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3 PRINCIPAL DESIGN CRITERIA

3.1 Purpose of Installation

The INL TMI-2 ISFSI provides for horizontal, dry storage of the TMI Unit 2 (TMI-2) core debris canisters in a high integrity steel DSC which is placed inside a massive reinforced concrete HSM. The DSC will be vented through a HEPA grade filter once it is placed inside the HSM to prevent build-up of combustible levels of hydrogen gas inside the DSC. The function of the DSCs and HSMs is to provide for the safe, controlled, interim storage of the TMI-2 canisters. The standardized NUHOMS® dry spent fuel storage system has been adapted for storing TMI-2 canisters and has been designated NUHOMS®-12T.

The ISFSI layout is based on the use of 30 HSMs. Each HSM holds one NUHOMS®-12T DSC containing up to 12 TMI-2 canisters. Therefore, 29 HSMs will contain all (344) TMI-2 canisters plus provide four additional TMI-2 canister spaces. An extra HSM serves as a backup in case temporary storage of a DSC is required or in case a challenged canister needs additional confinement. This spare HSM will include a cylindrical overpack so that it can be used as an additional confinement barrier. The INL TMI-2 ISFSI layout is shown in Figure 1.3-2. Those systems, structures and components considered to be important to safety are identified in Table 3.4-1. The design life of the DSC and HSMs is intended to be 50 years.

3.1.1 Material to be Stored

The material to be stored inside the DSC consists of canisters containing core debris removed from the damaged TMI Unit 2 during defueling operations. TMI-2 was a Babcock & Wilcox (B&W) pressurized water reactor. The material contained in the TMI-2 canisters is the remains of the TMI-2 core [3.1, 3.2]. Records of the contents of each canister were kept and define the materials to be stored [3.3]. Retrieved materials from the TMI-2 core include:

- Rubble bed debris.
- Partially intact fuel assemblies.
- Debris bed stratified material.

- Miscellaneous core component pieces (e.g., fuel rod segments, AmBeCm neutron startup sources, spacer grids, end fittings, control rod assembly spiders, springs, fuel pellets, etc.).

- In-core instrument assemblies.

There are three types of TMI-2 canisters that will be stored inside the DSC:

- TMI-2 *Fuel* canisters (large pieces of core debris).

- TMI-2 *Knockout* canisters (fines generated from the use of the debris vacuum system).

- TMI-2 *Filter* canisters (fines generated from the use of the debris vacuum system and defueling water cleanup system).

In this SAR, the TMI-2 *fuel* canisters, *knockout* canisters, and *filter* canisters are generically referred to as TMI-2 canisters and are shown in Figure 3.1-1, Figure 3.1-2, Figure 3.1-3, and the Appendix A drawings.

The *fuel* canister was a receptacle for pieces of core debris large enough to be picked up by mechanical devices. The *knockout* canister was part of the fines/debris vacuum system. It was designed to separate debris ranging in size from 140 μm up to the size of whole fuel pellets [0.95 cm (0.375 in) diameter by 1.5 cm (0.6 in) long] and larger pieces of resolidified, once-molten fuel. The inlet flow came directly from the defueling vacuum system inside the reactor, while the outlet flow went to a *filter* canister for further treatment. As part of either the defueling water cleanup system or the fines/debris vacuum system, the *filter* canister was designed to remove very small debris particles from the water. The *filter* assembly module fitting inside the canister shell was designed to remove particulates in the range of 0.5 to 800 μm. Details of the design and original function of the three types of canisters are provided in Reference 3.4.

Table 3.1-1 lists the principal design parameters determined for the TMI-2 canisters to be used as the design basis for the NUHOMS®-12T system documented in this SAR.

3.1.1.1 Physical Characteristics

The physical characteristics of the TMI-2 canisters and their contents are described in detail in the Safety Analysis Report for the transportation of TMI-2 Core Debris to INL [3.5], the design specification for the TMI-2 canisters [3.4], and are summarized in Table 3.1-1, Table 3.1-2 and table 3.1-3. The key physical parameters of interest are the canister weight, canister length, cross-sectional dimensions, canister contents, internal poisons, debris density, and debris weight. The values of these parameters form the basis for the criticality, mechanical, and structural design of the DSC and its internals.

3.1.1.2 Thermal Characteristics

The key parameter utilized to determine the heat removal requirements for the NUHOMS®-12T system design is the TMI-2 fuel decay heat power. The total decay heat power per TMI-2 canister is dependent on the total burnup and the cooling time of the fuel debris. To a lesser extent, total decay heat power is dependent on the initial enrichment, specific power (MW/MTU), and neutron flux energy spectrum.

The maximum heat load for any TMI-2 canister is 60 watts with an average heat load for all of the TMI-2 canisters of 29 watts/canister [3.6]. The thermal analysis of the TMI-2 DSC and HSM is conservatively based on a total decay heat of 860 watts. The thermal analysis of the DSC internals which include TMI-2 canisters with core debris is conservatively based on 80 watts/canister decay heat load.

This heat load is sufficiently low that the DSC and HSM are fully capable of dissipating the heat and keeping all temperatures within the recommended material temperature limits without the need for HSM cooling air vents.

3.1.1.3 Radiological Characteristics

The maximum initial enrichment of the TMI-2 fuel was 2.98 weight percent (w/o) U-235. The TMI-2 core has a fuel burnup of 3,175 MWD/MTU and a cooling time of 19 years. A summary of the TMI-2 canister radiological characteristics is provided in Table 3.1-3.

3.1.2 General Operating Functions

The general operating functions described below are applicable for the NRC 10 CFR 71 certified MP-187 transportation system. Appendix E provides the general operating functions for the 10 CFR 72 approved OS-197 Transfer Cask. The major difference between the two transportation approaches is that the NRC 10 CFR 72 approved OS-197 Transfer Cask does not require impact limiters, evacuation and helium backfill of the DSC, leak testing of the DSC closure weld, or installation of the vent/filter housing transportation covers.

The INL TMI-2 ISFSI is designed to maximize the use of existing INL facilities and equipment at INTEC and TAN, and to minimize the need to add or modify equipment. The ISFSI will be located within the existing INL security boundary. Services such as security, maintenance, training and emergency response will be performed by the M&O Contractor. The power provided for the ISFSI security system and lighting is obtained from the INTEC electrical grid. Other support services from INL are necessary only during DSC transfer and retrieval operations.

A brief description of the general operation of the system begins with an empty DSC and cask which have been prepared for loading and TMI-2 canisters which have been drained and dried and prepared for insertion into the DSC. During loading of the TMI-2 canisters into the DSC, the DSC rests in the cavity of the cask inside the TAN Hot Shop. The DSC will be sealed and then purged and backfilled with helium for leak testing. After purging, the DSC (still inside the cask) will be moved to the cask skid/trailer and transported to the ISFSI. The DSC will be pushed from the cask into the HSM by a hydraulic ram. The HSM rests on, but is not anchored to, a concrete ISFSI basemat.

The DSC is sealed to ensure that any flow of gases in or out of the DSC, during storage, is through a HEPA filter. This is accomplished by welding the closure plates in place and leak testing the welds. The inner cover is welded and inspected to the same criteria as the outer cover plate. The plates are welded to the shell and seal welded together at the purge and vent ports to provide redundant closures. Both the purge and vent ports are covered with vent housings that are sealed to the outer cover plate with dual metallic seals. During leak testing and transfer/transport activities the filters are closed by installing cover plates which are sealed to the vent housings with dual metallic seals. Acceptance leak testing is done with the DSC inside the cask by pulling a vacuum in the DSC, back filling with helium, sealing the cask, then pulling a vacuum in the annulus between the cask and the DSC with the discharge routed through a helium leak detector. When the DSC is placed in the HSM the test/transport covers are removed to allow the DSC to vent to atmosphere, thereby, removing radiolytically generated hydrogen from any residual moisture contained inside the DSC. The HEPA filters are screwed into the filter housing using a single elastomeric gasket under the flange of the filters. Filters are sintered stainless steel encased in stainless steel bodies originally developed for long term hydrogen gas venting of radiological waste containers. There are four, two-inch diameter filters located in the vent cover housing and one, two inch diameter filter located in the purge port vent cover housing. The vent port accesses the DSC in the headspace immediately above the top of the TMI canisters. This allows for direct removal of any gases emitted by the canisters. The purge port connects to a mechanical tube that goes to the bottom of the DSC to allow for gas circulation in the system. This also allows for complete purging of the DSC if, as discussed in section 4.3, any abnormally high gas build-ups are noted. Both the purge port filter and vent port filter housings allow for sampling of gases within the DSC. Additionally, the test/transport covers can be installed over the filters to allow equalization of gases within the DSC so representative gas samples can be obtained. The filter housings also have leak test ports for remotely testing the filter housing to DSC seals. The vent and purge ports can be accessed through the rear of the HSM during DSC storage. The HSM filter access ports exit the HSM rear wall through a vented steel door. The internal location of the filters and the heavy steel door that protects the access to the filters ensures safe operation of the filters.

The filters are constructed entirely from stainless steel. The filter media is sintered stainless steel that is certified by the supplier to have an efficiency of greater than 99.97% for particulate down to 0.3 microns. This material is welded into the threaded stainless steel filter body which in turn is threaded into the filter housings. The filter assembly before installation into the housing is also checked for filtration efficiency. This filter is completely passive and is constructed of stainless steel making in unaffected by the environment it will see at INL.

Once inside the HSM, the DSC and its payload of TMI-2 canisters will be in passive dry storage. Safe storage in the HSM is assured by passive heat transfer and massive concrete walls and slabs which act as biological radiation shields. The storage operation of the HSMs and DSCs is passive except for monitoring, surveillance, and/or purging of the DSC, and vent system HEPA grade filter change out if hydrogen gas build-up is detected. Chapter 5 addresses the operating steps in more detail.

3.1.2.1 Handling and Transfer Equipment

The handling and transfer equipment required for the NUHOMS®-12T system includes the cask rigging, cask turning skid, transfer cask, cask transportation skid and positioning system, a heavy haul transport trailer, a tractor, and a hydraulic ram system. This equipment is designed and tested to applicable governmental and industrial standards and is maintained and operated according to the manufacturer's specifications. Performance criteria for the cask, skids, trailer, and ram are shown in Table 3.1-4 and described in the following sections. The NUHOMS®-12T system and MP187 cask are compatible with the TAN Hot Shop crane.

All equipment will be functionally tested, including load tests as appropriate, to demonstrate that each item meets its operational requirements. The cask and DSC are designed, tested and documented as Important to Safety equipment to ensure that they will meet all design conditions. The non-safety related support equipment is designed and built to meet commercial codes and standards and functionally tested. This equipment is not required to meet accident-related criteria as its failure cannot result in an unanalyzed safety condition. For example the lifting yoke will be load tested to ANSI 14.6 and dimensionally checked by fit up to the MP-187 trunnions, the trailer will be load tested, the hydraulic ram and the skid positioning systems will be functionally tested to the design limits of the systems. Following the individual functional and load tests, a dry run(s) will be performed for the complete transportation and transfer parts of the system using dummy DSC loads simulating the TMI-2 fuel debris canisters. The test(s) will ensure that all parts of the system meet their functional requirements and correctly interface with the other components.

Cask: The loaded DSCs can be moved with any 10 CFR Part 72 approved transfer cask for on-site moves, or a 10 CFR Part 71 approved transportation cask. It is planned to transport the loaded DSCs from the TAN facility to the ISFSI using the MP187 cask with impact limiters in place. However, the MP187 cask is also designed for use in the on-site transfer mode without impact limiters. The internal cavity of the cask (nominal length of 187 inches) is longer than the NUHOMS®-12T DSC (nominal length 163.5 inches without filter assemblies). The additional cask length will be filled with two equal length spacers, one on each end.

Cask Transportation Skid and Positioning System Criteria: As with previously licensed NUHOMS® systems, the transportation skid and skid positioning systems provide for longitudinal and transverse movement to facilitate cask/DSC alignment with the HSM. The amount of transverse motion required is a few inches. The system has positive locks which prevent any possibility of movement or load shifting during transport.

Cask Turning Skid: Due to the design of the cask transportation skid, the cask turning skid is used at the TAN Hot Shop to allow for rotating the cask between horizontal and vertical positions.

Trailer Criteria: The heavy-haul trailer used to transport the cask, skid, and DSC from the TAN Hot Shop to the HSM at the ISFSI is a tractor-towed, multi-axle trailer. The principal criteria for the transport trailer are: 1) the capacity to bear the weight of the fully loaded cask with impact limiters and the transportation skid, plus the additional inertia forces associated with transport operations; and 2) the ability to adjust the height of the cask in order to achieve precise alignment with the HSM. This latter requirement is accomplished with the skid positioning system.

The trailer deck, jacks, and transportation skid assembly provide a rigid support structure for the cask on the ISFSI approach slab. That is, any springing, such as may result from tires, coil springs or other flexible members, is eliminated from the support system to prevent cask movement while the DSC is being transferred into the HSM.

