • If single-failure-proof transfer flask hoist is used	 Drop from maximum operational height Transfer flask drop is not an applicable Design Basis Event
Collision from land vehicle	Collision from transfer flask transporter at rated speed of 20 km/hr
Fires	Fire from transfer flask transporter fuel tank Other fires are site specific

A storage module may also require, at certain sites, to be designed to meet specific Design Basis Events such as the ones listed in Table 4. These events would not have normally been considered during the generic design of the module. For application at a specific site, the module shall be analysed in accordance with those site-specific events or specifically protected from the event(s).

Table 4. Site-Specific Design Basis Events to be Considered, When Necessary for Design of MACSTOR/KN-400 Storage Module

DESIGN BASIS EVENT	CRITERIA
Turbine explosion	Site specific turbine missile No internal scabbing
Tsunami	Site-specific No overturning
Dam failure (high velocity water flow, subsequent flood)	Site-specific No overturning
Aircraft crashes	Site-specific
Fires	Site-specific temperature and duration No damage to module or fuel
Landslide	Site specific No fuel overheating
Nearby explosion	Site specific pressure No collapse of storage cylinder

Shielding and Radiological Requirements

The concrete and metallic shielding materials of the MACSTOR/KN-400 module shall attenuate radiation from the spent fuel to contact dose rates specified in Table 5. For shielding assessments, the reference spent fuel having 6 years of cooling shall be assumed in every storage cylinder, even if in reality fuel having a longer cooling period maybe present.

Table 5. Shielding and Radiological Requirements

ITEM	CRITERIA
Contact dose rate on module	**25 mSv/h**
Temporary dose rate during fuel basket loading	250 µSv/h
Fence dose rate	2.5 µSv/h
Effective dose (occupational)	Less than 20 mSv per year
Effective dose (for public at Exclusion Zone Boundary) from normal operation	Less than 0.1 mSv yearly
Effective dose (for public at Exclusion Zone Boundary) following Design Basis Events	1 mSv

The shine calculations for the plug shall consider manufacturing tolerances for the shield plug and storage cylinder. The shield plug located at the top of the cylinder and the storage cylinder shall minimize shine by having a suitably shaped conical structure or other equivalent structure. Mating between the MACSTOR/KN 400 module, the flask guiding mechanism and the transfer flask shall be such that during fuel transfer operations, the radiation fields at the top of the module are limited to the values specified in Table 3. Air inlets and air outlets shall form a labyrinth to minimize shine. Other penetrations such as the ones for vent and drain lines, the ones for the IAEA safeguards equipment or for other devices shall have suitable bends to prevent radiation streaming. Additional as-built pieces of shielding materials may be used at specific locations such as air inlets and outlets and storage cylinder shield plug to limit the dose rate to values specified in Table 5..

The design shall minimize thermal and mechanical stresses in the structure and adapt the amount of reinforcing bars to limit the formation of concrete cracks to a width that will not affect shielding performance.

Heat Dissipation Requirements

The MACSTOR/KN-400 shall dissipate heat to maintain the fuel bundles within the limit specified in Table 2. The concrete temperature shall also be maintained within the limits specified in ACI 349. Heat dissipation through the storage module structure shall be by conduction, thermal radiation and passive convection of air through the air circuit. The air circuit shall provide redundant paths to minimize the effect of an air path(s) blockage and provide diversity by having the air circuit located on both sides of the module. The limit fuel and concrete temperature shall be maintained for relevant ambient air temperature conditions

The air inlets and outlets shall be equipped with suitably sized gratings to prevent entrance of debris, small animals and large insects. The air entrance height shall be elevated from the ground to minimize blockage by wind blown objects and enhance protection against floods. The design of the gratings shall facilitate visual inspection and periodic cleaning.

Confinement Requirements

During storage, the storage cylinder shall provide a confinement barrier between the fuel storage basket and the environment. The storage cylinder barrier shall thus act as a back-up to the confinement barrier provided by the fuel basket. The fuel basket shall provide the primary confinement barrier to the fuel bundles. During the short period during which the fuel basket loading and unloading operations are made, the storage cylinder is opened and the fuel storage basket shall provide the confinement barrier to the fuel bundles.

