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SNL SAR Review: Thermal

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Sections Reviewed

- Section 6.3 of the SAR was the thermal material reviewed
- This section consists of the following subsections:
  - 6.3.1 Introduction
  - 6.3.2 Design Basis
  - 6.3.3 Technical Specifications for Components and Thermal Properties of Materials
  - 6.3.4 Heat Load and Environmental Condition
  - 6.3.5 Methodology
  - 6.3.6 Model Verification
  - 6.3.7 Analytical Assumption and Results
  - 6.3.8 Conclusion
  - 6.3.9 Reference

General Comments: Design Criteria & Thermal Loads

- **The applicant used three design bases for the thermal evaluation of the storage system**
  - **NAC UMS design basis of 23 kW**
  - **INER-HPS design basis of 14 kW**
  - **“Project” maximum heat load of 7 kW**

General Comments:
Design Criteria & Thermal Loads (cont.)

Condition		Heat Load (kW)	Environmental Temperature (°C)	Insolation [8]	Condition of Concrete Cask Inlets and Outlets
Short Term Loading and Transfer		7	32[1]	—	—
Normal		14	32[2]	Yes	All inlets and outlets open
Off-Normal	Severe Cold	23	-40[3]	No	All inlets and outlets open
	Severe Heat	23	41.1[4]	Yes	All inlets and outlets open
	Half Air Inlets Blocked	23	32[2]	Yes	Half inlets blocked and all outlets open
Accident	Extreme Heat	23	56.1[5]	Yes	All inlets and outlets open
	All Air Inlets and Outlets Blocked	14	32[2]	Yes	All inlets and outlets Blocked
	Fuel Tank Fire	23	801.7[6] (During Fire) 32[2] (After Fire)	Yes	All inlets and outlets open
	Shrubbery Fire	23	73[7] (During Fire) 32[2] (After Fire)	Yes	All inlets and outlets open

General Comments:
Design Criteria & Thermal Loads (cont.)

- **Because the applicant states that the maximum heat load of 56 BWR fuel assemblies for the "project" is 7 kW, all the other heat loads used in the thermal analyses presented in the SAR are conservative assumptions of heat loads.**
- **Based on the information provided in the thermal chapter of the SAR, the SNL thermal reviewer understands that the applicant is seeking to license this proposed design for a heat rejection capacity of up to 7 kW.**
- **Other thermal loads such as insolation, extreme ambient temperatures, and fire were well justified and properly used in the analyses presented.**

General Comments:
Design Features

- **The proposed design consists of a canister inside a concrete dry-storage cask and an extra outer concrete structure for added shielding.**
- **This system is designed to remove heat from the canister containing the spent fuel without an active cooling system.**
- **Heat from the canister is removed by allowing air to enter the concrete overpacks and pass over the canister wall before leaving the overpacks by means of natural convection.**

General Comments: Model Specification, Configuration, and Assumptions

- Overall, the models used for the evaluation of the different thermal scenarios were well described.
- The gap between the concrete cask and the added outer concrete shielding structure and the gap between the concrete cask and the canister were all treated conservatively in all cases presented.
- System elements are assumed to be physically positioned in a form that reduces the ability of the system to reject the stored decay heat.
  - For example, fuel assemblies in the canister are assumed to be centered so that there is no direct contact with other components, which leads to a lower radial effective thermal conductivity.

General Comments: Model Specification, Configuration, and Assumptions (cont.)

- The axial distribution of decay heat was adopted from the FSAR for the UMS Universal Storage System.
- This distribution is presented in Figure 6.3.7-1 of the reviewed SAR.
- Decay heat was assumed the have a uniform distribution in the radial direction.
- The SAR provided seems to indicate the opposite of what was just described, but it is understood that those are repetitive typos, either in the original SAR or introduced during the translation from Chinese to English.

General Comments: Model Specification, Configuration, and Assumptions (cont.)

- All modes of heat transfer were employed or conservatively ignored in the analyses presented.
  - However, no radiation interchange between casks in the storage pad was mentioned in the SAR.
  - Instead, heat rejection of the cask on all cases but the fire cases was only by natural convection on the outer surface of the added concrete shield and, as specified in the SAR, “radiation was conservatively ignored.”
- Given that the steady-state temperature of the outer surface of the casks is relatively low and very similar to that of neighboring casks, the heat exchange between casks is likely to be lower than the heat rejection by radiation to the environment, especially when the spacing between casks is considered.
- For the fuel fire case, forced convection and radiation heat transfer were applied to the outer surface of the added concrete shield.

