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OPERATIONS DIVISION

SUMMARY OF THE TECHNICAL REVIEW OF THE SAFETY ANALYSIS REPORTS FOR PACKAGING (SARP) FOR THE TRANSNUCLEAR TRANSPORT/STORAGE CASKS: TN-BRP AND TN-REG

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NUCLEAR AND CHEMICAL WASTE PROGRAMS

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L. D. Bates
May 31, 1986

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1. INTRODUCTION

The Nuclear and Chemical Waste Programs and specifically the Operations Division at Oak Ridge National Laboratory (ORNL) was charged with coordinating the review of the Transnuclear (TN) Big Rock Point (BRP) and R. E. Ginna (REG) Safety Analysis Reports for Packaging (SARP).[1,2] This review was one of the requirements leading to the proposed issuance of Department of Energy (DOE) Certificates of Compliance for rail shipment of Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) spent fuel from the DOE site in West Valley, New York, to a DOE site in Idaho. A review team consisting of personnel with recognized expertise in the areas of nuclear criticality, thermal analysis, nuclear shielding, metallurgy, structural engineering, and containment was assembled to perform the review. This report summarizes the review sequence and states the assumptions and conclusions of that review. The overall review process is summarized in Sect. 2. Technical considerations for the TN-BRP are presented in detail in Sects. 3 through 11. Similar technical considerations for the TN-REG are presented in detail in Sects. 12 through 20. Section 21 summarizes the conclusions of the review. Because of the similarity between the two casks, the discussion regarding the TN-REG is somewhat sorter and assumes a familiarity with the discussion on the TN-BRP to minimize duplication of material.

It should be noted that this document and its reference material represents a status report that is indicative of the situation that existed in late 1985. The conclusions and evaluations presented herein were complete at that time although they were not presented in a formal manner. Subsequent to this time, the SARPs were revised and submitted for NRC review. Additional support from ORNL has occurred during this period and issues have continued to be refined. This report does not document these additional reviews and/or findings.

2. REVIEW PROCESS

The major goal of the review process was to determine that: (1) the data and analyses presented in the SARP fulfill the requirements of Title 10, Code of Federal Regulations, Part 71 (10 CFR Pt. 71)[3] and the applicable U.S. Nuclear Regulatory Commission (NRC) Regulatory Guides, and (2) the technical content of the analyses is accurate and complete, and reflects the use of acceptable and recognized analytical methodology. Technical areas which are considered in such analyses include a description of the packaging and its contents, mechanical properties of materials, general design standards, inspection standards, normal transport and accident conditions, containment, shielding, and criticality.

Each of these areas was covered in detail within the TN SARPs. ORNL reviewed each area for technical content and compliance with 10 CFR Pt. 71.

The preliminary design and supporting calculations for the TN-BRP cask were submitted by TN in March 1984; the first draft of the final SARP was supplied in February 1985 and revised in May 1985. In similar manner, the preliminary design and supporting calculations for the TN-REG cask were submitted by TN in April 1984; the first draft of the final SARP was supplied in April 1985 and revised in October 1985. Sections of each SARP document were reviewed by ORNL as they were prepared. Some of these sections required multiple submissions before the ORNL reviewers judged the technical content to be adequate.

The technical reviews were conducted in a variety of ways depending on the specific technical considerations. In general, the analysis presented in the SARP was examined for the adequacy of the assumptions and the applicability of the procedure. In some cases, calculations were then performed using the same or similar procedures in sufficient depth to verify the accuracy of the reported results. The results of the review were then transmitted to TN, and the differences noted were resolved.

The criticality, shielding, decay heat generation, and materials reviews (Sects. 4, 5, 6, and 11 for the TN-BRP and Sects. 13, 14, 15, and 20 for the TN-REG) depended heavily on independent calculations and analyses. The emphasis of the thermal, nondestructive examination, structural, and containment aspects (Sects. 7, 8, 9, and 10 for the TN-BRP and Sects. 16, 17, 18, and 19 for the TN-REG) was more oriented toward independent review of the material presented by TN. These different philosophies are evident in the format of the individual sections of this document.

The ORNL review was not typical of an NRC SARP review. ORNL reviewed independent submissions of individual sections of the SARPs as they were completed by TN. This process required a continuous cooperative exchange of communication between ORNL and TN. In many cases, reviews were conducted of preliminary material which was modified and required reanalysis and rereview. The process was successful in expediting the total review time after completion of the SARP; however, a greater effort was required on the part of the reviewers and the traceability and closure of comments was extremely difficult.

Each submission of a SARP section received from TN was distributed to the entire review team, and each reviewer prepared an individual set of comments. These comments were then reviewed to eliminate duplications, assembled into a composite comment letter, and transmitted to TN. The TN response was either by letter or by modification of the questioned portion of the SARP in subsequent submittals back to ORNL. A few of the comments required face-to-face discussions and the exchange of several letters before arriving at a satisfactory resolution. This process continued until all comments had been resolved. In addition to written review comments, a review meeting was held for each SARP (TN-BRP, February 27-28, 1985, TN-REG, April 23, 1985) in Oak Ridge, Tennessee, where the status of comments regarding the first draft of each final SARP was discussed by all concerned.

The following assumptions concerning the SARP review were considered in arriving at conclusions as to the adequacy of the design presented in the SARP.

1. There will be only one controlled shipment of each of the loaded casks assumed to be under DOE Certificates of Compliance and assumed to be from West Valley, New York, to Idaho National Engineering Laboratory (INEL).
2. The only fuel loaded into the casks will be the specific assemblies described in the SARP which are presently owned by Nuclear Fuel Services (NFS) and stored in the West Valley Nuclear Service Center fuel pool.
3. This specific fuel will be loaded into the cask in a specified arrangement determined by the criticality and shielding analyses.
4. The review evaluated the subject design only from the standpoint of transport requirements and conditions as defined in 10 CFR Pt. 71. Aspects related to long-term fuel storage and/or requirements of 10 CFR Pt. 72 were not considered.

5. Each SARP was reviewed only for technical adequacy and compliance with standards and was not reviewed for format or specific editorial form. It was agreed to review the subject material "piecemeal" as it was generated rather than wait for a completed package.
6. The design review was based on specific characteristics of the fuel to be shipped with appropriate safety factors as necessary to reflect possible inaccuracies in available information. Independent confirmation of fuel characteristics was not conducted by ORNL and the analysis did not consider failed fuel.
7. This review does not provide verification of physical inspection or certification of any aspects of cask procurement or construction. The review only evaluated design parameters and compliance with design standards as presented in the respective SARPs.

A Quality Assurance (QA) Plan[4] was prepared and implemented for the ORNL effort in review of the SARP. The primary emphasis of this QA plan was documentation control and QA of the design organization. A log system was established for document tracking and control, and a QA audit of TN[5] was conducted by ORNL to ensure that the design was being completed in a quality manner. The audit of TN emphasized the areas of control of engineering calculations, design control, computer program control, and drawing control. The conclusion of the audit was that TN has an acceptable quality program for design and compliance with this program was evident. It was discovered that the SARP is not considered to be a "design document" under NRC approved QA plans and there are potential problems with the linking of design changes and SARP revisions. This potential problem was recognized as a result of the audit and was given proper consideration.