The confinement boundary provided by the storage module during the dry storage period shall be made solely by the storage cylinder: e.g. the concrete is not used as a confinement boundary. The storage cylinder closure shall be seal welded and be accessible to allow appropriate non-destructive examination. The storage cylinder closure shall be made at the junction between the shield plug and the storage cylinder body. The storage cylinder shall be provided with vent and drain lines to allow periodic verification of the storage cylinder confinement integrity. The lines shall be brought from each storage cylinder to the outside of the MACSTOR/KN 400 module and shall be equipped with a manual isolation valve. The lines and the valves shall be a part of the storage cylinder confinement boundary.

The verification of the storage cylinder confinement integrity shall use the vent and drain lines to recirculate the storage cylinder air, by connecting the storage cylinder monitoring system to the vent and drain isolation valves.

Structural Integrity

The MACSTOR/KN-400 shall maintain its structural integrity during normal, off-normal and Design Basis Events.

During normal, off-normal or following Design Basis Events conditions over any prolonged period, the temperature of the structural concrete of the storage module shall be maintained within the limits of 66°C over larger areas and 93°C over local areas in the proximity of the storage cylinder, that are specified in ACI 349.

Heavy loads such as the transfer flask, the storage cylinder shield plug and flask guiding mechanism shall be moved as close as possible to the top of the module, to minimize the impact energy from a postulated drop of the equipment. If a non single-failure-proof transfer flask hoist is used to lift the loads, the drop of a load shall be considered in the list of Design Basis Events. The postulated drop height shall be from the maximum handling height of the load. The storage module shall maintain its structural integrity and maintain shielding to a level that allows recovery operations to be carried safely out. The structural design of the storage cylinder and module shall consider, as a Design Basis Events, the drop of a fuel basket into the storage cylinder. The postulated drop height shall be from the highest fuel basket position in transfer flask, to the bottom of the storage cylinder. This event may cause some deformation to the storage cylinder, as long as the fuel basket retrievability is ensured following the event. This Design Basis Event may cause the storage cylinder to no longer be suitable for storage and, for economic reason, shall then be sealed at its top and left empty.
The storage module shall be grounded in accordance with UBC(United State Building Regulation Code) for protection against lightning strikes.

5. APPLICABLE CODES, STANDARDS AND CLASSIFICATION

The MACSTOR/KN-400 module shall be designed to the requirements of the following Codes and Standards. These are grouped as follows:

1. **General design** Codes and Standards that applies to the entire design, supply and construction process, see Table 6
2. **Specific design, manufacturing and construction** Codes and Standards, see Table 7
3. **Quality Assurance** Codes and Standards, see Table 8.

Table 6. General Design Codes and Standards

NUMBER	TITLE	**Application**
Korean Atomic Energy Act		General Korean Nuclear Regulations
US 10CFR72	Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel and High-Level Radioactive Waste	General United states regualtion for a independent spent fuel storage
CSA/N292.2-96	Dry storage of irradiated fuel	General Canadian design code for a dry spent fuel storage facility
IAEA 116	Design of Spent Fuel Storage Facilities	General design code for a (wet or dry) spent fuel storage facility
IAEA INFCIRC 164	Safeguards Agreement in country of use	Design of equipment receptacles for IAEA Safeguards equipment
NBCC-1990	National Building Code of Canada	General Canadian design code for buildings

The storage cylinder is initially vented to atmosphere before being sealed and operates at or near atmospheric pressure under all normal, off-normal and Design Basis Events. The storage cylinder cannot reach an internal pressure of 100 kPa (15 psig) necessary to be classified as a pressure vessel and thus need not be classified as a pressure vessel. The storage cylinder is a welded structure designed to ASME Section VIII.

6. CONCLUSION AND FUTHUR STEP

In order to increase storage density of spent fuel from CANDU reactors, a new consolidating dry storage system was introduced and has been under development. As a basic step of the development, design requirements of the module was established considering functional and safety aspects. This paper showed that each important item to fulfil the requirements for successful implementation of the module to Wolsong environment. From the result of consideration to find optimised design features, it can be concluded that, detail analyses of the module will be carried out for the future steps to ensure confirmation with design requirement described in the paper and will finally be implemented to CANDU Wolsong site.