General Comments: Model Specification, Configuration, and Assumptions (cont.)

- **Conservatisms are used throughout all the work presented in the thermal chapter of the SAR.**
- **While the reasoning behind some of these conservatisms may not be clear, all cases had conservatism built into the model.**
- **Even with these conservatisms, critical components of the proposed system did not reach their allowable temperature limits.**

General Comments: Material Properties

- **Effective temperature-dependent thermophysical properties for the fuel region were calculated using plausible methods.**
- **The methods included weighted averages and the combination of well known equations with temperature solutions from finite element models.**
- **Material properties for the analyses were derived using a type of BWR fuel assembly that would yield the most conservative values.**
- **Temperature limits for materials and components of the system are presented including their reference.**

General Comments: Boundary Conditions

- Conservative boundary conditions were used throughout the thermal section of the SAR.
- Low convective heat transfer coefficients were used for convection over the outer surface of the outer concrete shield and the annulus between the concrete overpack and the canister.
- When no credit for convection was taken, radiation and conduction through the gas medium was typically assumed.
- Thermal radiation was ignored on the outer surface of the outer concrete shield in most cases.
- Fire temperature and insolation values indicated in 10CFR71 as well as forced convection for heating the system were used when appropriate.
- Good judgment on the use of boundary conditions was found throughout the document.

General Comments: Computer Programs

- The computer programs used for the analyses presented were ANSYS and RELAP5-3D.
  - ANSYS was used for the three-dimensional heat transfer analysis of the canister internals and the concrete cask with the added outer shielding.
  - RELAP5-3D was used for the one-dimensional analyses of natural convection and heat transfer in the annulus between the concrete overpack and the canister.
- The applicant explains that coupled calculations of the 3D ANSYS model and the 1D RELAP5-3D model were performed to evaluate steady-state cases.
- Because the coupling of these two codes is computationally expensive, transient thermal scenarios described in the SAR were evaluated using ANSYS and RELAP5-3D decoupled and making conservative assumptions to safely estimate the thermal response of components.
- The SAR contains a complete section on model verification (Section 6.3.6). In this section, the applicant explains how results from the ANSYS and RELAP5-3D models compare against the analyses performed by NAC. In general, results from the comparisons revealed reasonable agreement.

General Comments: Temperature Calculations

- Summaries of temperature results from the analyses are presented in a concise and effective form.
- Maximum obtained temperatures are also compared against temperature limits of important components to easily demonstrate meeting the requirements in the regulations.
- The temperatures presented in the SAR suggest that the storage cask system is capable of removing the desired decay heat of 7 kW without problems.
- Spallation on the surface of the concrete overpack was not discussed in the SAR. However, NUREG-1536 specifies that spallation doesn't need to be evaluated in the SAR.

General Comments: Pressure Analysis

- Pressure calculations presented in the SAR demonstrate that the canister is capable of maintaining containment during the normal and off-normal conditions as well as during the design-basis accident scenario.
- These calculations were performed assuming conservative bulk temperature values.
- However, it is specified that fuel cooling time is 40 years, which is a relatively long cooling period.

Specific Comments

- Comments presented in this section are ordered by page number.
- The only typographical errors listed in the report were those considered important for the technical understanding of the material.
- This presentation will cover only the most technically important of these comments

Specific Comments (cont.)

- Fuel fire scenario assumption – heating process (p. 6.3.5-3)
  - Is the canister inner wall temperature assumed to be fixed and the same as that under normal storage conditions to force the most heat into the canister during the fire scenario? No transient heat flux update forces to maintain a larger amount of heat flux from the hot gases to the canister. (See also 4th bullet in page 6.3.7-19)
- Fuel fire scenario assumption – cooling process (p. 6.3.5-4)
  - Is this considered to be conservative because heat flux release under normal storage conditions is lower than it would be after the canister has been heated by the hot gases from the fire? (See also 5th bullet in page 6.3.7-19)

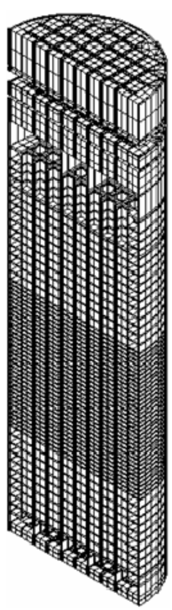
Specific Comments (cont.)