3. TN-BRP PACKAGE DESCRIPTION

The following material is provided to acquaint the reader with the design of the TN-BRP cask.

The structure of the TN-BRP packaging is a cask body consisting of a thick-walled forged carbon steel cylinder shell with an integrally-welded forged bottom and a bolted forged top lid. The cask body, which provides containment of radioactive material and radiation shielding, has a spent fuel cavity with a nominal diam of 64 in.* and a nominal length of 171 in. The cask body has a nominal wall thickness of 9.62 in. and a nominal bottom thickness of 9.75 in. The lid, which has nominal thickness of 9.75 in. is bolted to the shell by 48 1-5/8-in. diam hexagonal head bolts. The lid is sealed by double gaskets consisting of a single metallic O-ring and a single Viton O-ring.

The fuel is shipped dry in an inert gas (nitrogen) atmosphere. The heat generated by the spent fuel assemblies is rejected via the cask body to the surrounding air by convection and radiation. No forced cooling or cooling fins are required or provided.

The design pressure for the cask body is 150 psig at a temperature of 200°F. All surfaces of the cask body, except sealing surfaces, are protected against corrosion by metal spray coating. Sealing surfaces are stainless steel clad by weld overlay.

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*For consistency of reference to the TN SARPs, equivalent (non-SI) units will be used throughout this document.

There are two penetrations through the lid and three penetrations through the body. The penetrations through the lid are required for cask operation and consist of an access port and a vent port. The three body penetrations for research instrumentation required by DOE include two for gas sampling and one for temperature and pressure instrumentation. In addition, the lid contains internal interconnecting passages that connect the seal interspaces to an external overpressure chamber used as a gas reservoir for leak detection during storage.

Shield plugs are provided in each penetration to minimize radiation levels during transport. In addition, all lid penetrations will be closed by covers which fit flush with the exterior surfaces. No protrusions exist above the lid in the transport configuration. The lid penetrations are sealed by means of one metallic and one Viton O-ring. The body penetrations are sealed by two Viton O-rings.

Four trunnions, bolted to the cask body, are used to lift, tie-down, and rotate the TN-BRP cask. Two of the trunnions are located near the lid end of the body and two near the bottom.

Each trunnion is designed with two shoulders (diameters). The outer shoulder (small diameter) is designed for lifting the cask; the inner shoulder (large diameter) is designed for rotating the cask for tie-down and for support of the cask during transport.

The basket, which fits into the cavity of the cask body, spaces the fuel assemblies, transfers heat to the cask body wall, and provides neutron-absorbing material to ensure that nuclear criticality safety requirements are met. The basket contains 44 compartments, each of which is capable of storing 2 BRP fuel assemblies stacked end-to-end. Any empty fuel compartment spaces will be filled by spacers.

Impact limiters are installed on the cask body, one at each end, before transport. The impact limiters are made of balsa and redwood in carbon steel containers. One impact limiter is bolted to the lid and the other is bolted to the cask bottom. The impact limiters are designed to meet the requirements of the accident conditions.

Additional detail on the TN-BRP cask described may be obtained by reference to the TN-BRP SARP.[1]

ABSTRACT

The Safety Analysis Reports for Packaging for two spent fuel shipping casks were technically reviewed by the Oak Ridge National Laboratory. The casks were designed by Transnuclear, Inc., for shipment of 85 Big Rock Point boiling water reactor fuel elements and 40 R. E. Ginna pressurized water reactor fuel elements from West Valley, New York, to Idaho Falls, Idaho. The intent of the review was to ensure compliance of the casks with the requirements the applicable Federal Regulations contained in 10 CFR Pt. 71 and allow issuance of Department of Energy Certificates of Compliance for transport by the Department of Energy Idaho Operations Office. The review was performed by a team of Oak Ridge National Laboratory staff assembled for their expertise in criticality analysis, shielding, metallurgy, nondestructive testing, thermal analysis, structural analysis, and containment.

This report describes the review processes, the findings in each technical area, and the overall conclusion that a Certificate of Compliance could be issued for the proposed single shipment under the specified conditions and constraints.

4. TN-BRP CRITICALITY SAFETY REVIEW

4.1 SUMMARY OF REVIEW PROCESS

In an effort to expedite the review of the final SARP,[1] it was requested that the ORNL review team be kept informed of the TN-BRP design process and be provided with draft copies of the SARP chapters as they were prepared. Thus, in March 1984, TN submitted the preliminary design and supporting information for the TN-BRP cask,[6] and comments were provided. Following this exchange, TN began submitting draft portions of the SARP for review and comment.[7] In February 1985 the first complete SARP was submitted to ORNL. Then, following a late February meeting with staff from TN, ORNL, DOE, and NFS,[8] "final" comments on the SARP were generated. Revisions to the SARP were then issued to ORNL in May 1985. After another exchange of comments the completed SARP for the TN-BRP cask was issued[1] by TN in September 1985. This SARP document is also the reference for the findings and conclusions presented herein.

The general discussion below is relevant for the TN-BRP criticality, shielding, and decay heat analyses (Sects. 4, 5, and 6) as well as the TN-REG criticality, shielding, and decay heat anlalyses (Sects. 13, 14, and 15). All these analyses were conducted by the review staff of the Nuclear Engineering Applications Department (NEAD) of Martin Marietta Energy Systems Computing and Telecommunications Division using the described computational techniques.

The review process undertaken for each of the various submittals involved (1) reading and becoming familiar with the new and/or revised material, (2) noting inconsistencies in the material, (3) noting portions of the material that were poorly presented or lacked clarity, (4) evaluating the justification for calculational assumptions and procedures, and (5) performing calculations to verify the adequacy of calculational values provided in the SARP. The content of the SARP was specifically reviewed to ensure the cask met the requirements of 10 CFR Pt. 71,[3] as revised September 6, 1984.

Comments generated during the review process were collected and forwarded through the Task Leader to TN. To avoid confusion, this section will not attempt to document each comment and its resolution, but simply supply the findings and conclusions of the NEAD review staff relative to the . al SARP submittal. Note, however, that significant changes were necessary in the criticality and shielding portions of the draft SARP in order to resolve the NEAD review staff comments. Calculational results generated by NEAD review staff will be presented in this report where expedient for justifying the acceptance of assumptions or calculated results provided in the SARP.

