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Determination of Design Basis for a Storage System for Spent Fuel in Korea

국내 사용후핵연료 저장시스템의 설계기준 설정 인자 고찰

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Abstract

Safe operation and maintenance of engineered dry storage systems for spent fuel from nuclear power plants basically depends on adequately adopted design requirements. The most important design target of the system are those which provide the necessary assurances that spent fuel can be received, handled, stored and retrieved without undue risk to health and safety of workers and the public. To achieve these objectives, the design of the system incorporates features to remove spent fuel residual heat, to provide for radiation protection, and to maintain containment over the lifespan of the system as specified in the design specifications. The features also provide for all possible anticipated operational occurrences and design basis events in accordance with the design basis as guided by the designated regulations. The general performance requirements of a projected storage system are introduced in this paper. The storage system is designed to store fuel assemblies in associated with designated regulatory requirements. Small increases/decreases in maximum burnup can be adjusted with cooling time. These variations are compensated for by a corresponding small site-specific increase/decrease in the design basis-cooling period, as long as the maximum heat load and radioactivity of loaded fuel assemblies are met. Generic design basis events considered for the storage system are summarized. Shielding and radiological requirements along with mechanical and structural are derived in this study.

Key words : Spent fuels, Storage, Design Basis

요 약

원자력발전소에서 나온 사용후핵연료 건식저장시스템의 안전한 운영과 유지는 기본적으로 적절하게 선택된 설계기준에 좌우된다. 저장시스템의 가장 중요한 설계목표는 저장된 사용후핵연료로부터 작업자의 안전과 대중에게 과도한 위험이 없이 보관, 취급, 수납 및 감시할 수 있는 신뢰를 제공하는 것이다. 이러한 목표를 달

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성하려면, 시스템의 설계, 사용후핵연료로부터의 잔류 열을 제거하고 방사선 차폐를 제공함과 동시에 설계 기준에 지정된 시스템의 수명동안 격납을 유지하기 위한 기능을 포함한다. 운영 중 발생가능한 설계사항은 설계 기준에 반영되어야 한다. 본 논문에서는 건식저장시스템의 일반적인 성능 요구 사항을 소개하였다. 저장시스템은 인허가를 위한 규제 요구 사항과 연관하여 사용후핵연료를 저장할 수 있도록 설계된다. 여기서 최대연소도의 증가는 냉각기간과 맞물려 가감할 수 있다. 이때 열부하와 방사능의 크기가 최대 설계기준 연소도의 기준을 설정하는 주요한 인자가 된다. 이외에 건식저장시스템의 설계기준사고와 다른 분야 즉 기계 및 구조 그리고 차폐 및 방사선적인 요구사항들의 종류가 기술되었다.

중심단어 : 사용후핵연료, 저장, 설계기준

I. Introduction

In Korea, 21 nuclear power plants are presently operating including four CANDU 6 reactors. These units are achieving high capacity factors since their commercial operation and now generate annually a number of spent fuel assemblies. KRMC is undertaking to develop a higher performance dry storage system reflecting current situation in Korea.

The design of the storage system shall aim at the following objectives 1) to enhance the design features of existing storage system by accommodating update technology, 2) to optimize design from the existing designs domestic and abroad 3) 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.

II. General Description of Design Requirements

As functional aspects following requirements shall be addressed for the storage system;

a. To safely accommodate baskets containing design basis PWR fuel assemblies.
b. To passively dissipate heat generated by the stored fuel, to maintain fuel assemblies and other components at acceptable temperatures.
c. To provide sufficient shielding to attenuate gamma and neutron radiation below design requirements.
d. To provide confinement and containment to the storage system.
e. To provide adequate structural integrity during construction, normal and abnormal operation and during Design Basis Events.
f. To provide capability for periodic surveillance of each storage cask or module.
g. To provide a basic intrusion resistance against removal of fissile material and provide receptacles for installation of Safeguards monitoring equipment by the IAEA.
h. To maintain life-long integrity in terms of corrosion and other aging effect.

The storage system shall be designed to the general provisions listed in Table 1. These performance requirements have been derived from the previous performance, operation experience and regulatory requirements.

Table 1. Parameters included as General Performance and Capacity Requirements

PARAMETER
Design basis dry storage period
Design basis fuel
Assembly integrity
Location of fuel storage site
Location of module
Maximum distance to storage site fence
Minimum distance to EZB(or size of buffer)
Capacity: • Quantity of fuel assemblies per basket • Quantity of fuel baskets per module • Quantity of modules per pad • Quantity of modules per pad
Air cooling mechanism(not applicable to cask)
Monitoring and surveillance

III. Acceptance Criteria of Fuel

The storage system shall be designed to store fuel assemblies having the following parameters listed in Table 2. The parameters provide basis of safety and usually maximum quantity with respect to the specified design basis fuel. Variations in maximum burnup can be compensated by a corresponding small site-specific , in other word as discharged fuel characteristics, increase/ decrease in the cooling time as long as the total heat release and radioactivity per a unit cask or cylinder are met.