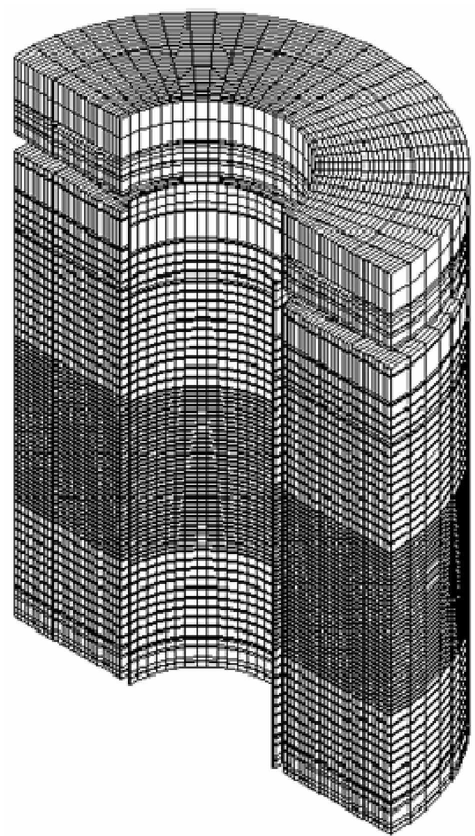
- **Shrubbery fire scenario assumption (p. 6.3.5-7)**
  - **Ambient temperature is raised to 73°C. The text at the bottom of page 6.3.7-9 seems to indicate that the ambient temperature of 36.5°C was doubled for conservatism. However, a better explanation in this chapter of the SAR would be helpful, especially when first mentioned in the chapter.**

Specific Comments (cont.)

- **ANSYS FEA models (p. 6.3.5-20)**
  - **The mesh is denser closer to the base of the canister and concrete cask. However, no explanation is provided for this peculiarity.**

Canister Model





Concrete Cask Model

Specific Comments (cont.)

- **Model Verification – Summary of results – Item 4 (p. 6.3.6-4)**
  - It is not clear why, if the air flow rate is less than that calculated by NAC, the capacity of heat removal by convection is 5.6% more than NAC's results. In fact, more heat removal makes the applicant's analysis less conservative. However, it is mentioned that the methods used are different and a 5.6% difference in results from empirical correlations are typically acceptable.
- **Model Verification – Summary of results – Item 8 (p. 6.3.6-4)**
  - The two pressure values are the same. However a slight conservatism is claimed. This could be a typographical error.

Specific Comments (cont.)

- Model Verification – Summary of results – Item 9 (p. 6.3.6-5)
  - The applicant mentions a "10% deviation" from the results obtained by NAC. The applicant explains that this deviation is because "the incorrect number of fuel rods [was] used to calculate the volumetric heat generation rate of the fuel pellets and the old conductivity of helium [was] used". The applicant then adds that "it relatively tends towards reasonable conservation".
  - The statements in this section of the document are not clear. Therefore, is not clear if the calculated values are indeed conservative.

Specific Comments (cont.)

- **Modeling assumptions (p. 6.3.7-2)**
  - The applicant indicates that “the most conservative data of the homogeneous thermal-conductivity properties … are used” for the four types of fuels that are planed to be stored in the system. These values are presented in Tables 6.3.5-3 to 6.3.5-5. However, the applicant also sates that after comparison with properties of fuels in NAC’s design, it was decided to “adopt” the properties used by NAC for added conservatism. If the properties calculated by the applicant were cataloged in the SAR as conservative and are more relevant, why not use them?
  - This comment applies to anywhere homogeneous thermal conductivity properties are mentioned (e.g., pp. 6.3.7-4, 6.3.7-7, 6.3.7-8, 6.3.7-16, etc.).

Specific Comments (cont.)

- B. Analysis results p. 6.3.7-5
  - The applicant makes the statement that "there is no upper limit for the operations of this stage." Does the applicant means that fuel is not stored in transfer casks for too long and that 600 hours (25 days) should be enough time to transfer the canister?

Specific Comments (cont.)