Any analyses performed by the NEAD review staff were done using various modules of the SCALE computational system.[9] This system was developed by NEAD for the Transportation and Certification Branch of the NRC's Office of Nuclear Material Safety and Safeguards to provide a tool for evaluation of nuclear fuel facility and cask designs. SCALE is a modular code system that enables a user to easily perform a variety of neutronic and thermal analyses by proper back-to-back execution of well-established functional modules. In addition, easy-to-use control modules have been developed to automate and standardize analytic sequences. Using a simplified, free-form input format, a user is able to prepare a control module input with easily visualized engineering parameters and keywords. The control module then automatically performs any necessary data processing (e.g., cross-section preparation), generates the input to the functional modules, initiates module execution in proper sequence, and performs any needed post-processing of the analytic results. Standardization is further enhanced by the incorporation of a host of validated data bases, e.g., composition, property, cross section, which allow easy input (via keywords) and data accessibility. Note that the analyses performed by the NEAD review staff are confirmatory in nature and thus, all the modeling details of the analyses are not reported here.

4.2 REVIEW OF SARP CONTENT

The TN-BRP cask was designed to hold 85 "short" BWR assemblies varying in length from 76.06 in. to 84.17 in. The fuel assembly characteristics required for criticality safety review or analysis are provided in Figs. 1.3-1.5 and Figs. 6.1-6.4 of the SARP. The identification numbers for the assemblies are shown in Table 5.1 of the SARP. This information was obtained from the operators of the Big Rock Point reactor (Consumers Power) and the fuel fabricator (General Electric). The criticality safety review was performed based on the supplied fuel assembly descriptions.

The review of Chap. 6 of the SARP indicated that TN generated an acceptable set of calculational benchmarks for their codes and subsequently used these calculational tools in a proper manner to ensure that a conservative k-eff value was obtained per the requirements of 10 CFR Pt. 71. Specifically, TN:

1. searched for and found that the optimum water moderation occurred at full density,
2. determined the UO_2 assembly type with the largest reactivity,
3. assumed the Pu in the three available mixed-oxide assemblies to be 100% ^{239}Pu,
4. assumed a fully loaded cask containing the most-reactive UO_2 assemblies and eight mixed-oxide assemblies (Pu = 100%, ^{239}Pu),
5. assumed an infinite length of active fuel,
6. assumed an infinite array of the casks, and
7. assumed initial fuel enrichments with no credit for burnable poisons or fuel depletion.

The computer codes used by TN for cross-section processing (NITAWL) and evaluation of the effective multiplication factor (KENO IV) are widely recognized as acceptable tools for this type of analysis. The 27-group cross-section set also represents a validated data library for criticality analysis. These codes and the cross-section set are all part of the SCALE package developed by the ORNL Nuclear Engineering Applications Department (NEAD) review staff of Computing and Telecommunications Division which was responsible for the analyses presented in this review.

With the assumptions and codes previously specified, TN obtained a value of 0.903 $\pm$ 0.005 for the effective multiplication factor (k-eff). This value is below the acceptable upper limit typically used in criticality safety assessments of transport casks, that is K-eff + $2\sigma \leq 0.95$. The calculated k-eff did not consider any deformation or movements of the basket. However, consultation with the ORNL structural reviewer confirmed the SARP contention that any deformation or movements of the basket during normal or accident conditions do not compromise the integrity of the basket or its ability to keep fuel assemblies within their respective compartments. Our opinion is that the minor deformations or movements of the basket indicated by Chap. 2 of the SARP are not significant and would not alter the k-eff value beyond the 2 sigma uncertainty limit.

In conjunction with the SARP review, a review of the TN report concerning boron verification in the basket was also completed. This report adequately summarizes the efforts to ensure the boron content in the basket and is satisfactory to the NEAD review staff. However, a review by persons familiar with the chemical testing procedures and by Quality Assurance (QA)/Quality Control (QC) personnel is recommended. One shortfall of the final SARP is that this report is not referenced in the SARP section on boron verification (SARP Sect. 8.1.11), nor are the methods and procedures of the report included in the SARP.

4.3 CALCULATIONAL VERIFICATION

A detailed review and check of the submitted KENO IV input would be a tedious, time-consuming, and perhaps error-prone project. However, because assurance of subcritical conditions is imperative, it was decided to develop an independent model of the cask and fuel contents and perform analyses at ORNL to verify criticality safety of the cask. Analyses were performed both for transport and loading conditions. Loading conditions were considered because the analyses were also used to support the criticality safety report written at the West Valley site for the DOE-Idaho Safety Officer.

The NEAD review staff performed the calculations using the CSAS25 analysis sequence within the SCALE computational system. (The CSAS25 sequence uses BONAMI-S and NITAWL-S for cross-section processing and resonance self-shielding and subsequently accesses KENO V.a for the criticality analysis.) The model developed for the analysis includes a pin-by-pin description of each assembly in the cask. The cask was filled with the most-reactive UO_2 assembly type (Type F) and the three mixed-oxide assemblies (Type EP). The entire finite cask (not just a quadrant) was modeled, and a 5-in. water gap (no basket material) was placed between the fuel stacks. Only the fuel region of an assembly was modeled, and the active fuel length of 70 in. (Type F fuel) was assumed for the total assembly height. The borated steel basket was modeled with the same height as the assemblies, and a fuel assembly was placed in every compartment. The bottom stack of fuel assemblies was placed on the floor of the cask, and 5 in. of water was assumed between the top assemblies and the cask lid. The SCALE 27-group cross-section set was used for all calculations.

The first calculations, which were performed before submittal of a final SARP, used the early design boron specification of 1.56 wt % in the basket. Table 1 presents the earliest calculated results that provide an indication of the low sensitivity of k-eff to the boron above 1.3 wt % and to the specular reflection boundary condition. Table 2 provides results for a series of calculations performed to determine the EP assembly configuration that provides the highest k-eff value. Figures 1–6 show the EP loading configurations used where all blank compartments are assumed to hold Type F assemblies. Figure 5 illustrates the fuel configuration that gave the maximum k-eff value. Instead of the fuel configuration of Fig. 5, the SARP model assumed four infinitely long EP assemblies (or eight actual assemblies) to be located in the four central compartments. This was deemed acceptable because (1) eight rather than three assemblies were assumed in the SARP model, (2) the SARP model is more consistent with the specified loading pattern, and (3) the k-eff value obtained with the optimum (Fig. 5) loading is in basic agreement with the value reported in the SARP.

After the final SARP was submitted, several more calculations were performed as a final check and as an aid to the West Valley review of cask loading. These calculations were all performed with 1.3 wt % boron in the basket plates. Table 3 presents the k-eff values obtained with the EP loading pattern of Fig. 5 and various densities of water

Table 1. Criticality analysis results for the TN-BRP cask showing sensitivity of boron wt % and assumed boundary condition[a]

Case	Boron (wt %)	Multiplication factor	Histories
BRP1	1.56	0.856 ± 0.004	29100
BRP1REF[b]	1.56	0.854 ± 0.004	30000
BRP1A	1.3	0.856 ± 0.004	30000
BRP1B	1.0	0.880 ± 0.004	30000
BRP1C	0.0	1.066 ± 0.004	30000

[a] All calculations performed with a closed cask loaded with only Type F assemblies.

[b] Full specular reflection boundary condition. All other cases run with vacuum outer boundary.