Hydraulic Ram System Criteria: The hydraulic ram system consists of a double acting hydraulic cylinder mounted on a firm base, with a grapple affixed to the piston. It is used to apply a push or pull force to transfer the DSC to/from the cask/HSM. The hydraulic ram is capable of exerting sufficient force during the entire insertion and retrieval strokes to effect the transfer. The ram has the capacity to move the DSC assuming a coefficient of friction of one for the DSC sliding in the cask or in the HSM. The ram cannot exert a force greater than 11.5 kN (70,000 pounds), which is somewhat greater than the loaded weight of the DSC, but less than or equal to the allowable force for which the DSC is designed. The stroke of the ram is sufficient to complete the transfer. During DSC transfer operations, the ram is firmly attached to the rear surface of the cask to transfer the reaction load during insertion and retrieval.

3.1.2.2 Waste Processing, Packaging, and Storage Areas

The gases evacuated from the DSC during purging and sealing at the TAN Hot Shop will be handled in accordance with TAN operating procedures.

A limited amount of dry active waste is generated from temporary protective clothing and material used during fuel loading, DSC purging, and sealing operations. These wastes will also be handled within the TAN Hot Shop according to TAN operating procedures.

The only other waste generated by the NUHOMS®-12T system is the storage components themselves at the end of their service life. These will be treated and disposed of during ISFSI decommissioning.

Table 3.1-1
Principal Parameters for the Bounding TMI-2 Canister to be Stored in NUHOMS®-12T DSC

Parameter	Value
Physical Parameters	
Maximum loaded Canister Weight	≤ 1327 Kg (2926 lb.)
Average of 12 Heaviest	1318 Kg (2905 lb.)
No. of Canisters per DSC	≤ 12 Canisters
Thermal Characteristics	
Maximum Decay Heat Power per Canister	≤60 W
Average Decay Heat Power per Canister	29 W*
Thermal Design Basis	
Maximum Decay Heat Power for one TMI-2 Canister	≤80 W
Total Decay Heat Power for DSC Loaded with 12 TMI-2 Canisters	860 W
Radiological Characteristics	
Maximum Initial Enrichment	2.98 w/o U-235
Burnup	3175 MWD/MTU
Post-Irradiation Cooling Time	≥ 19 years

* 29 watts/canister was obtained by multiplying the average canister decay heat of 15 watts/canister by the hot channel peaking factor of 1.879.

Table 3.1-2
TMI-2 Canister Data *

Parameters	Type of Canister Fuel	 *Filter*	 *Knockout*
Overall length (maximum) (cm)	381.0	381.0	381.0
(in)	150.0	150.0	150.0
Outer diameter (nominal) (cm)	35.56	35.56	35.56
(in)	14.00	14.00	14.00
Canister contents	Up to partial fuel assemblies	Small fines, 0.5 to 800 µm	140 µm to gravel size
Criticality control	Boral sheets	B_4C rods	B_4C rods
Fittings			
- inlet (cm)		6.35	5.08
- inlet (in)		2.5	2
- outlet (cm)		6.35	5.08
- outlet (in)		2.5	2.0
- drain (cm)	0.95	0.95	0.95
- drain (in)	0.375	0.375	0.375
- vent(cm)	0.635	0.635	0.635
- vent (in)	0.25	0.25	0.25
Empty canister weight (nominal)			
- in air (kg)	559	655	475
(lb)	1230	1440	1046
Bottom head design	Reversed dish	Reversed dish	Reversed dish
Top head design	Flat plate with skirt (bolted closure)	Flat plate with skirt (welded closure)	Flat plate with skirt (welded closure)

(*) From Reference 3.4

Table 3.1-3
TMI-2 Summary of Bounding Canister Source Term Characteristics

Gamma Source (γ/sec/canister)	6.37E+14
Gamma Power (MeV/sec/canister)	1.88E+14
Neutron Source (n/sec/canister)(1)	6.90E+05
Activity (Curie/canister)	3.17E+04
Specific Power (MW/MTU)	27.14(2)

(1) Neutron source term for each of two canisters, one stored in DSC 1/HSM 4 and another stored in DSC 5/HSM 22, is 8E6 neutrons/canister due to the presence on AmBeCm startup source material. [3.32]

(2) This specific power is consistent with the average TMI-2 burnup. The above listed source terms were calculated using this specific power multiplied by the hot channel peaking factor of 1.879 as discussed in Chapter 7 (page 7.2-1).

Table 3.1-4
NUHOMS® Transfer Equipment Criteria

Component	Requirement	Criteria
Cask Interface	Orientation	Vertical to Horizontal
	Contact Dose	ALARA
	Support Points	Upper Lifting Trunnions and Lower Support Trunnions
Cask Transportation Skid	Weight Capacity	Cask + DSC + Impact Limiters
	Cask Positioning	Horizontal Translation and Rotation
Cask Turning Skid	Weight Capacity	Cask + DSC
	Cask Rotation Orientation	Allows Vertical to Horizontal to Vertical Rotation
Transport Trailer	Payload Capacity	330,000 lb Payload
	Cask Positioning	Vertical Translation at Each Corner
	Rigidity	Cask is Solidly Supported During DSC Transfer Operation
	Turning Radius	Turn 90° in 48 ft wide lane
Hydraulic Ram	Capacity	11.5 kN (70,000 lbf) Push and Pull
	Load Limit	Maximum Force is Limitable
	Base Mounting	Immobile During DSC Transfer

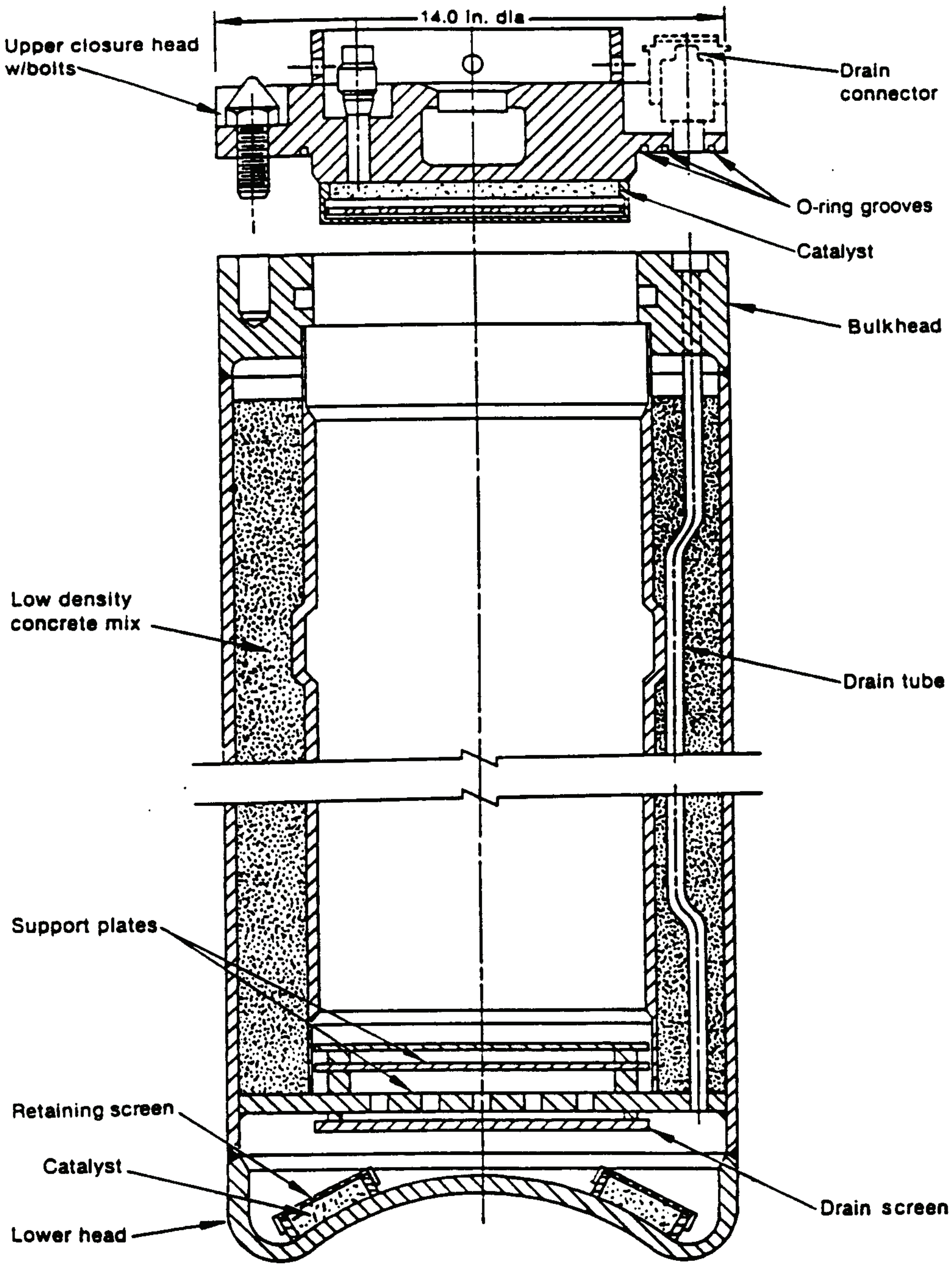

Figure 3.1-1
TMI-2 *Fuel* Canister
[Reference 3.1]

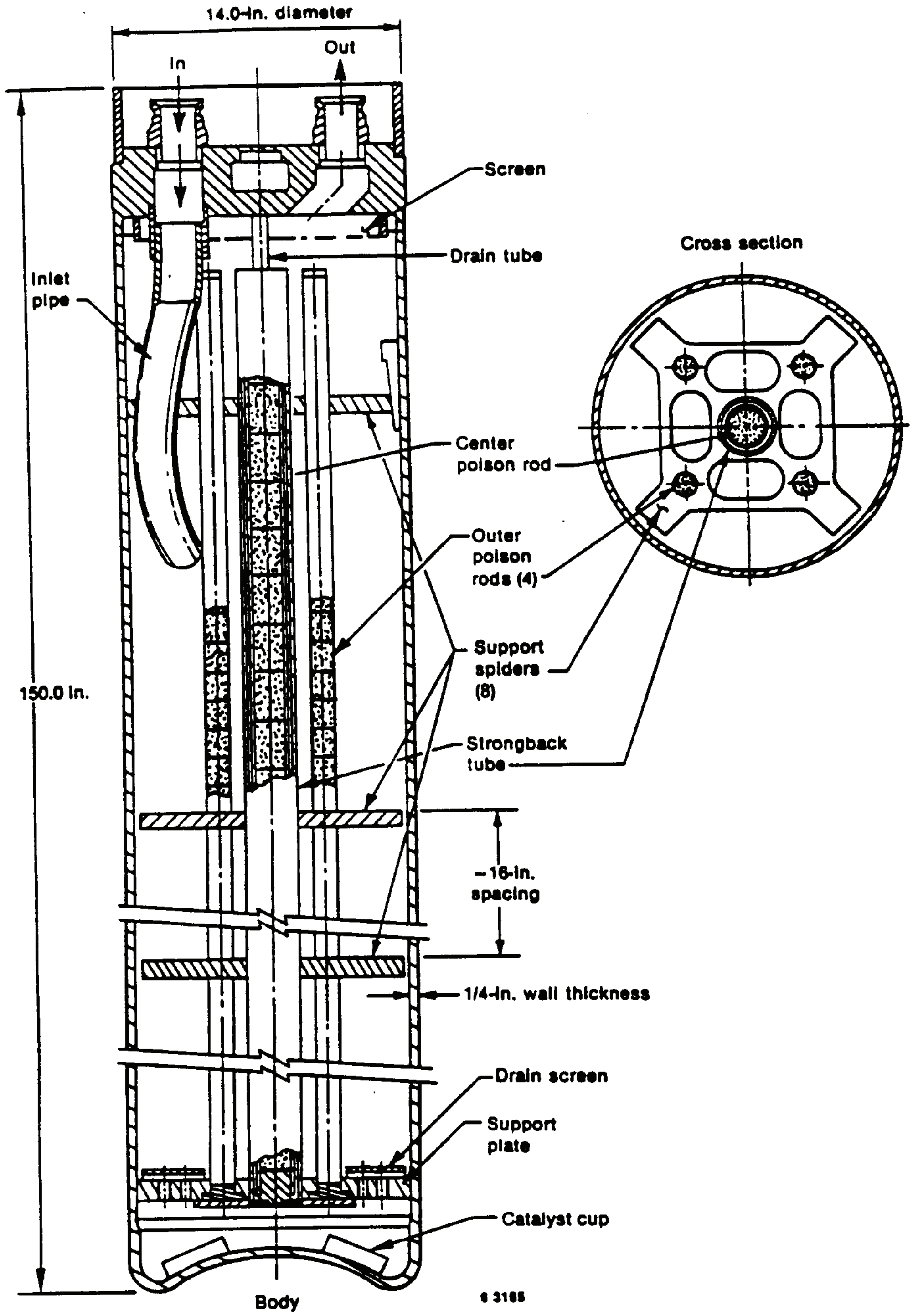

Figure 3.1-2
TMI-2 *Knockout* Canister
[Reference 3.1]