IV. SAFETY Requirements

Any storage system 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 system 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 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 Design 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 so called EZB that are less than values specific in Table 5 for Design Basis Events.

For the event consisting in the drop of a fuel into basket, the basket shall be designed to maintain its general structural integrity so as to allow fuel retrievable in safe after

Table 2. Acceptance Criteria for Design basis Fuel for Storage System.

PARAMETER
Design basis fuel cooling period
Fuel age spread in specific system
Design basis maximum fuel burnup
Assembly heat release for design basis fuel burnup
Assembly radioactivity of design basis fuel burnup
Irradiation period/specific power
Fuel assembly initial Uranium 235 enrichment
Fuel *integrity(defect or not)*
Design basis average basket configuration
Design basis canister(if applicable) configuration
Maximum initial fuel assembly temperature*(for cladding, fuel meat with an ambient air temperature)*

Table 3.Generic Design Basis Events Considered for a storage system.

DESIGN BASIS EVENT
Design Basis Earthquake (ground motion acceleration)
Wind caused by Typhoon or Hurricanes
Tornado winds and missiles
Severe air flow blockage conditions
Fuel drop in storage basket or canister
Drop of storage cylinder shield plug
Drop of flask guide mechanism
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
Collision from land vehicle
Fires

Table 4. Design Basis Events(site-specific)

DESIGN BASIS EVENT
Turbine explosion
Tsunami
Dam failure *(high velocity water flow, subsequent flood)*
Aircraft crashes
Fires(natural and man-made)
Landslide
Nearby explosion

Table 5.Items for Shielding and Radiological Requirements.

ITEM
Contact dose rate on cask or module
Temporary dose rate during fuel basket loading
Fence dose rate[1])
Effective dose (occupational)
Effective dose (for public at Exclusion Zone Boundary) from normal operation
Effective dose (for public at Exclusion Zone Boundary) following Design Basis Events

following the event.

A storage system also requires in every case 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 system. For application at a specific site, the system shall be analyzed in accordance with those site-specific events or specifically protected from the event(s).

1. Storage Site

Storage site is can be located on-site or off-site from existing nuclear power plants(NPPs). In case of on-site, geological survey data for the existing nuclear power plants can be applied to structural and seismic analysis during basic design stage since site location was not fixed until the determination of specific site. If geological survey data on a designated is quite a different from that on the existing NPPS, evaluation, analysis or design shall be performed for change of basic design reflecting the difference or reinforcement of storage system base and ground. Layout of storage system shall be designed on the basis of layout planning considering enough space between modules or casks for operation convenience, cooling air fluidity, visual inspection and construction work. Storage site shall be provided with drain facility. Potentially contaminated drain and non-contaminated drain shall be separated. Radiation monitoring equipment such as area monitoring shall be installed at the site boundary and other measurement and monitoring equipment for operation shall be provided.

2. Radiological Requirements

The shielding materials of a storage system the A storage system shall attenuate radiation from the spent fuel to contact dose rates derived based on ALARA principle. For shielding assessments, the design basis fuel shall be assumed in full of every storage facility, even if in reality fuel having a longer cooling period maybe present and full capacity can be achieved after quite a while.

The sky shine calculations that might occur for the out-door operation shall consider manufacturing tolerances for the shield gap between shield plug and fuel basket. In case of air bent cooling system, air inlets and air outlets shall form a labyrinth to minimize scattering. 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. If necessary additional pieces of shielding plate may be used at specific locations such as air inlets and outlets and storage cylinder shield plug to limit the dose rate to values for a certain period of time.

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.

3. Thermal Requirements

A storage system dissipates heat to maintain the fuel assemblies within the limit specified by previously determined in terms of fuel integrity. The structure such as 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 modular storage system. The limit fuel and structure 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 windblown objects and enhance protection against floods. The design of the gratings shall facilitate visual inspection and periodic cleaning.

4. Cotainment Requirements

During storage, a storage system shall provide a confinement and/or containment barrier between the fuel basket or canister and the environment. The leak tightening seal of storage cask can act as a back-up to the confinement barrier provided by the fuel basket or canister. The fuel basket shall provide the primary confinement barrier to the fuel assemblies. During the short period during which the fuel loading and unloading operations are made, the storage canister is opened.

The storage basket shall be provided with vent and drain lines to allow periodic verification of the storage confinement integrity. The lines shall be brought from each storage canister to the outside of the storage system and shall be equipped with a manual isolation valve. The lines and the valves shall be a part of the storage basket confinement boundary.

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

5. Structural Integrity

A storage system 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 system shall be maintained within the limits of 66 °C over larger areas and 93 °C over local areas in the proximity of the storage basket, that are specified in ACI 349.