Table 2. Criticality analysis results for the TN-BRP cask for variations in loading configuration of the mixed-oxide (EP) assemblies[a]

Case	Boron (wt %)	EP assembly location	Multiplication factor
BRP2	1.56	Fig. 1	0.865 ± 0.004
BRP3	1.56	Fig. 2	0.858 ± 0.004
BRP4	1.56	Fig. 3	0.878 ± 0.004
BRP5	1.56	Fig. 4	0.858 ± 0.004
BRP6	1.56	Fig. 5	0.889 ± 0.005
BRP7	1.56	Fig. 6	0.880 ± 0.004

[a]All calculations performed with (1) vacuum outer boundary condition, (2) a closed cask loaded with Type F assemblies and three Type EP assemblies, and (3) 30,000 histories.

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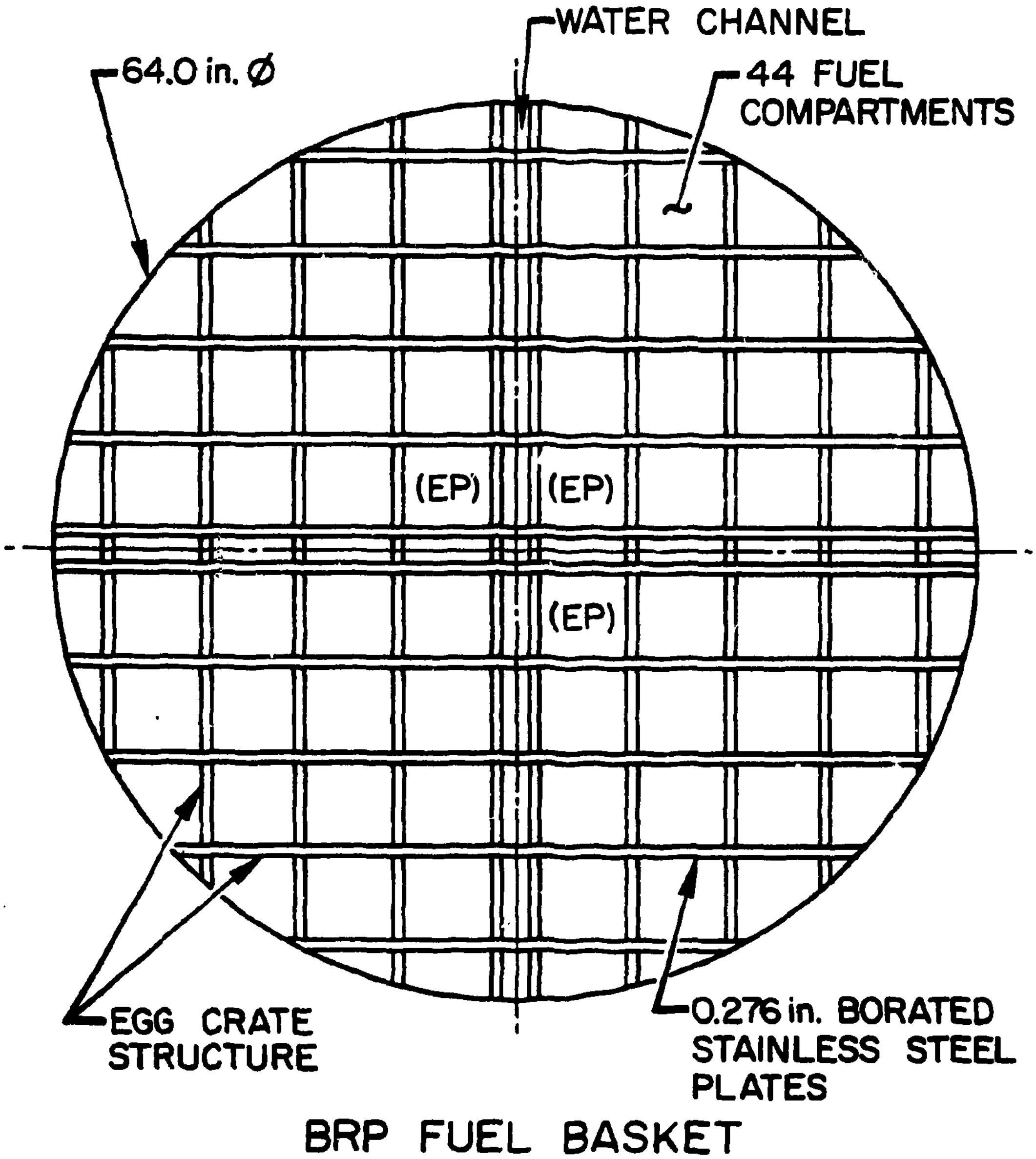

Fig. 1. Locations of EP fuel assemblies for case BRP2 loading. Parentheses denote EP assembly in bottom portion of basket.