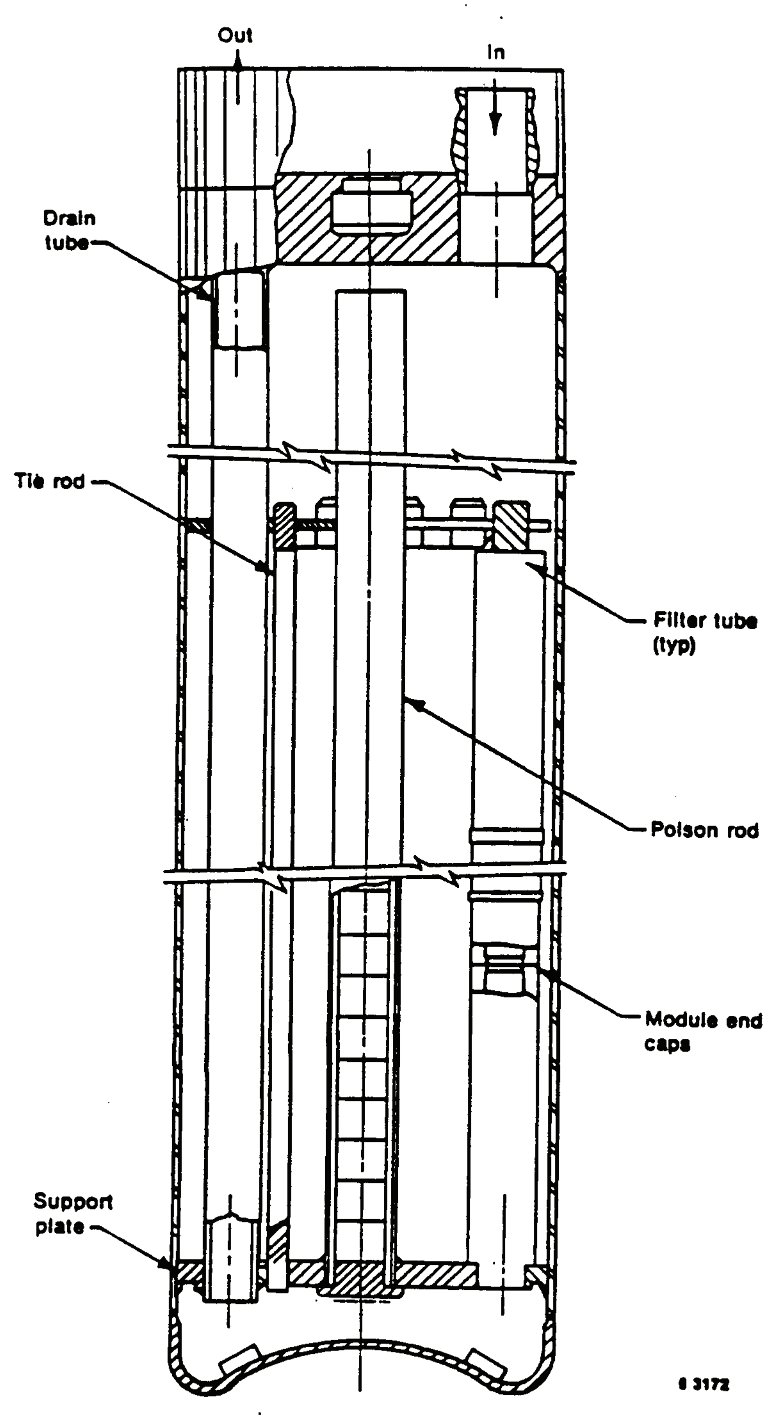

Figure 3.1-3
TMI-2 *Filter* Canister
[Reference 3.1]

3.2 Structural and Mechanical Safety Criteria

The reinforced concrete HSM and the DSC are the NUHOMS®-12T system ISFSI components which are important to safety. Consequently, they are designed and analyzed to perform their intended functions under the extreme environmental and natural phenomena specified in 10 CFR 72.122 [3.7] and ANSI-57.9 [3.8]. As stated previously, the cask must be designed and constructed to meet 10 CFR Part 71 requirements for a transportation cask and 10 CFR Part 72 requirements for an on-site transfer cask. As such, the cask shall meet all regulatory requirements to protect the DSC and TMI-2 canisters during transfer from the TAN facility to the INTEC ISFSI.

Table 3.2-1 summarizes the design criteria for the principal NUHOMS® system components. This table also summarizes the applicable codes and standards utilized for design. The extreme environmental and natural phenomena design criteria discussed below comply with the requirements of 10 CFR 72.122 and ANSI-57.9. A description of the structural and mechanical safety criteria for the other design loadings listed in Table 3.2-1, such as thermal loads and cask drop loads, are provided in Chapter 8.

3.2.1 Tornado and Wind Loadings

The TMI-2 ISFSI is located at the INL INTEC site. For this site, the design basis wind load is 100 mph at 30 feet above grade and the design basis tornado wind loads are specified by NRC Regulatory Guide l.76 [3.9] and NUREG-0800, Section 3.5.1.4, Region III [3.10] and modified by NUREG/CR-4461 [3.11] and Reference 3.12. The design basis wind effects are much less severe than the specified tornado wind and missile loads or seismic effects and, therefore, are not evaluated in detail for the HSM. The Region I design basis tornado wind loads for the MP187 cask envelope the Region III criteria.

3.2.1.1 Applicable Design Parameters

The design basis tornado (DBT) intensities used for the HSM are obtained from Reference 3.11 for Region III. For Region III, the maximum rotational plus translational wind speed is 61 m/sec (200 miles per hour), the radius of the maximum rotational speed is 45.7 m (150 feet), the pressure drop across the tornado is 10.3 kN/m^2 (1.5 psi), and the rate of pressure drop is 4.1 kN/m^2 (0.6 psi) per second. The maximum transit time based on the 2.2 m/sec (5 miles per hour) minimum translational speed is not used since an infinite transit time is conservatively assumed.

3.2.1.2 Determination of Forces on Structures

The effects of a DBT are evaluated for the HSM. Tornado loads are generated for two separate loading phenomena: First, pressure forces created by drag, as air impinges and flows past the HSM; and second, impact, penetration, and spalling forces created by tornado-generated missiles impinging on the HSM. The atmospheric pressure change induced forces are considered. In the following paragraphs, the determination of these forces is described.

The determination of the DBT velocity pressure is based on the following equation as specified in ANSI 58.1-1982 [3.13].

$$q = 0.00256\ K_z(IV)^2$$

Table 5 of ANSI A58.1 [3.13] defines the Importance Factor (I) to be 1.07 and the velocity pressure exposure coefficient (K_z) to be 0.8 applied to the full HSM height of 4.4 m (14.5 feet). Since the generic design basis HSM dimensions are relatively small compared to the 45.7 m (150 ft) rotational radius of the DBT, the velocity value of combined rotational and translational wind velocity of 61 m/sec (200 miles per hour) is conservatively used in the above equation as follows:

$$q = 0.00256 \times 0.8 \times [1.07 \times 200]^2 = 94 \text{ psf}$$

The calculated DBT velocity pressure is converted to a design wind pressure by multiplying this value by the appropriate pressure and gust response coefficients specified in Figure 2 and Table 8 of ANSI A58.1-1982. With a gust response coefficient of 1.31 as used in Table 3.2-2, the wind pressure used in this analysis bounds that obtained using the basic wind pressure formula $q = 0.00256 \times V^2$. The magnitude and direction of the design pressures for various HSM surfaces and the corresponding pressure coefficients are tabulated in Table 3.2-2. The effects of overturning and sliding of the HSM under these design pressures are evaluated and reported with the stress analysis results in Section 8.2.

3.2.1.3 Ability of Structures to Perform Despite Failure of Structures Not Designed for Tornado Loads

The HSM protects the DSC from adverse environmental effects and is the principal NUHOMS® structure exposed to tornado wind and missile loads. Furthermore, all components of the HSM (regardless of their safety classification) are designed to withstand tornadoes and tornado-based missiles. The cask protects the DSC from adverse environmental effects such as tornado winds during transit to the ISFSI. The analyses of the HSM for tornado effects are contained in Section 8.2.2.

Since the HSMs are located outdoors in a large open area, there is no possibility of an adjacent building collapsing on an HSM. HSM air vents are not required for cooling because the heat loads from the TMI-2 canisters stored in the DSCs are very low. This eliminates the possibility of HSM vent blockage as an accident condition. Also, the design assumes that the gaps between modules are filled with debris to determine the worst case thermal loads. The effect of blockage of the gaps between modules is presented in Section 8.2.10.

3.2.1.4 Tornado Missiles

The determination of impact forces created by the DBT generated missiles for the HSM is based on the criteria provided by NUREG-0800, Section 3.5.l.4, III.4 for Region III [3.10].

For the overall effects of a DBT missile impact, overturning, and sliding on the HSM, the force due to the 1800 Kg deformable massive missile impact at 70 mph is applied to the structure at the most adverse location. Conservation of momentum is assumed to demonstrate that sliding and/or tipping of a single stand-alone module will not result in an unacceptable condition for the module. The coefficient of restitution is assumed to be zero and the missile energy is transferred to the module to be dissipated as sliding friction, or an increase in potential energy due to raising the center of gravity. The force is evenly distributed over the impact area. The magnitude of the impact force for design of the local reinforcing is calculated in accordance with Bechtel Topical Report "Design of Structures for Missile Impact" [3.14].

For the local damage analysis of the HSM for DBT missiles, 125 Kg armor piercing artillery shell impacting at 70 mph is used for the evaluation of concrete penetration, spalling, scabbing and perforation thickness. The 1" solid sphere is not evaluated as there are no small openings in the HSM which lead directly to the DSC. The modified National Defense Research Committee (NDRC) empirical formula is used for this evaluation as recommended in NUREG-0800, Section 3.5.3 [3.15]. The results of these evaluations are reported in Section 8.2.

3.2.2 Water Level (Flood) Design

As described in Section 2.4, the maximum postulated flood for the INTEC ISFSI site is elevation 4917' ASL. To avoid all flood related loads on the HSM, the lowest elevation for the ISFSI base slab will be 4917'. This will assure that HSMs are not subjected to any flood loading throughout their lifetime.

3.2.3 Seismic Design Criteria

3.2.3.1 Input Criteria

The design basis response spectra of NRC Regulatory Guide (R.G.) l.60 [3.16] is used for the INL TMI-2 ISFSI design earthquake as defined in 10 CFR 72.102 (a)(2). Since the DSC can be considered to act as a large diameter pipe for the purpose of evaluating seismic effects, the "Equipment and Large Diameter Piping System" category in NRC Regulatory Guide 1.61, Table 1 [3.17]. Hence, a value of three percent of critical damping for the design basis earthquake is used. Similarly, from the same R.G. table, a value of seven percent of critical damping is used for the reinforced concrete HSM. The horizontal and vertical components of the design response spectra (Figures 1 and 2, respectively, of NRC Regulatory Guide 1.60) correspond to a maximum horizontal and vertical ground acceleration of 1.0g. The maximum ground displacement is proportional to the maximum ground acceleration, and is set at 36 inches for a ground acceleration of 1.0g.

NRC Regulatory Guide 1.60 also states that for sites with different acceleration values specified for the design basis earthquake, the response spectra used for design should be linearly scaled from R.G. 1.61 Figures 1 and 2 in proportion to the maximum specified horizontal ground acceleration. Per Section 2.6 of this SAR the horizontal ground acceleration component specified for design of the TMI-2 ISFSI is 0.36g. The vertical acceleration component is two-thirds of the horizontal component which is 0.24g.

3.2.3.2 Seismic-System Analyses

To establish the amplification factors associated with the design basis response spectra, frequency analyses are performed as described in Section 8.2.3 for the NUHOMS® system components. The results of these analyses show that the dominant lateral frequency for the reinforced concrete HSM is 36.3 Hertz. The DSC is supported by the front and back HSM concrete walls and has a calculated dominant lateral frequency of 23.8 Hertz along the support structure. The corresponding horizontal seismic acceleration used for design of the HSM is 0.36g. The dominant DSC and HSM vertical frequency is 67.9 Hertz, which results in a vertical seismic design acceleration of 0.24g. The resulting seismic design accelerations used for the DSC are .49g horizontally and 0.24g vertically.

3.2.4 Snow and Ice Loads

The maximum 100 year roof snow load, specified for the INL TMI-2 ISFSI location for an unheated structure, is 1.4 kN/m^2 (30 psf). This value is conservative as compared to 18.1 psf calculated using the formula $P_f = 0.7C_eC_tIP_g = 0.7x0.9x1.2x1.2x20 = 18.1$ psf from ANSI A58.1-1982, Tables 18 through 20. For the purpose of this SAR, a total live load of 6.24 kN/m^2 (130 psf) is used in the HSM analysis to envelope all postulated live loadings, including snow and ice.

3.2.5 Load Combination Criteria

3.2.5.1 Horizontal Storage Module

The INL TMI-2 ISFSI reinforced concrete HSM is designed to meet the requirements of ACI 349 [3.18] and is constructed to ACI 318 [3.19]. The ultimate strength method of analysis is utilized with the appropriate strength reduction factors as described in Table

3.2-2. The load combinations specified in Section 6.17.3.1 of ANSI 57.9-1984 are used for combining normal operating, off-normal, and accident loads for the HSM. All seven load combinations specified are considered and the governing combinations are selected for detailed design and analysis. The HSM design load combinations and the appropriate load factors are presented in Table 3.2-3. The effects of duty cycle on the HSM are considered and found to have negligible effect on the design. The corresponding structural design criteria and load combination methodology for the DSC support structure are summarized in Table 3.2-5 and Table 3.2-7 [3.21]. The HSM load combination results are presented in Section 8.3.5.