Heavy loads such as the transfer cask, the storage 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 equipments. 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 system 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 basket and module shall consider, as a Design Basis Events, the drop of a fuel into the storage basket. The postulated drop height shall be from the highest fuel position in handling to the bottom of the storage basket. This event may cause some deformation to the storage basket, as long as the fuel basket retrievability is ensured following the event. This Design Basis Event may cause the storage canister to no longer be suitable for storage.

6. Radiation Protection Plan and Radiation Safety System

Radiation protection plan shall be established such that radiation exposure against operating personnel shall be maintained as low as reasonable achievable (ALARA) within limit prescribed in MEST notice 2009-17. Radiation safety system shall be designed considering the following aspects. Radiation protection plan shall include radiation exposure control plan and health physics plan, and conform to designated radiation protection plan.

- Potential radioactive contamination by operation of the dry storage facility shall be minimized.
- Necessity for direct handling work of radioactive material such as radioactive waste generating from handling of spent fuel and operation of storage facility shall be minimized and appropriate radiation protection facility shall be provided when inevitable.
- When necessary, radiation work area shall be provided and potential contaminated equipment, tool, material, etc. shall be arranged in this area. Access to this area shall be controlled. Arrangement for this access control shall be planned in the most reasonable and efficient way considering interconnection with other existing nuclear facilities.
- Amount of radioactive material released into surrounding environment shall be minimized.
- Handling facility, auxiliary facility, radiation monitoring facility, decontamination facility and work procedure shall be provided to achieve radiation protection goal in accordance with the radiation protection principle.
- Secondary radioactive waste which may be generated from facility operation shall not be released without control.

- Monitoring equipment for measurement of airborne radioactivity concentration in the air inside the module with annunciation and necessary action shall be provided to prevent contamination of operating personnel thru inhalation and/or skin.

V. Design of IAEA Safeguards Provisions

Designer will design the IAEA Safeguards provisions in accordance with the requirements of IAEA INFCIRC 164.

VI. Applicable Codes, Standards and Classification

The A storage system shall be designed to the requirements of the following Codes and Standards. These are grouped as follows:

a. General design Codes and Standards that applies to the entire design, supply and construction process, see Table 6.
b. Specific design, manufacturing and construction Codes and Standards, see Table 7.
c. Quality Assurance Codes and Standards, see Table 8.

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 basket is a welded structure designed to ASME Section VIII.

Any SSC(system structure and components) important to safety of storage system eg, concrete structure, canister and other items shall be designed, fabricated and installed to the requirements of the following codes and standards.

Table 6. Applicable Code and Standard for General Design, Fabrication and Construction

Code & Standard	Title
-	Korean Nuclear Law
US 10 CFR 72[2]	Licensing Requirements For The Independent Storage Of Spent Nuclear Fuel and High-Level Radioactive Waste
IAEA 116	Design of Spent Fuel Storage Facilities
IAEA INFCIRC 164	Safeguards Agreement in country of use

Table 7. Applicable Code and Standard for Concrete Structure.

Code & Standard	Title
ACI 349-97 & ACI 349R-97	Code Requirements for Nuclear Safety Related Concrete Structures and Commentary, American Concrete Institute
ACI 318-99 & ACI 318R-99	Building Code Requirements for structural Concrete and Commentary, American Concrete Institute
ANSI/ASCE 7-95	Minimum Design Loads for Buildings and Other Structures Commentary, American Society of Civil Engineers
ANSI/ANS 57.9	Design Criteria for an Independent Spent Fuel Storage Installation(Dry Storage Type)
NRC Regulatory Guide 1.60	Design Response Spectra for Seismic Design of Nuclear Power Plants, 1973
NRC Regulatory Guide 1.61	Damping Values for Seismic Design of Nuclear Power Plants, 1973
KCS	Design Codes & Standards for concrete structures in Korea,
UBC	US Building Regulation Code
KBC	Korea Building Regulation Code

Table 8. Applicable Code and Standard for Storage Cylinder and Other Structure.

Code & Standard	Title
ASME Section VIII	ASME B&PV Section VIII Division 1
CAN/CSA- S16.1-94	Limit States Design of Steel Structures
ASTM E5 15-90 (2000)	Standard Test Method for Leaks using Bubble Emission Technique
IAEA/SG/INF/3	IAEA Safeguards, An Introduction

VII. Conclusion and Futher Step

In order to develop a storage system for spent fuels from PWR reactors, a series of parameter and items to be considered for design requirements of a storage system was outlined. 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 fulfill the requirements for successful implementation of the module to the future storage condition. From the result of consideration to find optimised design features, it can be concluded that, detail analyses of the system will be carried out for the future steps to ensure confirmation with design requirement described in the paper and will finally be implemented to the future dry storage system in Korean site(s).

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[1] Enforcement Decree of the Atomic Energy Act), 2008.12.31, MEST

[2] 10CFR72 Licensing Requirements For the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste and Reactor Related Greater Than Class C Waste.