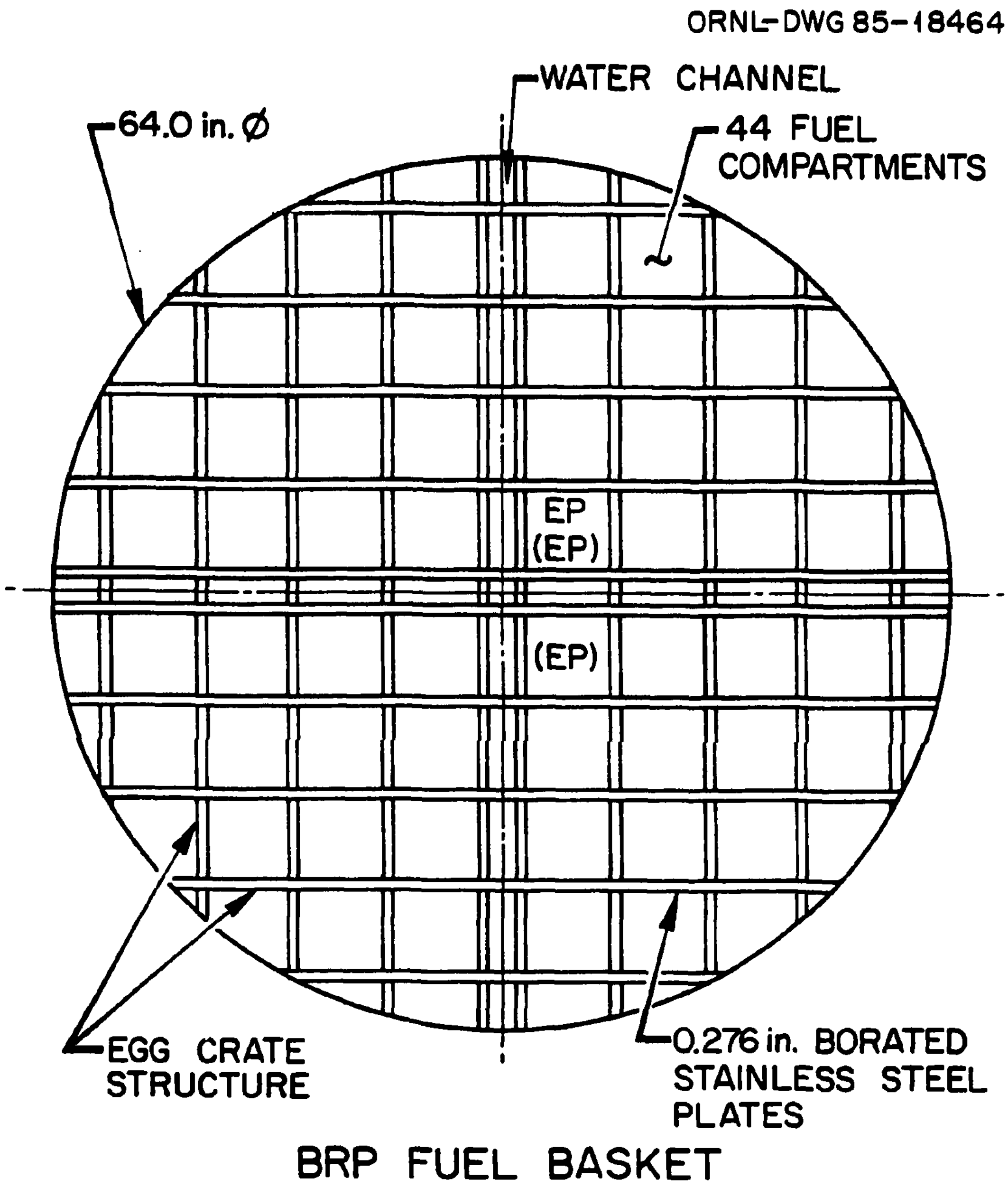

Fig. 2. Location of EP fuel assemblies for case BRP3 loading. Parentheses denote EP assemblies in bottom portion of basket.

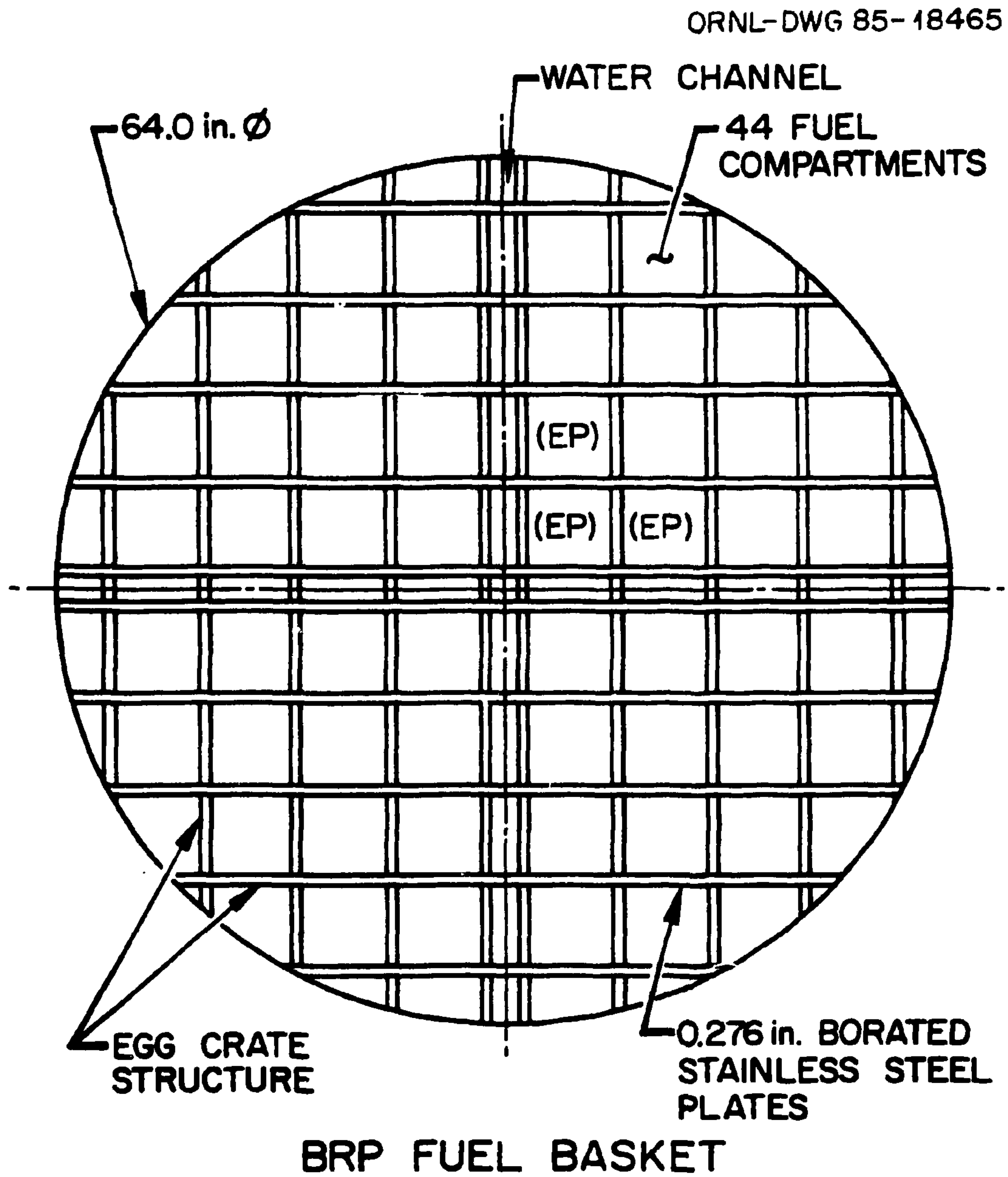

Fig. 3. Location of EP fuel assemblies for case BRP4 loading. Parentheses denote EP assemblies in bottom portion of basket.