3.2.5.2 Dry Shielded Canister

The DSC shell and closure plates are designed by analysis to meet the allowables of the ASME Boiler and Pressure Vessel Code [3.20] Section III, Division l, Subsection NB. The DSC shell and closure plates are conservatively designed utilizing linear elastic or non-linear elastic-plastic analysis methods. The load combinations considered for the DSC shell and closure plates normal, off-normal and postulated accident loadings are shown in Table 3.2-4. ASME Code Service Level A and B allowables are conservatively used for normal and off-normal operating conditions. Service Level C and D allowables are used for accident conditions such as a postulated cask drop accident. Using this acceptance criteria ensures that, in the event of a design basis drop accident, the confinement boundary will not be breached. The maximum shear stress theory is used to calculate principal stresses. Normal operational stresses are combined with the appropriate off-normal and accident stresses. It is assumed that only one postulated accident condition occurs at any one time. The accident analyses are documented in Section 8.2. The structural design criteria for the DSC shell and closure plates are summarized in Table 3.2-6. The effects of fatigue on the DSC shell and closure plates due to thermal and pressure cycling are addressed in Section 8.3.

The internal support structure is designed to maintain its geometric arrangement for normal operating events. There are no design requirements for the internal structure for postulated accident events. The DSC internal support structure is not required to maintain criticality control of the TMI-2 canisters.

Table 3.2-1
Summary of INL TMI-2 ISFSI Storage Component Design Loadings

Component	Design Load Type	SAR Section Reference	Design Parameters	Applicable Codes
Horizontal Storage Module:	---	---	---	ACI 349-85 and ACI 349R-85 (design) ACI 318-95 (con-struction only)
	Design Basis Tornado	3.2.1	Max. wind pressure : 123 psf Max. speed: 200 mph	NRC Reg. Guide 1.76, Region III and ANSI A58.1 1982
	DBT Missile	3.2.1	Max. speed: 70 mph Types: 1800 Kg automobile 276 lbs artillery shell	NUREG-0800, Section 3.5.1.4
	Flood	3.2.2	There are no flood loads since HSMs are above flood plain	10 CFR 72.122(b)
	Seismic	3.2.3	Horizontal free field zpa: 0.36g (both directions) Vertical free field zpa:0.24g	NRC Reg. Guides 1.60 and 1.61
	Snow and Ice	3.2.4	Maximum load: 30 psf (included in live loads)	ANSI A58.1-1982
	Dead Loads	8.1.1.5	Dead weight including loaded DSC (concrete density of 150 pcf assumed)	ANSI 57.9-1984
	Normal and Off-normal Operating Temperatures	8.1.1.5	DSC with spent fuel rejecting 860 W of decay heat. Normal ambient temperatures: -20°F to 87°F; 67 Btu/hr-ft^2 solar insolation. Off-normal ambient temperatures: -50°F to 103°F; 105 Btu/hr-ft^2 solar insolation.	ANSI 57.9-1984

Table 3.2-1
Summary of INL TMI-2 ISFSI Storage Component Design Loadings
(continued)

Component	Design Load Type	SAR Section Reference	Design Parameters	Applicable Codes
	Accident Condition Temperatures	8.2.7.2	Same as off-normal conditions	ANSI 57.9-1984
	Normal Handling Loads	8.1.1.1	Hydraulic ram load of 70,000 lb. (35,000 lb./rail)	ANSI 57.9-1984
	Off-normal Handling Loads	8.1.1.4	Hydraulic ram load of 70,000 lb. (70,000 applied to one rail)	ANSI 57.9-1984
	Live Loads	8.1.1.5	Design load: 130 psf (includes snow and ice loads)	ANSI 57.9-1984
	Fire and Explosions	3.3.6 8.2.9	Enveloped by other design basis events	10 CFR 72.122(c)
Dry Shielded Canister: [confine-ment boundary only]	---	---	---	ASME Code, Section III, Subsection NB, Class 1 Component
	Flood	3.2.2	There are no flood loads since HSMs are above flood plain	10 CFR 72.122(b)
	Seismic	3.2.2	Horizontal free field zpa: 0.36g Vertical free field zpa: 0.24g	NRC Reg. Guides 1.60 & 1.61
	Dead Loads	8.1.1.2	Weight of loaded DSC: 30,000-60,000 lb. enveloping	ANSI 57.9-1984
	Normal and Off-Normal Pressure	8.1.1.2	Enveloping internal pressure of > -14.7 psig, ≤15 psig	10 CFR 72.122(h)
	Test Pressure	8.1.1.2	Enveloping internal pressure of 22.5 psig.	10 CFR 72.122(h) and 10 CFR Part 71

Table 3.2-1
Summary of INL TMI-2 ISFSI Storage Component Design Loadings
(continued)

Component	Design Load Type	SAR Section Reference	Design Parameters	Applicable Codes
	Normal and Off-normal Operating Temperature	8.1.1.2, 8.1.2.2	DSC with spent fuel rejecting 860 W of decay heat. Normal ambient temperatures: -20°F to 87°F; 67 Btu/hr-ft^2 solar insolation. Off-normal ambient temperatures: -50°F to 103°F; 105 Btu/hr-ft^2 solar insolation.	ANSI 57.9-1984
	Normal Handling Loads	8.1.1.2	Hydraulic ram load of 70,000 lb.	ANSI 57.9-1984
	Off-normal Handling Loads	8.1.2.1	Hydraulic ram load of 70,000 lb.	ANSI-57.9-1984
	Accidental Cask Drop Loads	8.2.5	Equivalent static deceleration of 75g for vertical end drop and horizontal side drops, and 25g oblique corner drop	10 CFR 72.122(b)
	Accident Internal Pressure	8.2.7 8.2.9	Enveloping internal pressure of 15 psig	10 CFR 72.122(h)
Dry Shielded Canister Support Structure:	---	---	---	AISC Specifi- cation for Structural Steel Buildings
	Dead Weight	8.1.1.4	Loaded DSC plus self weight	ANSI-57.9-1984
	Seismic	3.2.3	DSC reaction loads with hori- zontal free field zpa of 0.36g and vertical free field zpa of 0.24g	NRC Reg. Guides 1.60 & 1.61

Table 3.2-1
Summary of INL TMI-2 ISFSI Storage Component Design Loadings
(continued)

Component	Design Load Type	SAR Section Reference	Design Parameters	Applicable Codes
	Normal Handling Loads	8.1.1.4	DSC reaction loads with hydraulic ram load of 70,000 lb. (35,000 lb./rail)	ANSI-57.9-1984
	Off-normal Handling Loads	8.1.1.4	DSC reaction loads with hydraulic ram load of 70,000 lb. (70,000 lb. in one rail)	ANSI-57.9-1984

Table 3.2-2

Design Pressures for Tornado Wind Loading

Wall Orientatio n	Velocity Pressure (psf)	Gust Response Factor	Max/Min Pressure Coefficient	Max/Min Design Pressure (psf)
North	94	1.32	+0.1.06	99
East	94	1.32	-0.92	-87
South	94	1.32	-0.66	-62
West	94	1.32	-0.92	-87
Roof	94	1.32	-0.92	-87

Notes:

1. Wind direction assumed to be from North. Wind loads for other directions may be found by rotating table values to desired wind direction. For example, if the wind was from the east, the design pressure would be 99 psf on the east wall, -62 psf on the west wall, and -87 psf on the roof, north, and south walls.
2. Negative values indicate suction pressure.

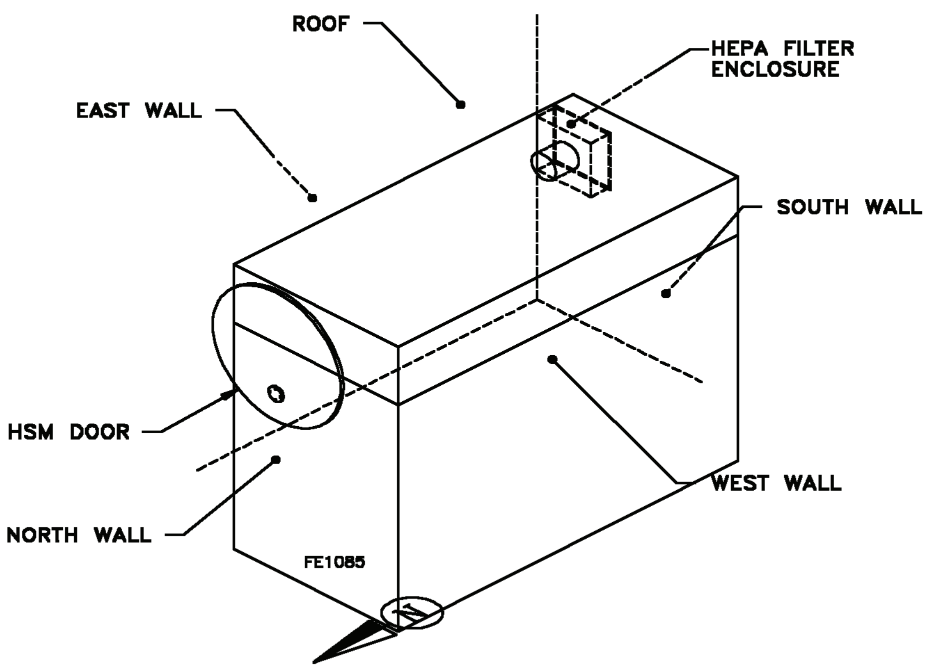

Table 3.2-2
HSM Ultimate Strength Reduction Factors

Type of Stress	Reduction Factor
Flexure	0.9
Axial Tension	0.9
Axial Compression	0.7
Shear	0.85
Torsion	0.85
Bearing	0.7

Table 3.2-3
HSM Load Combination Methodology

Case No.	Load Combination[1]	Loading Notation
1	1.4D + 1.7L	D = Dead Weight[2]
2	1.4D + 1.7L + 1.7R_o	E = Earthquake Load
3	0.75 (1.4D + 1.7L + 1.7T + 1.7W)	R_o and R_a = Normal and Off-normal Handling Loads.
4	0.75 (1.4D + 1.7L + 1.7T)	
5	D + L + T_o + E	L = Live Load[3]
6	D + L + T_o + W_t	T_o and T_a = Normal, Off-normal or Accident Condition Thermal Load
7	D + L + R_a + T_a	Wt = Tornado Generated Wind Load[4] W = Wind Load

---

(1) The HSM load combinations are in accordance with ANSI-57.9-1984. The effect of creep and shrinkage are included in dead weight load for Cases 2 through 7.

(2) Dead loads (D) are evaluated for ±5% to simulate most adverse loading.

(3) Live loads (L) are varied between 0 and 100% of design load to simulate most adverse conditions for the HSM.

(4) Design Basis Tornado loads include wind pressure, differential pressure, and missile loads. Missile loads are additive to wind pressure and other loads. Local damage is permitted at the point of impact if there is no loss of intended function on any structure important to safety.

Table 3.2-4
DSC Shell and Closure Plates Load Combinations and Service Levels

Load Case		Test Conditions (3)	Normal Operating Conditions				Off-Normal Conditions				Accident Conditions							
			A1	A2	A3	A4	B1	B2	B3	B4	D1	D2	C1	C2	C3	C4	C5	C6
Dead Weight	Vertical, DSC Empty		X															
	Vertical, DSC w/Fuel			X														
	Horizontal, DSC w/Fuel	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X
Thermal	Inside HSM: -20° to 87°F					X							X	X	X		X	
	Inside Cask: -20° to 87°F			X	X		X		X			X						X
	Inside HSM: -50° to 103°°F	X						X		X						X		
	Inside Cask: -50°F to 103°°F										X							
Internal Pressure	Normal Pressure			X	X		X							X				
	Off-Normal Pressure					X		X	X	X								
	Accident Pressure										X	X	X(2)		X(2)	X(3)	X(2)	X(2)
Test Pressure		X																
Handling Loads	Normal DSC Transfer				X	X									X			
	Jammed DSC Loads						X	X	X								X	X
Cask Drop (end, side, or corner drop)												X						
Seismic													X					
Flooding														X				
ASME Code Service Level		(1)	A	A	A	A	B	B	B	B	D	D	C	C	C	C	C	C

NOTES:

1. The stress limits of NB-3226 apply.
2. Accident pressure for Service Level C condition is applied to inner closure plates. Accident pressures on the outer closure plates are evaluated for Service Level D allowables.
3. Test conditions include pressure during ASME Code hydrostatic test.

Table 3.2-5
DSC Support Structure Load Combination Methodology

Allowable Stress (S)[4]	
Case No.	Load Combination[1]
1	S > D[2] + L[3]
2	S > D + L + R_o
3	1.33S > D + L + W
4	1.5S > D + L + T + W
5	1.33S > D + L + T + R_a
6	1.6S > D + L + T_o + E
7	1.33S > D + L + R_a + T_a

(1) Load combinations are per ANSI 57.. For definitions of loads see Table 3.2-4.

(2) Dead load (D) includes weight of loaded DSC and is increased +5% to simulate most adverse loading.

(3) Live load is varied 0 - 100% to obtain critical section.

(4) Maximum shear stress allowable is limited to 1.4 S.