- Second paragraph (p. 6.3.7-11)
  - There is mention of a shield structure added to the air inlets. However, this structure is not described in the thermal section. What is mentioned is that the effect of this added shield structure on the canister shell temperature is less than 1%.
  - More details in this section of the SAR about this shield structure would help the reader to understand this better.

Specific Comments (cont.)

- First paragraph (p. 6.3.7-13) - The applicant states:
  - "Except for full blockage of the air inlets and outlets, the NAC UMS design basis heat load of 23kW is conservatively assumed for the analyses of off-normal and accident conditions."
  - This is possibly an unnecessary conservatism and inconsistency throughout this SAR. That is, different scenarios are analyzed using different heat loads. However, the SNL thermal reviewer understands that the license application is limited by the lowest decay heat load used in the analyses, which is 7 kW.

Specific Comments (cont.)

- (b) Blockage of Half of Air Inlets (p. 6.3.7-14)
  - Are all inlets blocked 50% or 50% of the inlets (i.e., 2 inlets) blocked? If two inlets are blocked, which two? If all inlets are blocked 50%, should the applicant perform an analysis considering 100% blockage of 2 of the four inlets?
- Penultimate bullet (p. 6.3.7-19)
  - The applicant assumes an 8-minute fire but no justification is provided or referenced. Is this time based on the amount of fuel carried by the transfer vehicle? How much fuel is assumed and what is the size of the assumed pool?

Specific Comments (cont.)

- (b) Full Blockage of Air Inlets and Outlets (p. 6.3.7-22)
  - Figure 6.3.7-16 should be reference in the text provided that earlier in the document it was mentioned that the minimum time to reach temperatures of concern was going to be calculated. The text in this page mentions result to 72 hours. However, Figure 6.3.7-16 shows results up to about 170 hours.

Specific Comments (cont.)

- **2nd paragraph (p. 6.3.7-24)**
  - The applicant states that the shrubbery fire was assumed to last 2 hours. However, no reasoning for that assumption was given in the text.
- **Table 6.3.7-4 (p. 6.3.7-39)**
  - Why is the temperature limit for the heat transfer disks in the canister lower for the normal storage condition than it is for the other cases? The same is reported in Table 6.3.8-1 on page 6.3.8-3.

Specific Comments (cont.)

- Table 6.3.7-4 Maximum Temperatures of the Cladding and Major Components for the Normal Storage Condition

Components	Temperature (°C)	
	Heat Load 14 kW	Limits
Fuel Cladding	236.8	400.0
Support Disk	221.8	371.1
Heat Transfer Disk	221.2	343.3
Canister Shell	134.3	426.6
Concrete-Concrete Cask	63.2 (Bulk) 71.9 (Local)	65.5 (Bulk) 93.3 (Local)
Concrete-Added Outer Shield	61.4 (Bulk) 71.0 (Local)	
Average Bulk Gas Temperature in the Canister	154.9	—

14kW vs. 7kW

Temperatures are very close to the limit

Specific Comments (cont.)

- **Table 6.3.7-4 (p. 6.3.7-39)**
  - The bulk temperature of the concrete cask and the added concrete shield are very close to the temperature limit. However, the temperature limit seems low. This may not be a problem, especially if the license application is for 7 kW heat removal capacity (14 kW heat load was assumed for the analysis of the Normal Storage Condition). This comment also applies to item 3 on page 6.3.8-1 and Table 6.3.8-1 on page 6.3.8-3.

Conclusions

- Overall, the material presented in the thermal section of the SAR, Section 6.3, seems complete and provides enough information for a regulator to make a technically-informed decision about licensing if the applicant provides some relatively minor clarifications.
- Cask components and spent fuel roads remained within their operating temperature ranges, even with all the conservative assumptions that were made for each analysis described in the SAR.
- Comparisons and verifications with other SAR sections such as structural evaluations were not performed as part of this review.

References

- Sanders, T.L., et al., "A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements," SAND90-2406, TTC-1019, UC-820, Sandia National Laboratories, November 1992.
- Section 6.3 (Thermal Evaluation) of the Safety Analysis Report submitted by the licensee for the Spent Nuclear Fuel Interim Dry Storage Cask Facility at the Chinshan Nuclear Power Station.
- US NRC, "Standard Review Plan for Dry Cask Storage Systems," NUREG-1536, US NRC, Washington, DC, January 1997.