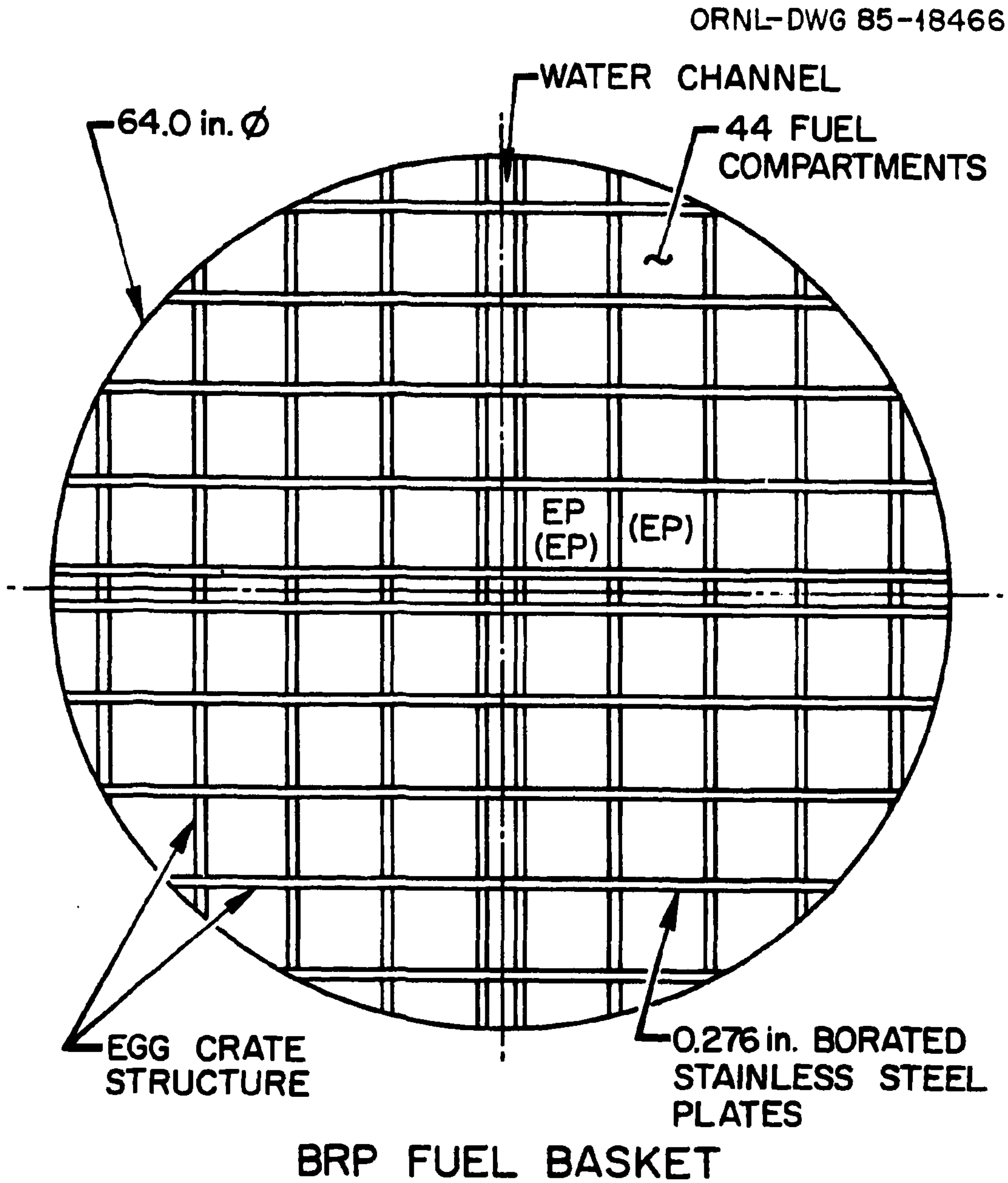

Fig. 4. Location of EP fuel assemblies for case BRP5 loading. Parentheses denote EP assemblies in bottom portion of basket.

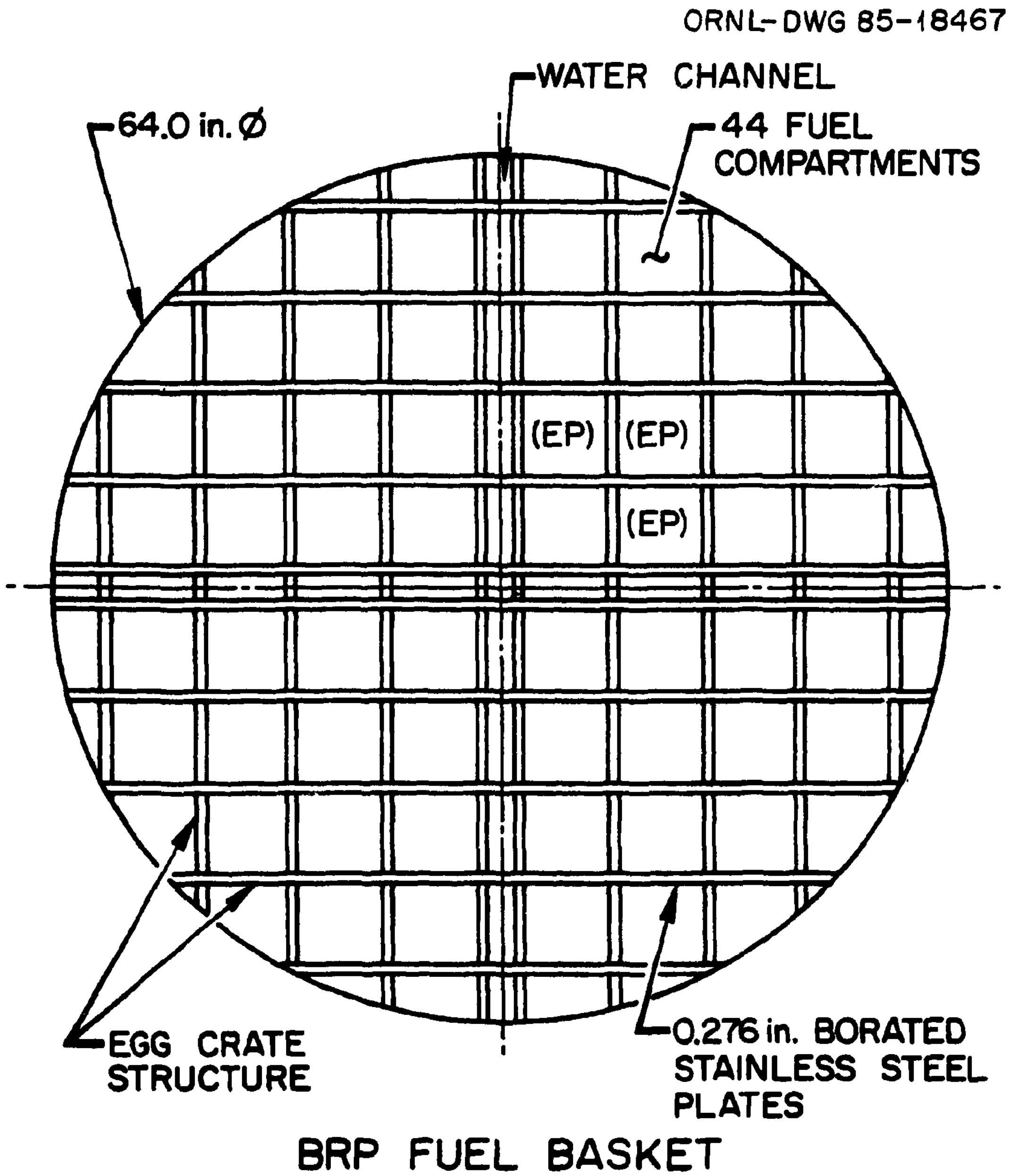

Fig. 5. Location of EP fuel assemblies for case BRP6 loading. Parentheses denote EP assemblies in bottom portion of basket.