Table 3.2-6
Structural Design Criteria for DSC

	Stress Type	Stress Values[1]		
		Service Levels A & B	Service Level C	Service Level D
DSC[2] Shell & Closure Plates	Primary Membrane	S_m	Greater of 1.2 S_m or S_y	Smaller of 2.4 S_m or 0.7 S_u
	Primary Membrane + Bending	1.5 S_m	Smaller of 1.8 S_m or 1.5 S_y	Smaller of 3.6 S_m or S_u
	Primary + Secondary	3.0 S_m	N/A	N/A
DSC Fillet Welds	Primary	0.50 S_m	Greater of 0.65 S_m or 0.50 S_y	Smaller of 1.2 S_m or 0.35 S_u
	Primary + Secondary	0.75 S_m	Smaller of 0.9 S_m or 0.75 S_y	N/A

(1) Values of S_y, S_m, and S_u versus temperature are given in Table 8.1-3.

(2) Includes full penetration volumetrically inspected welds.

Table 3.2-7
Structural Design Criteria for DSC Support Structure

Allowable Stress (S)	
Stress Type	Stress Value(1)
Tensile	0.60 S_y(2)
Compressive	(See Note 2)
Bending	0.60 S_y(3)
Shear	0.40 S_y(4)
Interaction	(See Note 5)

(1) Values of S_y versus temperature are given in Table 8.1-3.

(2) Equations E2-1 or E2-2 of the AISC Specification [3.13] are used as appropriate.

(3) If the requirements of Paragraph F1.1 are met, an allowable bending stress of 0.6 S_y is used.

(4) Maximum allowable shear stress for Cases 4 to 7 is limited to 1.4S (0.56 S_y)

(5) Interaction equations per the AISC Specification are used as appropriate [3.21].

3.3 Safety Protection System

3.3.1 General

The NUHOMS®-12T system is designed for safe and secure, long-term confinement and dry storage of the TMI-2 canisters. The storage components, structures, and equipment which are designed to assure that this safety objective is met are shown in Table 3.3-1. The key elements of the NUHOMS®-12T system and its operations which require special design consideration are:

A. Double closure seal welds on the DSC shell form a confinement boundary.

B. Personnel radiation exposure minimized during DSC loading, closure, and transfer operations.

C. Design of the DSC for postulated accidents.

D. Design of the HSM passive heat removal system for effective decay heat removal to prevent further degradation of the TMI-2 core debris.

E. Passive vent system to remove hydrogen and oxygen gases that are generated as a result of radiolysis.

These items are addressed in the following subsections.

3.3.2 Protection by Multiple Confinement Barriers and Systems

3.3.2.1 Confinement Barriers and Systems

The radioactive material which the INL TMI-2 ISFSI confines is TMI-2 core debris and the associated contaminated materials. These radioactive materials are confined by the multiple barriers listed in Table 3.3-1.

During fuel loading operations at the TAN Hot Shop, the transportation cask is lifted from the transport skid, transferred to the turning skid, and then uprighted. The cask is then transferred to the work stand, the DSC is installed into the cask, and the previously dried TMI-2 canisters are placed into the cask/DSC. This operation assures that the exterior DSC surface loose contamination levels are within those required for shipping cask externals (see Section 3.3.7.1.2). Compliance with these contamination limits is assured by taking surface swipes of the upper (outside) end of the DSC while resting in the cask prior to cask closure.

Once inside the sealed DSC, the TMI-2 canisters are confined by the DSC shell and by multiple barriers at each end of the DSC. The cladding of TMI-2 fuel was severely damaged during the TMI-2 accident and thus, radioactive materials are not confined by fuel cladding. The TMI-2 canisters provide the first barrier for confinement of radioactive materials. The TMI-2 canisters have two small penetrations, a purge port and a fill port, which are left open during storage. The path that fuel debris must travel to get out of the canisters is not direct and the penetrations are such that the open penetrations do not compromise the canister confinement function. Additionally, the vent penetrations in the *fuel, knockout* and *filter* canisters are screened to various extents which helps prevent fuel particles from escaping the canisters. The DSC has a series of barriers to ensure the confinement of radioactive materials. The DSC cylindrical shell is fabricated from rolled steel plate which is joined with full penetration 100% radiographed welds. All top and bottom end closure welds are multiple-pass welds. This effectively eliminates pinhole leaks which might occur in a single pass weld, since the chance of pinholes being in alignment on successive weld passes is not credible. Furthermore, the DSC cover plates are sealed by separate, redundant closure welds. The DSC confinement boundary welds are examined as required by the Appendix A drawings using the acceptance criteria of the ASME Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB [3.20].

The *knockout* and *filter* canisters also have two larger ports (2" and 2-1/2" nominal) that were closed with expandable mechanical plugs. The plugs are designed to seal an opening by expanding a four-piece grip section and an elastomeric seal over a tapered mandrel by screwing a nut down the bolt stem of the mandrel. To secure the plugs against potential internal canister pressure, the nuts were tightened to a specified torque. The *debris* canisters have an elastomeric gasket between the canister body and the bolted head which allowed the water-tight seal necessary for the dewatering operation at TMI.

The elastomeric parts of the TMI-2 canisters that would form a part of the confinement barrier are rendered ineffective in the heated vacuum drying system. The loss of elastomeric parts in the *debris* canisters does not affect the confinement function because the lid remains in place and the path that fuel debris must travel to get out of the *debris* canisters is very small and still not direct. The loss of elastomeric parts in the *filter* and *knockout* canisters could cause the loss of the expandable mechanical plugs. Therefore, the confinement function of the expandable mechanical plugs will be supplemented by a mechanical closure (in other words, not welded) designed to be secured over the top of the larger ports (2" and 2-1/2" nominal).

DSC-02 was loaded with eight *filter* canisters before the functional effect on the expandable mechanical plugs due to the loss of the elastomeric parts was recognized. Because of the low radioactive material inventory in DSC-02, the remaining effectiveness of DSC-02 as a confinement barrier, and the lack of a credible driving force for the movement of radioactive material, the expandable mechanical plugs are not needed in TMI-2 canisters contained in DSC-02.

3.3.2.2 Ventilation - Offgas

No HSM cooling air vents are required to remove the decay heat since the decay heat generated by the TMI-2 fuel debris inside the DSC is low.

The DSC is vented to reduce the accumulation of gases generated due to radiolysis. A venting system is provided inside the HSM with access through the rear wall. The venting systems are depicted in Chapter 4 figures and the Appendix A drawings. The DSC cavity gases will vent through the HEPA filters into the HSM cavity which is in turn vented through holes provided in the rear access door. The ability to close off the vents and sample ahead of and behind the HEPA filters provides the capability to periodically monitor gas composition and rate of change. Although not anticipated, pressure build-up in the DSC and radioactive material release from the HSM can be checked. The design features and operation and maintenance procedures will assure that the system can be monitored, tested and purged (if necessary) during system operation.

3.3.3 Protection by Equipment and Instrumentation Selection

3.3.3.1 Equipment

The HSM and the DSC are the storage equipment which are important to safety. Other equipment associated with the INL TMI-2 ISFSI is required for handling operations at TAN, and utilized for transfer and transportation operations.

3.3.3.2 Instrumentation

The NUHOMS®-12T is a passive system, and no safety-related instrumentation is necessary. The maximum temperatures and pressures are conservatively bounded by analyses (see Section 8.1.3). Therefore, there is no need to monitor the internal cavity of the DSC for pressure or temperature during normal operations. The DSC is conservatively designed to perform its confinement function during all worst case normal, off-normal, and postulated accident conditions. The HSM is designed with no cooling vents and the concrete temperatures are conservatively enveloped by calculation. No temperature monitoring system is required to detect a blocked vent accident event or the presence of debris between adjacent HSMs.

3.3.4 Nuclear Criticality Safety

The NUHOMS®-12T system is designed to be subcritical under all credible conditions. Regulations specific to nuclear criticality safety of the cask system are contained in 10 CFR 72.124 and 72.236(c). Other pertinent regulations include 10 CFR 72.24(c)(3), and 72.236(g). Aside from DSC flooding, at least two unlikely, independent, and concurrent or sequential changes to the conditions essential to criticality safety must occur before an accidental criticality is possible. Criticality safety of the design is based on permanent fixed neutron-absorbing materials inside the TMI-2 canisters, drying the TMI-2 canisters before loading them into the DSCs and the prevention of water intrusion into the DSC. Criticality safety of the NUHOMS®-12T system does not rely on the use of burnup credit, the use of burnable neutron absorbers, or more than 75 percent credit for fixed neutron absorbers. Loading operations are done after all free liquid water has been removed from the individual TMI-2 canisters and with a dry DSC. Unloading operations would be performed in a dry environment without submerging the DSC in water.

The DSC and TMI-2 canisters are designed to ensure nuclear criticality safety during worst case dry loading operations. Design measures are taken to exclude the possibility of flooding the DSC cavity during the transfer operations and storage period. Prior to the loading operations, the TMI-2 canisters are vacuum dried. The DSCs are located in the HSMs above the level of the design basis flood. Multiple barriers prevent direct impingement of externally applied water on the vent system openings. The thermal reservoir of the massive concrete HSM and steel DSC is not readily affected by daily temperature variations. Changes can occur in the water content inside the DSC and the TMI-2 canisters due to atmospheric moisture. An evaluation [3.29] shows, however, that over a 40 year storage period, using very conservative assumptions, a small amount of water can be acquired from the atmosphere in each TMI-2 canister. This amount was taken into account in canister drying acceptance criteria so that criticality safety would not be compromised over time in storage. The cask and HSM are designed to provide adequate drop and/or missile protection for the DSC and the TMI-2 canisters are designed to maintain the fuel configuration after a drop accident. There is no credible accident scenario which would result in the possibility of water intrusion into the DSC. Chapter 2 addresses the ISFSI flood level and demonstrates that flood water intrusion during vented storage is not credible.

Control methods for the prevention of criticality for the DSC consist of the material properties of the fuel, the geometric confinement of the fuel within the TMI-2 canisters, and the inherent neutron absorption in the steel components of the TMI-2 canister structures.

3.3.4.1 <u>Original Criticality Evaluation</u>

The original criticality safety analysis for the system is presented in sections 3.3.4.1 and 3.3.4.2. A second criticality safety evaluation [3.30] is presented in section 3.3.4.3. The second criticality evaluation was performed to account for readsorbed atmospheric water and bound water.

The key factors and assumptions to be used in the original criticality safety analysis are as follows:

1. Moderator is water at a density of 8.8E-5 grams/cc (corresponding to saturated air at 120°F at 14.7 psia) and an additional amount of hydrogen equivalent to 100% volume fraction hydrogen gas at standard temperature and pressure.

2. The geometry of the TMI-2 canister shells is maintained and the fuel is confined within the TMI-2 canisters.

3. The TMI-2 canisters contain fixed poisons.

Because of the administrative controls placed on transportation of the DSC from TAN to INTEC (Appendix E), there is no credible event that could lead to a cask drop accident during the 10 CFR 72 transport and transfer operations. In addition, there is no credible event whereby the DSC could be accidentally flooded with water during transport and transfer operations. Since moderator intrusion due to precipitation or flooding during storage is prevented and not considered credible, subcriticality of the DSC is assured during storage at the ISFSI.

3.3.4.1.1 Reactivity Equivalence and Criticality Analysis Methods

A. Computer Code Description

The Criticality Safety Analysis Sequence No. 2X (CSAS2X) included in the SCALE-4.3 [3.22] package of codes was used for the criticality evaluation.

B. Computer Code Application

The SCALE-4.3 package is an extensive computer package which has many applications, including cross-section processing, criticality studies, and heat transfer analyses. The package is comprised of many functional modules which can be run independently of each other. Control Modules were created to combine certain function modules in order to make the input requirements less complex and shorter. For this evaluation, only four functional modules and one control module were used. This included the Control Module CSAS2X which utilizes the criticality code KENO-V.a and the preprocessing codes BONAMI-S, NITAWL-II, and XSDRNPM-S. The 44 group ENDF/B-V cross-section library was used for this evaluation. KENO V.a, in conjunction with the 44 group ENDF/B-V cross-section library of nuclear cross-section data, was used to calculate the multiplication factor, k_{eff}, of the NUHOMS®-12T ISFSI. KENO V.a utilizes a three-dimensional Monte-Carlo computation scheme. The preprocessing codes used for this evaluation are the functional modules BONAMI-S, NITAWL-II, and XSDRNPM-S. They are consolidated into the control module CSAS2X. BONAMI-S has the function of performing Bondarenko calculations for resonance self-shielding. The cross-sections and Bondarenko factor data are pulled from an AMPX master library. The output is placed into a master library as well. Dancoff approximations allow for different fuel lattice cell geometries. The main function of NITAWL-II is to change the format of the master cross-section libraries to one which the criticality code can access. It also provides the Nordheim Integral Treatment for resonance self-shielding. XSDRNPM-S is a discrete-ordinates code which solves the one-dimensional Boltzmann equation. XSDRNPM-S is also used to collapse cross-sections, do shielding analysis, and produce bias factors for

Monte-Carlo shielding calculations. The main function of XSDRNPM-S in this evaluation is to weight the fuel lattice cells in order to be able to smear the fuel region over a large area in a complex geometry.

3.3.4.2 Criticality Evaluation

This section presents the analyses which demonstrate the acceptability of storing TMI-2 canisters in the DSC under normal fuel loading, handling, and storage conditions. A nominal case model is described and a neutron multiplication factor, k_{eff}, presented. Uncertainties are addressed and applied to the nominal calculated k_{eff} value. The final k_{eff} value produced represents a maximum with a 95 percent probability at a 95 percent confidence level.

A. Basic Assumptions

The methodology and assumptions used for this evaluation are extremely conservative and bounding. While no credit can be taken for the magnitude of conservatism, it should be noted that bounding methods and assumptions are used when definitive data is not available for the payload. The most reactive TMI-2 canister is present in 12 locations in the models. This was done to avoid administrative controls on the loading of the DSCs and to simplify the computer models. This evaluation is done once for normal, off-normal, and accident conditions using the accident conditions. During accident conditions the DSC basket is assumed to fail, that is, it completely disappears from the model. The poison structures in the *knockout* canisters are displaced the maximum credible amount, one inch. The poison tube and internals of the *filter* canister are compressed and pushed to one side of the canister shell. The filter elements are assumed to disappear from the model. The *fuel* canister does not experience any deformation or displacement of the poison shroud during accident conditions. The following assumptions are used in the DSC criticality evaluation:

1. Batch 3 fresh fuel only (2.98w/o uranium-235).

2. Enrichment: batch 3 average + 2σ.

3. No cladding or core structural material.

4. No soluble poison or control materials from the core.

5. Fuel lump is whole fuel pellets for *knockout* and *fuel* canisters.

6. Fuel lump is 850 microns for *filter* canister.

7. Fuel is UO_2 and no credit is taken for degradation to less dense oxides.

8. Moderator is water at a density of 8.8E-5 grams/cc (corresponding to saturated air at 120°F at 14.7 psia) and additional hydrogen equivalent to 100% volume fraction hydrogen gas at standard temperature and pressure.

9. Fuel pitch is minimized for triangular pitch columns of cylindrical fuel pellets.

10. Canister fuel regions are filled to theoretical maximum capacity without weight restrictions.

11. Fuel is smeared to fill all volume available in the fuel regions.

12. Fixed poison concentrations are 75% of minimum specified during original fabrication of poison components.

B. Fuel Modeling Techniques

As discussed previously, there are three types of TMI-2 canisters: *fuel*, *knockout*, and *filter*. For criticality calculations, each canister type was assumed to carry its most reactive possible payload; close packed whole fuel pellets when moderatored with 8.8E-5 gram/cc of water. The entire region inside the TMI-2 canisters which could contain fuel is modeled as pure fuel moderator mix without any non-fissile material. As such, the mass of fuel exceeds the maximum payload measured in any of the TMI-2 canisters. Maximum fuel particle size in the *fuel* and *knockout* canisters is limited to whole pellets, [0.375 inches in diameter and 0.50 inches long]. The *filter* canisters were designed and used such that particle size in the canister is limited to the range of 0.5 to 800 microns [3.19]. As such, the maximum particle size modeled in the *filter* canisters is 850 microns [3.4]. Fuel is assumed to be of the maximum enrichment in the TMI-2 core, 2.98w/o uranium-235. The 2.98w/o uranium-235 includes a factor of 2-sigma added to the batch 3 (highest) average enrichment. No credit is taken for irradiation of the fuel. The material is assumed to consist of pure uranium-dioxide at a density of 10.0 grams/cc. Fuel has been modeled as cylindrical stacks of pellets in a triangular pitch. The triangular pitch generally provides a slightly more reactive fuel region than a square pitch. The fuel region moderator in the HSM and cask models includes the addition of hydrogen equivalent to 100% hydrogen gas at standard temperature and pressure to the 8.8E-5 gram/cc water.

C. TMI-2 Canisters and DSC Models Input

The *fuel* canister is a receptacle for large pieces of core debris that were picked up by the grapple and placed in the canister. An internal shroud controls the size of the internal cavity and provides a means of encapsulating the neutron absorbing material used for criticality control. As part of the debris vacuum system, the *knockout* canister separates the medium size debris from the water by reducing the flow velocities, thereby allowing the particles to settle out. An internal screen helps retain all but the very small fines in the canister. An array of four rods around a central rod, all containing boron carbide (B_4C) pellets is included for criticality control. To remove very small fines, the *filter* canister utilizes filter elements fabricated from a stainless steel media. These elements are joined together to form a filter bundle permitting a flow rate up to 125 gpm while filtering out particles as small as 0.5 microns. A center rod containing B_4C pellets ensures that the canister contents remain subcritical. The drawings provided in Appendix A give detailed dimensions of the canisters.

The canister models used for the criticality evaluation are very simple and use nominal dimensions. No attempt has been made to address the many simplifications contained in the canister models since the results of the evaluation are well below the accepted regulatory margin. The bounding normal and/or accident conditions have been used in the evaluation such that only a single geometry for each canister is used.

The *fuel* canister model has constant cross-sectional configuration throughout the length of the 150 inch canister. The *fuel* canister is made up of six concentrically arranged regions. The center region is the fuel region modeled as a cuboid. Seventy-five percent of the minimum concentration of boron originally specified in the poison material is used in the model.

The *knockout* canister model has constant cross-sectional configuration throughout the length of the 150 inch canister. The poison tubes have been displaced one inch to bound the drop testing results [3.18]. Seventy-five percent of the minimum concentration of boron originally specified is used in the canister model. There is no change in the TMI-2 canister shell diameter due to a drop accident.

The *filter* canister model has a constant cross-section. The canister internals were slumped to one side since drop testing was not performed on the *filter* canister. Again, no increase in shell diameter was modeled. The DSC model is simplified as a cylinder with shield plugs and end covers. The basket and vent and purge assemblies are not modeled. The 12 TMI-2 canisters are triangular pitch, close packed. The cask model is relatively complete, except for impact limiters which are not modeled. No changes were made to the DSC model or the HSM model. The HSM is simplified to include only the significant features of the structure: a cylindrical, two foot thick shell of concrete and two foot thick end slabs.

The input decks for the three types of TMI-2 canister, a DSC loaded with 12 *knockout* canisters in the MP187, and a DSC loaded with 12 *knockout* canisters in an HSM have been provided in Appendix D of this SAR.

D. Atom Number Densities

Most atom number densities were calculated by the material information processor (MIP) contained in SCALE-4.3. The data for the preprocessing is controlled entirely by the

MIP. It requires data to specify the cross-section library, the composition of each mixture, and the geometry of the fuel unit cell. For the purpose of this calculation, the compositions of the mixtures are specified by either volume percentage of a mixture (such as the concrete in the *fuel* canister) or by atomic density (a/b-cm) based on the values reported in the 125-B SAR [3.20]. Where the number densities were calculated by the MIP, they are taken from a typical CSAS2X output and repeated in Table 3.3-2 for completeness.

The minimum B-10 surface density in the borated aluminum contained in the *fuel* canisters was specified such that the mean of the test samples from the production run would be a minimum of 0.040gm/cm^2 at a 95/95% confidence level giving at least a 2σ margin [3.18]. A minimum B_4C density equivalent to 1.45 gm/cc at 73w/o boron having 18.34w/o Boron-10 was specified for the poison tubes in the *knockout* canister [3.18]. The atomic number densities for the Boron-10 in the borated aluminum and B_4C were conservatively taken to be 75% of the values used in Reference 3.20. The atomic number densities for the low density concrete (LDC) contained in the *fuel* canisters is based on the fabrication data provided on the Reference 3.21 drawing. The mist moderator density is calculated based on the water content of 100% humid air at 120° Fahrenheit at 1 atmosphere pressure and the atom density for hydrogen gas was taken from Reference 3.25. The fuel atomic number densities are calculated by the MIP based on actual UO_2 density of 10.0 grams/cc [3.21][3.28] and a theoretical density of 10.98 grams/cc [3.23]. The volume fraction of the fuel is simply the ratio of the actual density to the theoretical density. The MIP then calculates atomic number densities based on the weight percentages supplied (2.98w/o Uranium-235). The atomic number densities for the neutron shield material were taken from Reference 3.24. It should be noted that the boron carbide added to the shielding material was conservatively not accounted for in the calculations.

E. Benchmark Comparisons

The bias and uncertainty methodology applied in the calculation of the DSC final k_{eff} result is based on CSAS2X/44 group ENDF/B-V calculated results for the set of 19 critical experiments summarized in Table 3.3-3. A representative number of the benchmark experiments include stainless steel separating materials and are very similar to the DSC conditions. The inclusion of benchmark systems which differ from DSC conditions in some respects, such as separating materials, is justified by inspection of the Table 3.3-3 k_{eff} results which do not indicate any significant trends. The calculated k_{eff} results for the group of experiments analyzed demonstrates the calculational accuracy of the method under a variety of conditions, including those representative of the NUHOMS®-12T system.

The benchmark cases are generally representative of the cask and fuel features and parameters that are important to reactivity. The 44 Group ENDF/B-V and CSAS2X using the same modeling techniques used for the modeling contained in this calculation result in a maximum negative bias ($-\Delta k_b$) of 0.00762, including 2σ. This bias is to be added to the maximum system multiplication factor.

F. Additional Bias and Uncertainties and Determination of Worst-Case Maximum k_{eff}

The results of the three types of TMI-2 canisters indicate that the *knockout* canister is the most reactive. Parametric studies were not performed for fabrication tolerances in the TMI-2 canisters or the DSC. Many rough estimates and assumptions were used in the models, however, the overall models are very conservative and the results indicate a very large safety margin. Uncertainty in the results due to simplifications and use of nominal dimensions is addressed by adding a very large factor of 0.05 to the system reactivity results. The worst case loading of 12 *knockout* canisters was modeled in the MP187 and a simple approximation of an HSM and gave results of 0.54881 ± 0.00062 and 0.54051 ± 0.00082, respectively. With the code bias, 2σ (for the worst case model) and the 0.05 factor for modeling uncertainties, the resulting maximum system multiplication factor is 0.60005.

G. Analysis Results

The multiplication factor (k_{eff}), including all biases and uncertainties at a 95 percent confidence level, does not exceed 0.95 under all credible normal, off-normal, and accident conditions. The NUHOMS®-12T system is designed with the fundamental criterion that the DSC will not be flooded. This is achieved, in part, by locating the bottom of the DSC above the design flood elevation of 4917'. Aside from DSC flooding, at least two unlikely, independent, and concurrent or sequential changes to the conditions essential to criticality safety must occur before an accidental criticality is possible. Criticality safety of the design is based on favorable geometry, permanent fixed neutron-absorbing materials, and the prevention of water ingress into the system. Criticality safety of the system does not rely on the use of burnup credit, the use of burnable neutron absorbers, or more than 75 percent credit for fixed neutron absorbers.

The most reactive canister type for a bounding evaluation of the NUHOMS®-12T ISFSI is the *knockout* canister. The maximum system multiplication factor including all biases and uncertainties at a 95 percent confidence level, is 0.60767 under all credible normal, off-normal, and accident conditions.

3.3.4.3 Second Criticality Safety Evaluation

In an attempt to improve the demonstration that the water parameter in the fuel matrix is bounded, two evaluations were provided to identify conservative values of water from two sources: (1) retention of physically or chemically adsorbed water during the drying process (such water can have a very low equilibrium pertial pressure at elevated temperatures) and (2) readsorption of atmospheric water vapor over the 40 year storage period.

The key factor and assumption used in the secondary criticality safety analysis is that the geometry of the TMI-2 canister shells is maintained and the fuel is confined within the TMI-2 canisters.

3.3.4.3.1 Reactivity Equivalence and Criticality Analysis Methods

A. Computer Code Description

Calculations were performed using the three-dimensional Monte Carlo code KENO V.a which is part of the SCALE-4 modular code system. All calculations were performed on an HP workstation operating under HP-UX with Version 9.05 of the Fortran compiler. Configuration Release 1.10 of the SCALE-4.0 code system and the associated 27-energy-group ENDF/B Version 4 cross-sections were used to evaluate the KENO V.a models. SCALE 4.0 was used in the analysis because of a problem in SCALE 4.3 which doubles the k_{eff} calculation in KENO V.a when using an ICE mixed AMPX format working library. The problem with SCALE 4.3 did not affect the original evaluation. NRC Information Notice 91-26 identifies problems with "working-format" libraries distributed with the SCALE 4.0 package. Since the analysis did not use a working-format library, and since SCALE 4.0 and the 27 energy group cross-sections were benchmarked by comparison to experimental data, the use of SCALE 4.0 is not an issue.

B. Computer Code Application

The fuel models use cell weighting of the cross-sections to describe the fuel region. The SCALE code functional module XSDRNPM was used to create homogeneous cell-weighted cross sections, which have the characteristics of heterogeneous cells. For low-enriched fuels, it is more conservative to model the fuel as heterogeneous rather than homogeneous. The cell-weighted cross sections are calculated from two materials; the fuel and the moderator, and two dimensions; the fuel diameter and pitch. The SCALE functional modules WAX and ICE are used when multiple cell-weighted fuel regions are needed.