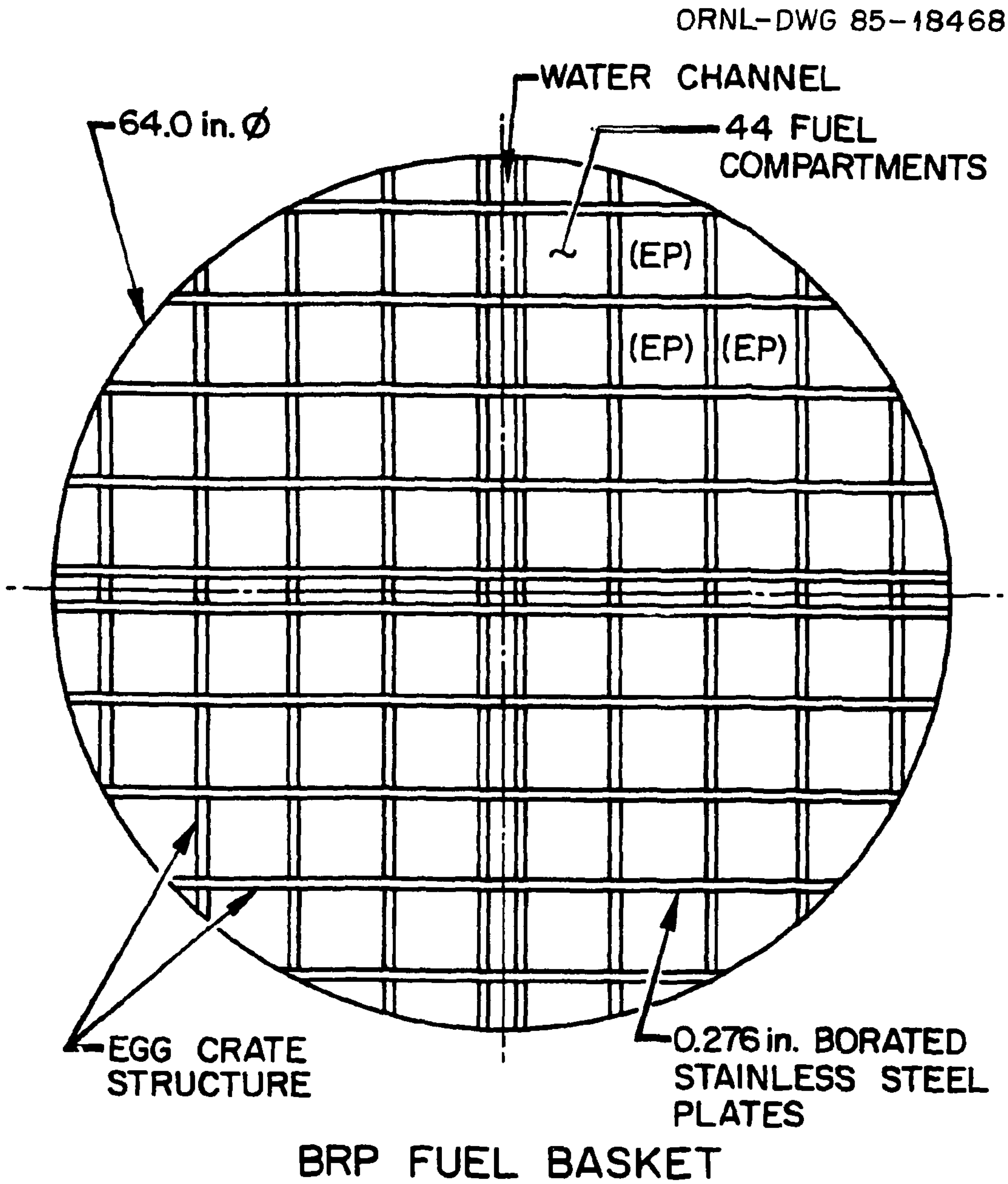

Fig. 6. Location of EP fuel assemblies for case BRP7 loading. Parentheses denote EP assemblies in bottom portion of basket.

Table 3. Criticality analysis results for the TN-BRP cask for variations in water density[a]

Case	Water density (g/cm^3)	Multiplication factor
BRP8	1.0	0.891 ± 0.004
BRP9	0.95	0.893 ± 0.004
BRP22	0.9	0.869 ± 0.004
BRP10	0.7	0.803 ± 0.004
BRP11	0.5	0.691 ± 0.003
BRP12	0.2	0.523 ± 0.003
BRP13	0.1	0.457 ± 0.002

[a]All calculations performed with (1) 1.3 wt % boron in basket, (2) a closed cask loaded with Type F assemblies in the configuration of Fig. 5, and (3) 30,000 histories.

moderator. The results verify the TN assumption that full-density water provides moderation conditions that are optimum (or so near optimum as to be satisfactory).

Table 4 presents a final set of results for a series of loading scenarios and for the cask in transport. These calculations were done with 1.3 wt % boron in the basket, and 90,000 histories were used to ensure acceptable results. All cases except BRP19 and BRP23 were done with the lid removed. All cases except BRP19 have an infinite water reflection around the cask. For all of these cases, the EP assemblies were placed in the top layer because this configuration was felt to be the most reactive with the lid removed. Cases BRP16 and BRP17 indicate the negative reactivity associated with removing a Type F assembly located in the center of a quadrant. For both cases, the assembly loading pattern of Fig. 3 was used; however, the EP assemblies were placed in the top stack and only Type F assemblies were in the bottom (i.e., the top and bottom patterns of Fig. 3 were interchanged). Case BRP18 uses the optimum EP assembly pattern of Fig. 5 except the top and bottom are again interchanged to put the EP assemblies on top. The result is the conservative maximum k-eff value for the loaded open cask in water. By comparison, case BRP23 is loaded just as for case BRP18 except the lid is on (cask filled with water), and a slight decrease in k-eff is seen. Case BRP19 uses the loading pattern of case BRP18 in an infinite array of closed, water-filled casks per the requirement of 10 CFR Pt. 71.

Table 4. Criticality analysis results for the TN-BRP cask for various loading and transport scenarios[a]

Case	Loading pattern	Lid removed	Infinite H_2O reflector	Multiplication factor
BRP16	Fig. 3 with top and bottom interchanged	Yes	Yes	0.893 ± 0.003
BRP17	Fig. 3 with top and bottom interchanged, assembly Type F touching EPs removed	Yes	Yes	0.865 ± 0.002
BRP18	Fig. 5 with top and bottom interchanged	Yes	Yes	0.912 ± 0.003
BRP23	Fig. 5 with top and bottom interchanged	No	Yes	0.902 ± 0.002
BRP19	Fig. 5 with top and bottom interchanged	No[b]	No[b]	0.898 ± 0.003
BRP20	Fig. 5 with top and bottom interchanged, one EP next to flux trap replaced with F and EP horizontal across top with lid removed	Yes	Yes	0.887 ± 0.002
BRP21	Fig. 5 with top and bottom interchanged, F assembly horizontal across top with lid removed	Yes	Yes	0.914 ± 0.002

[a]All calculations performed with 1.3 wt % boron in basket and for 90,000 histories.

[b]Infinite square pitch array of closed water-filled casks with a minimum of 2 in. of water between casks.