3.3.4.4 Criticality Evaluation

This section presents the analyses that demonstrate the acceptability of storing TMI-2 canisters in the DSC under normal fuel loading, handling, and storage conditions. A nominal case model is described and a neutron multiplication factor, k_{eff}, presented. Uncertainties are addressed and applied to the nominal calculated k_{eff} value. The final k_{eff} value produced represents a maximum with a 95 percent probability at a 95 percent confidence level.

A. Basic Assumptions

The methodology and assumptions used for this evaluation are extremely conservative and bounding. Bounding methods and assumptions were used when definitive data was not available for the payload. The most reactive TMI-2 canister is present in 12 locations in the models. This was done to avoid administrative controls on the loading of the DSCs and to simplify the computer models. During accident conditions the DSC basket is assumed to fail. The poison structures in the canisters are modeled in the nominal position, but filled with water instead of boron carbide. The following assumptions are used in the DSC criticality evaluation:

1. Batch 3 fresh fuel only (2.98wt/% uranium-235).

2. Enrichment: batch 3 average + 2σ.

3. No cladding or core structural material.

4. No soluble poison or control materials from the core.

5. Fuel lump is a whole fuel pellet.

6. *Filter* canisters are enveloped by *knockout* canisters.

7. Fuel is UO_2 and no credit is taken for degradation to less dense oxides.

8. Canister fuel regions are filled with 1908 lb of UO2, which is the maximum reported canister payload.

9. Fuel is smeared to fill all volume available in the fuel regions.

10. Water and fuel are modeled at the top of the canisters, rather than at the bottom or sides (the nominal canister configuration), since this produces more conservative results.

B. Fuel Modeling Techniques

As discussed previously, there are three types of TMI-2 canisters: *fuel*, *knockout*, and *filter*. For criticality calculations, a knockout canister containing 1908 lbs of UO_2 was modeled to envelope all canister types. The entire region inside the TMI-2 canisters that could contain fuel is modeled as pure fuel moderator mix without any non-fissile material. Fuel is assumed to be of the maximum enrichment in the TMI-2 core, 2.98wt/% uranium-235. The 2.98wt/% uranium-235 includes a factor of 2-sigma added to the batch

3 (highest) average enrichment. No credit is taken for irradiation of the fuel. The material is assumed to consist of pure uranium-dioxide at a density of 10.1 grams/cc. Fuel has been modeled as cylindrical stacks of pellets in a triangular pitch. The triangular pitch generally provides a slightly more reactive fuel region than a square pitch.

Calculations were performed to find the optimal fuel pellet diameter, optimal fuel pitch, optimal moderation between fuel pellets, and optimal moderation between canisters. The optimal fuel pellet diameter was found to be between 0.939 and 1.878 cm. Thus, the nominal pellet diameter (0.939 cm) was used in the calculations as the most reactive. The optimal fuel pitch was found to be between 1.3 and 1.45 cm. The optimal water density between pellets was found to be full density water. It was found during this process that the most conservative model was one in which all of the water inside the canisters was modeled in the top part of the canister, and the remaining fuel was modeled with no interspersed moderation. Thus, the fuel was modeled in a "wet region" and a "dry region." In the wet region, the fuel was modeled with the optimal pitch and full density water between rods. In the dry region, the fuel was modeled touching, with void between the rods. The optimal moderation between canisters was found to be in the range of 0.4 to 1.0 water volume fraction.

In most cases, the boron columns in the canisters were modeled as full density water. Using this conservatism, a limit of 8.0 liters of water per canister was established. A comparison was also made in which 75% of the boron was modeled in the poison columns of each canister. In this case, the canisters would be limited to containing just over 14.0 liters of water per canister. There was no difference in the reactivity when the canisters were filled entirely with fuel. The water limit applies to bound water (water that cannot migrate in the TMI-2 canisters at worst case storage conditions), unbound (or free) water, and water re-acquired from the atmosphere.

C. TMI-2 Canisters and DSC Models Input

The canister models used for the criticality evaluation are very simple and use nominal dimensions. The *knockout* canister model has constant cross-sectional configuration throughout the length of the 150 inch canister. The poison tubes were modeled in the nominal positions. The boron was replaced with full density water in most calculations. There is no change in the TMI-2 canister shell diameter due to a drop accident.

The HSM and DSC were modeled collapsed to fit tightly around the canister array. The HSM is simplified to be a 2-foot-thick reflector on all sides.

The input decks for a DSC loaded with 12 *knockout* canisters in an HSM have been provided in Appendix D of this SAR.

D. Atom Number Densities

Atom number densities were calculated by hand with the aid of a spreadsheet program. All calculated atom number densities were checked by an independent criticality safety analyst for consistency and correctness.

The fuel atomic number densities are calculated based on UO_2 density of 10.1 grams/cc.

E. Benchmark Comparisons

Benchmark experiments involving arrays of hydrogen moderated, low-enriched UO_2 rods were modeled to validate the SCALE 4.0 code. The TMI fuel modeled in the analysis had an H/X ratio of about 150, while the H/X ratio for the benchmark experiments ranged between 100 and 200. The largest deviation from unity was 0.7%, and therefore a 1% bias (0.01 Δk_{eff}) was conservatively added to all results in the analysis.

F. Additional Bias and Uncertainties and Determination of Worst-Case Maximum k_{eff}

The 1% bias added to the calculations (as discussed above) was judged to be sufficient, and thus no additional bias was added to the calculations. The models are very conservative. As stated above, the optimal fuel pellet diameter, optimal fuel pitch, optimal moderation between fuel pellets, and optimal moderation between canisters were used in the models. The worst case loading of 12 *knockout* canisters each containing 1908 lb of UO2 was modeled in the DSC inside an approximation of the HSM. The analysis calculated the maximum amount of water mixed with fuel inside of each TMI canister that would remain below the 0.95 criterion (including the 1% bias and two standard deviations of the statistical uncertainty (σ) associated with the calculations).

G. Analysis Results

The multiplication factor (k_{eff}), including all biases and uncertainties at a 95 percent confidence level, does not exceed 0.95 under all credible normal, off-normal, and accident conditions. The NUHOMS®-12T system is designed with the fundamental criterion that the DSC will not be flooded. This is achieved, in part, by locating the bottom of the DSC above the design flood elevation of 4917'. Aside from DSC flooding, at least two unlikely, independent, and concurrent or sequential changes to the conditions essential to criticality safety must occur before an accidental criticality is possible. Criticality safety of the design is based on favorable geometry, permanent fixed neutron-absorbing materials, and the prevention of water ingress into the system. Criticality safety of the system does not rely on the use of burnup credit, the use of burnable neutron absorbers, or credit for fixed neutron absorbers.

The most reactive canister type for a bounding evaluation of the NUHOMS®-12T ISFSI is the *knockout* canister. With 8.0 liters of water mixed with the fuel in each TMI canister, the maximum system multiplication factor including all biases and uncertainties at a 95 percent confidence level is 0.9235 under all credible normal, off-normal, and accident conditions. This model includes 1722 liters of water (the optimal amount) between the canisters inside the DSC.

3.3.4.4.1 Safety Criteria Compliance

This second criticality safety evaluation shows that significant amounts of moderator (water) can remain in the TMI-2 canisters without compromising criticality safety. Up to 8.0 L of water can be present in the fuel region of each TMI-2 canister and still have a k_{eff} less than 0.95. More moderator can be present as bound water if the water volume fraction is less than 0.3-0.4. Bound water in this sense is water that can not migrate in the fuel debris at the worst case assumed storage conditions. Christensen [3.31] provides the technical basis which shows that the water content of TMI-2 canisters in storage is less than allowed by this additional criticality safety evaluation, throughout the 40-year life of the ISFSI. This EDF also provides the acceptance criteria to be used to ensure that essentially all free water is removed during the heated vacuum drying process.

3.3.4.4.2 Off-Normal Conditions

Postulated off-normal conditions do not result in a system reactivity which exceeds the k_{eff} value calculated and presented in Section 3.3.4.1 through 3.3.4.4.

Additionally, off-normal conditions potentially resulting in reactivity increases over the normal conditions considered are addressed.

Even though small amounts of condensation could occur in the DSC during storage at INTEC, no mechanism exists which could cause an amount of condensation inside the DSC that would compromise criticality safety or exceed the criteria limiting k_{eff} of 0.95. The analyses presented in this SAR section demonstrate that the criteria limiting k_{eff} to 0.95 is satisfied under all postulated conditions for the system.

3.3.5 Radiological Protection

The TMI-2 ISFSI is designed to maintain on-site and off-site doses ALARA during transfer operations and long-term storage conditions. ISFSI operating procedures, shielding design, and access controls provide the necessary radiological protection to assure radiological exposures to station personnel and the public are ALARA. Further details on design considerations for radiation protection for on-site and off-site doses resulting from the TMI-2 ISFSI operations and the ISFSI ALARA evaluation are provided in Chapter 7.

3.3.5.1 Access Control

The INL TMI-2 ISFSI is located within the INL controlled area. The INL TMI-2 ISFSI Security Plan describes the remote sensing devices which are employed to detect unauthorized access to the ISFSI. In addition to the controlled access, an HSM access door may be tacked or fully welded in place after insertion of a loaded DSC. The HSM access door weighs approximately three tons and requires heavy equipment for removal. This ensures that there is ample time to respond to an unauthorized entry into the ISFSI before access can be gained to any radiological material. The vent system access door in the rear module wall is locked shut.

3.3.5.2 Shielding

For the NUHOMS®-12T system, shielding is provided by the HSM, cask, and shield plugs of the DSC. The HSM is designed to minimize the surface dose to limit occupational exposure and the dose at the ISFSI fence. Experience has confirmed that the dose rates for the HSM are extremely low. The cask and the DSC top shield plug are designed to limit the surface dose rates (gamma and neutron) ALARA. Temporary neutron shielding may be placed on the DSC shield plug and top cover plate during closure operations. Similarly, additional temporary shielding may be used to further reduce surface doses. Radiation zone maps of the HSM, cask, DSC surfaces and the area around these components are provided in Chapter 7.

3.3.5.3 Radiological Alarm Systems

There are no radiological alarms required for the INL TMI-2 ISFSI.

3.3.6 Fire and Explosion Protection

The ISFSI contains no permanent flammable material and the concrete and steel used for their fabrication can withstand any credible fire hazard. There is no fixed fire suppression system within the boundaries of the ISFSI. The facility is located such that the plant fire brigade can respond to any fire emergency using portable fire suppression equipment. Flammable materials that may be brought into the ISFSI on a temporary basis include fuel for necessary vehicles and construction materials. Use of non-flammable consumable materials will be emphasized. Administrative controls will be established to control any temporary fire loads within the boundary of the ISFSI.

Due to the positive drainage of the ISFSI approach slab, a fuel spill large enough to cause puddling would also tend to drain toward the east-west edge of the slab and away from the HSMs. This drainage, coupled with the expected rapid detection of any fire by the fuel transfer personnel will tend to limit the spread and severity of any fire. In addition, INL fire fighting assistance is available if required. The damage caused by any fire will be negligible given the massive nature of the casks. A spill too small to cause puddling would be very difficult to ignite due to the relatively high flash point of diesel fuel and, in any case, such a small fire would not pose a credible threat to the ISFSI.

ISFSI initiated explosions are not considered credible since no explosive materials are present in the DSCs other than hydrogen generated by radiolysis. Due to the low hydrogen concentrations which are available, only hydrogen deflagration could occur. However, an ignition source must be present to initiate deflagration. The system is designed without any known ignition sources present. Externally initiated explosions are considered to be bounded by the design basis tornado generated missile load analysis presented in Section 8.2.2. Analyses have been performed in compliance with 10 CFR 72.94 to confirm that no conditions exist near the ISFSI that would result in pressures due to off-site explosion or aircraft impact which would exceed those postulated herein for tornado missile or wind effects.

3.3.7 Materials Handling and Storage

3.3.7.1 TMI-2 Canister Handling and Storage

All TMI-2 canister handling, including placement into the DSC is governed by INL procedures. Subcriticality during storage is discussed in Section 3.3.4. The criterion for a safe configuration is an effective mean plus two-sigma neutron multiplication factor (k_{eff}) of 0.95. Section 3.3 calculations show that the expected k_{eff} value is below this limit.

3.3.7.1.1 Temperature Limits

The fuel rods stored in the TMI-2 fuel canisters are severely damaged. A majority of the cladding on the fuel rods was either melted during the accident, or was cut during dismantling of the core debris for storage in the TMI-2 canisters. Therefore, cladding temperature limits for this fuel are of little significance during storage. However, to prevent further fuel degradation, the cladding temperature limits in Reference 3.27 are applied to this fuel during storage.

The cladding temperature limits in Reference 3.27 are 724°F (384°C) for long term storage and 1058°F (570°C) for short term conditions. These limits are based on an inert atmosphere dry storage of intact fuel rods. TMI-2 fuel is stored in an air atmosphere, but the fuel temperatures calculated are significantly cooler. Therefore, further cladding degradation is not expected.

3.3.7.1.2 Surface Contamination Limits

DSC exterior contamination is minimized by preventing radioactive material from contacting the DSC exterior. This provides assurance that the DSC exterior surface has less residual contamination than required for shipping cask externals (Table V, 10 CFR 71.87(i)(1)). Surface swipes of the upper (outside) end of the DSC exterior will be taken after DSC closure, but prior to installing the cask lid to assure that the maximum DSC removable contamination does not exceed:

Beta/Gamma Emitters	22,000 dpm/100 cm^2
Alpha Emitters	2,200 dpm/100 cm^2

The cask external contamination is minimized by the use of smooth, easily decontaminated surface finishes to minimize personnel radiation exposures during cask handling operations at the TAN facility. 49 CFR 173.443(d) [3.17], which governs contamination levels for off-site shipment in a closed exclusive use vehicle, is used as a basis for the cask maximum removable contamination limits as:

Beta/Gamma Emitters	22,000 dpm/100 cm^2
Alpha Emitters	2,200 dpm/100 cm^2

Confinement of radioactive material associated with TMI-2 fuel debris is provided by the DSC steel shell, vent system and double seal welded inner and outer closures.

3.3.7.2 Radioactive Waste Treatment

Radioactive waste, such as HEPA grade filters that have been replaced as needed, is generated during the storage period for the DSC. Radioactive wastes generated during DSC loading operations (contaminated water from purging the DSC and potentially contaminated air and helium from the DSC cavity) are treated using existing systems and procedures as described in Chapter 6.

3.3.7.3 Waste Storage Facilities

The requirements for on-site waste storage are satisfied by existing INL facilities for handling and storage of radioactive waste and dry active wastes as described in Chapter 6.

3.3.8 Industrial and Chemical Safety

No hazardous chemicals or chemical reactions are involved in the NUHOMS®-12T system loading and storage operations. Industrial safety relating to handling of the cask and DSC are addressed by the INL industrial hygiene program which meets the Occupational Safety and Health Administration (OSHA) requirements.

Table 3.3-1
Radioactive Material Confinement Barriers for NUHOMS® System

Confinement Barriers and Systems

1. TMI-2 Canister

2. DSC Confinement Boundary (including vent system HEPA grade filters, DSC shell)

3. Top DSC Shield Plug

4. Top Shield Plug DSC Closure Weld

5. Top Cover Plate

6. Top Cover Plate Weld

7. Inner and Outer Bottom Cover Plates

8. Inner and Outer Bottom Cover Plate Welds

Table 3.3-2
Atomic Number Densities

Material	Density (g/cc)	Component	Atomic Number Density (barn-atoms/cc)
Type 304 Stainless Steel	7.92	Chromium	1.74286E-02
		Manganese	1.73633E-03
		Iron	5.93579E-02
		Nickel	7.72070E-03
Lead	11.344	Lead	3.29690E-02
Boron Carbide	1.35	Boron-10	9.525E-03
		Boron-11	5.08E-02
		Carbon	1.58E-02
Borated Aluminum	2.5	Boron-10	5.265E-03
		Boron-11	2.81E-02
		Aluminum	4.72E-02
Low Density Concrete	1.0	Hydrogen	1.93631E-02
		Oxygen	2.15365E-02
		Sodium	1.43800E-04
		Magnesium	3.58590E-05
		Aluminum	2.83850E-03
		Silicon	8.7196E-04
		Calcium	1.3101E-03
		Iron	1.3576E-05
“Mist” Moderator	8.8E-05	Hydrogen	5.88400E-06
		Oxygen	2.94200E-06
Hydrogen Gas (Radiolysis)	8.9E-05	Hydrogen	5.3E-05
Fuel	10.0	Uranium-235	6.71835E-04
		Uranium-238	2.15967E-02
		Oxygen	9.73434E-02
MP187 Neutron Shield Material	1.76	Oxygen	3.7793E-02
		Aluminum	7.0275E-03
		Carbon	8.2505-03
		Calcium	1.4835E-03
		Hydrogen	5.0996E-02
		Silicon	1.2680-03
		Iron	1.0628E-04
Carbon Steel	7.8212	Iron	8.34982E-02
		Carbon	3.92503E-03
Concrete	2.2994	Oxygen	3.55219E-02
		Hydrogen	8.50102E-03
		Iron	1.93013E-04
		Carbon	2.02171E-02
		Sodium	1.62991E-05
		Magnesium	1.86016E-03
		Aluminum	5.55805E-04
		Silicon	1.70002E-03
		Calcium	1.11006E-02
		Potassium	4.03004E-05

Table 3.3-3
Benchmark Critical Experiments

VECTRA Case. #	Enrich-ment (w/o)	Rod Pitch (mm)	Absorber Material	Absorber Thickness (mm)	Abs. to Cluster Distance (mm)	Reflector Material	Refl. to Cluster Distance (mm)	Critical Cluster Sep. (mm)	Series 3 $K_{eff} \pm 1$ s
3	4.31	25.40	SS304	4.85	2.45	Moderator	N/A	85.8	0.99525 ± 0.00045
4	4.31	25.40	SS304	4.85	32.77	Moderator	N/A	96.5	0.99342 ± 0.00052
5	4.31	25.40	SS304	3.02	4.28	Moderator	N/A	92.2	0.99382 ± 0.00050
6	4.31	25.40	SS304	3.02	32.77	Moderator	N/A	97.6	0.99392 ± 0.00052
11	4.31	25.40	Boral	7.13	32.77	Moderator	N/A	67.2	0.99496 ± 0.00050
60	2.35	16.84	SS304	3.02	N/A	Steel	13.21	82.8	0.99740 ± 0.00046
62	2.35	16.84	Boral	2.92	N/A	Steel	13.21	26.9	0.99671 ± 0.00046
68	4.31	18.92	SS304	3.02	N/A	Steel	19.56	137.5	1.00231 ± 0.00054
70	4.31	18.92	Boral	2.92	N/A	Steel	19.56	83.0	1.00188 ± 0.00054
103	2.35	20.32	SS304	4.85	6.45	Moderator	N/A	68.8	0.99871 ± 0.00045
104	2.35	20.32	SS304	4.85	27.32	Moderator	N/A	76.4	0.99739 ± 0.00045
105	2.35	20.32	SS304	4.85	40.42	Moderator	N/A	75.1	0.99776 ± 0.00046
106	2.35	20.32	SS304	3.02	6.45	Moderator	N/A	74.2	0.99762 ± 0.00045
107	2.35	20.32	SS304	3.02	40.42	Moderator	N/A	77.6	0.99676 ± 0.00045
108	2.35	20.32	SS304	3.02	6.45	Moderator	N/A	104.4	0.99844 ± 0.00047
109	2.35	20.32	SS304	3.02	40.42	Moderator	N/A	114.7	0.99782 ± 0.00047
114	2.35	20.32	Boral	7.13	6.45	Moderator	N/A	63.4	0.99734 ± 0.00046
115	2.35	20.32	Boral	7.13	44.42	Moderator	N/A	90.3	0.99815 ± 0.00047
116	2.35	20.32	Boral	7.13	6.45	Moderator	N/A	50.5	0.99800 ± 0.00046

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3.4 Classification of Structures, Components, and Systems

Table 3.4-1 provides a list of major INL TMI-2 ISFSI components and their classifications. Components are classified in accordance with the criteria of 10 CFR Part 72 [3.2]. Structures, systems, and components classified as "important to safety" are defined in 10 CFR 72.3 as those features of the ISFSI whose function is:

1. To maintain the conditions required to store spent fuel safely,

2. To prevent damage to the spent fuel container during handling and storage, and

3. To provide reasonable assurance that spent fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

These criteria are applied to the INL TMI-2 ISFSI system components in determining their classification in the paragraphs which follow.

3.4.1 Dry Shielded Canister

The DSC provides shielding for and confinement of the radioactive materials. The DSC vent provides a diffusion path for hydrogen generated by radiolysis. Therefore, the DSC confinement boundary, which includes the vent system, is designed to remain intact, with no loss of function, under all accident conditions identified in Chapter 8. The DSC is designed, constructed, and tested in accordance with the quality assurance requirements for components "important to safety" as provided in 10 CFR 72.24(n) and 72.140(b) and described in Chapter 11. The welding materials required to make the closure welds on the DSC top shield plug and top cover plate are specified with the same ASME Code criteria as the DSC shell (Subsection NB, Class 1).

3.4.2 Horizontal Storage Module

The HSM is considered "important to safety" since it provides physical protection and shielding for the DSC during storage. The reinforced concrete HSM is designed in accordance with ACI 349-85. The level of testing, inspection, and documentation provided during construction and maintenance is in accordance with the quality assurance requirements provided in 10 CFR 72.140(b) and as described in Chapter 11.

3.4.3 ISFSI Basemat and Approach Slabs

The INL TMI-2 ISFSI basemat is classified as “not important to safety” because the HSMs are not anchored to the pad. Approach slabs are also classified as "not important to safety" and are designed, constructed, maintained, and tested as commercial grade items.

3.4.4 Transfer Equipment

3.4.4.1 Transport Cask and Cask Rigging

The MP-187 transportation cask is "important to safety" since it protects the DSC during handling and is part of the primary load path used while handling the DSC at TAN. The cask is designed, constructed, tested, and will be licensed in accordance with the requirements of 10 CFR Part 71 for a transportation cask. These criteria exceed the requirements of standard 10 CFR 72.140(b) for an "important to safety" transfer cask.

The rigging used for handling of the cask at the TAN facility is designed and will be procured under INL procedures and is not a part of the licensed activities addressed by this document.

3.4.4.2 Other Transfer Equipment

The NUHOMS®-12T transfer equipment (i.e., ram, skid, trailer) are necessary for the successful loading of the DSC into the HSM. However, the analyses described in Chapter 8 demonstrate that the performance of these items is not required to provide assurance that DSCs and the TMI-2 canisters can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public. Therefore, these components are classified as “not important to safety." These components are designed, constructed, and tested in accordance with accepted engineering practices.

3.4.5 Auxiliary Equipment

The vacuum drying system and the automated welding system are classified as "not important to safety." Performance of these items is not required to provide reasonable assurance that TMI-2 canisters can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public. Failure of any part of these systems may result in delay of operations, but will not result in a hazard to the public or operating personnel. Therefore, these components need not comply with the requirements of 10 CFR Part 72. These components are designed, constructed, and tested in accordance with accepted engineering practices.

Table 3.4-1
NUHOMS® Major Components and Safety Classification

Component		10 CFR Part 72 Classification
Dry Shielded Canister (DSC)		
	Basket Assembly	Not Important to Safety
	Shield Plugs	Important to Safety(1)
	DSC Shell	Important to Safety(1)
	Cover Plates	Important to Safety(1)
	Weld Filler Metal	Important to Safety(1)
	Vent System (including HEPAs)	Important to Safety(1)
Horizontal Storage Module (HSM)		
	Reinforced Concrete	Important to Safety(1)
	DSC Support Structure	Important to Safety(1)
ISFSI Basemat and Approach Slabs		Not Important to Safety
Transfer Equipment		
	Cask	Important to Safety(1)
	Cask Rigging(2)	Not Important to Safety
	Trailer/Skid	Not Important to Safety
	Uprighting Skid	Not Important to Safety
	Ram Assembly	Not Important to Safety
	Dry Film Lubricant	Not Important to Safety
Auxiliary Equipment		
	Vacuum Drying System	Not Important to Safety
	Automated Welding System	Not Important to Safety

(1) Structures, systems and components “important to safety” are defined in 10 CFR 72.3 as those features of the ISFSI whose function is (1) to maintain the conditions required to store spent fuel safely, (2) to prevent damage to the spent fuel container during handling and storage, or (3) to provide reasonable assurance that spent fuel can be received, handled, packaged, stored, and retrieved without undue risk to the health and safety of the public.

(2) Rigging is not required for NRC licensed activities.

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3.5 Decommissioning Considerations

Decommissioning of the INL TMI-2 ISFSI will be performed in a manner consistent with the decommissioning of the INTEC facilities since all system components are constructed of materials similar to those found in existing INTEC facilities. Details of conceptual plans for decommissioning the TMI-2 ISFSI are contained in DOE-ID's "Conceptual Plan for Decommissioning" provided as an enclosure to the License Application for the INEL TMI-2 Independent Spent Fuel Storage Installation.

The DSC may be minimally contaminated internally by radioactive materials from the TMI-2 canisters and may be slightly activated by spontaneous neutron emissions from the TMI-2 canisters. The DSC internals may be cleaned to remove surface contamination and the DSC disposed of as low-level waste. Alternatively, if the contamination and activation levels of the DSC are small enough (to be determined on a case-by-case basis), it may be possible to decontaminate the DSC and dispose of it as commercial scrap.

The NUHOMS®-12T system can be decommissioned by removing the TMI-2 canisters and transporting the HSMs off-site. Closure removal techniques can allow for reuse of the DSC shell/basket assembly. Economic and technical conditions existing at the time of TMI-2 canister removal would be assessed prior to making a decision to reuse the DSC.

The final decommissioning plan for the TMI-2 ISFSI will be developed and submitted to NRC at a later date prior to commencing decommissioning activities. Because no contamination of the outer surface of the DSC is expected, no contamination is expected on the internal passages of the HSM. It is anticipated that the prefabricated HSMs can be dismantled and disposed of using commercial demolition and disposal techniques. Alternatively, the HSMs may be refurbished and reused for storage at another site.

The decommissioning plans for the INL TMI-2 ISFSI are addressed in the Conceptual Decommissioning Plan which will be prepared and submitted in accordance with 10 CFR 72.30.

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