The last two cases given in Table 4 were performed to analyze a loading accident scenario proposed by West Valley where an assembly is assumed to fall across the top of an almost fully loaded open cask. Case BRP21 is for a fully loaded cask with the EP assemblies loaded on top in the pattern shown in Fig. 5 and with a Type F assembly laying across the open cask directly over the EP assemblies. There is conservatively assumed to be only 5 in. of water between the horizontal assembly and the fuel in the top stack of assemblies. Thus, this accident model is adequate (or perhaps conservative) for even the worst case scenario where the assembly has one end laying on the top of the basket (because the distance from the top of basket to active fuel is at least 5 in. and probably 8 to 10 in.). Case BRP20 is a repeat of case BRP21 except an EP assembly is laying across the open cask and a Type F assembly is used to replace one of the EP assemblies.

The conclusion drawn from the analyses is that the TN-BRP design as presented in the SARP assures a subcritical configuration during loading and transport when loaded with the fuel for which it was designed. The calculations also serve to confirm the validity of the k-eff values presented in the SARP.

5. TN-BRP SHIELDING REQUIREMENTS REVIEW

5.1 REVIEW OF SARP CONTENT

Chap. 5 of the SARP[1] presents the shielding evaluation performed by TN to ensure that the cask would meet the dose requirements specified in 10 CFR Pt. 71.[3] This chapter of the SARP provides (1) a description of the available cask shielding, (2) the irradiation characteristics of the fuel contents, (3) a description of the procedures for generating the radiation sources, (4) necessary information regarding the calculation of cask dose rates, and (5) an evaluation of the dose from the cask penetrations. The evaluated dose rates and corresponding 10 CFR Pt. `. limits are shown in Table 5.2 of the SARP. This table indicates that the available shielding for the TN-BRP is adequate to satisfy the 10 CFR Pt. 71 limits for rail shipment with the designated fuel contents.

The final shielding calculations performed by TN for the SARP were done using well-established codes and cross-section libraries. TN used the ORIGEN code[10] for the fuel depletion analysis while the BUGLE-80 coupled cross-section set[11] was used with the ANISN[12] and XSDOSE[13] codes to perform the radiation transport and dose evaluations. Assumptions used by TN in terms of the cobalt impurity content in the assemblies (assumed 100% uncertainty in nominal ^{59}Co content), the peaking factor employed (1.2), use of one-dimensional analysis methods, and the homogenization of the fuel have been found acceptable and/or conservative ' a methodology and models used for generating the radiation sources, performing the transport calculations, and evaluating the dose rates are reasonable and acceptable procedures. The above statement holds for both the cask body analysis, and the analysis performed on the cask penetrations.

As with the criticality review, the NEAD review staff reviewed the shielding evaluation assuming the fuel contents specified in the SARP to be correct. The contents of the TN-BRP cask are limited to the specific 85 BWR fuel assemblies. The irradiation data specified in the SARP are particularly important to the shielding evaluation, and any significant changes could invalidate the calculated doses. However, it appears that TN has used reliable sources (reactor utility and West Valley) to obtain the irradiation data. Verification of removal of the cobalt rods from the 9x9 and 11x11 assemblies is recommended by the reviewers prior to cask loading of the fuel. If all the cobalt rods have not been removed as noted, the radiation sources and doses could be much higher than those predicted in the SARP.

Administrative procedures also need to be in place to ensure that the cask is loaded in accordance with the pattern specified in Chap. 7 of the SARP. The loading pattern shown in the SARP is required because the fuel assemblies with the highest burnup (highest radiation source) were, of necessity, placed in the cask center for the shielding analyses.

5.2 CALCULATIONAL VERIFICATION

Although the evaluation procedures and calculational tools used by TN were judged to be acceptable, it was decided that selected verification analyses would increase the confidence of reviewers in the results and methodology used and serve to better familiarize the reviewers with the details and assumptions used in the SARP evaluation. Therefore, after receiving the final SARP in September 1985, verifying calculations were performed using the SAS2 and SAS1 modules of the SCALE system[9] and employing the basic methodology and procedures presented in the SARP. For normal transport conditions, an axial shielding analysis for the cask bottom and a radial shielding analysis were performed in an effort to obtain reasonable agreement with the reported dose rates in the SARP. Only reasonable agreement was expected with the analysis because:

1. different cross sections, flux-to-dose conversion factors, and ORIGEN data libraries were used;
2. the radiation source was obtained using only two depletion and decay cases (using average burnup and conservative decay values), whereas TN developed the radiation sources based on five depletion cases and the accurate decay time for each assembly; and
3. the mesh spacing, angular quadrature, and (in some cases) material number densities were different.

A comparison of the partial results obtained at ORNL and the corresponding results reported in the SARP are provided in Table 5.

The differences in the respective analyses (as cited above) and the uncertainty (cross-section data, methods, and assumptions) associated with any shielding analysis of this type led to the conclusion that the TN results presented in the SARP appear reasonable in comparison to those calculated by the NEAD review staff. The fact that the radial 2 m dose rate calculated at ORNL is higher than the 10 CFR Pt. 71 limit does not overly concern the reviewers because of the approximate nature by which the fuel source was obtained (the TN method is more precise) and because of the prudent, but most likely excessive, amount of cobalt (double nominal content) used in all the TN analyses. Using the more probable nominal cobalt amounts in the analyses would reduce the results between 30% and 50%, as shown in Table 5.

Table 5. Calculated maximum dose rates for normal transport compared with SARP values[a]

Location	Total dose rate (millirem/h)			
	SARP	ORNL: Double Nominal Cobalt	ORNL: Nominal Cobalt	10 CFR Pt. 71 limit
Package surface side	86.9	114.5	57.4	1000
Package surface bottom	84.0	62.4		1000
2 m from vehicle side	8.0	10.2	6.8	10
2 m from vehicle bottom	8.7	8.3		10

[a]SARP values taken from Table 5.2 of Ref. 1.

6. TN-BRP DECAY HEAT GENERATION REVIEW

6.1 REVIEW OF SARP EVALUATION

The methodology used to obtain the decay heat values for the thermal evaluation is presented in Chap. 3, Appendix 3, of the SARP.[1] TN used the fuel burnup and decay characteristics to calculate heat generation values via the ORIGEN code.[10] Before the analysis, TN ran ORIGEN to enable comparison with results available in U.S. NRC Regulatory Guide 3.54.[14]

To obtain the total heat generation, the BRP fuel was grouped by discharge date, and an ORIGEN analysis was performed using the average burnup associated with each discharge date. The decay heat value from each ORIGEN run was multiplied by the total metric tons of uranium (MTU) for the discharge group and "normalized" to the Regulatory Guide values by factors of 1.01 to 1.04. The total calculated decay heat was 5.8 kW after a 15% increase was added to conform to the Regulatory Guide requirements for BWR fuel. The 15% increase is included in the Regulatory Guide to cover generic uncertainties associated with using this type of analysis for BWR fuel. TN further raised the total decay heat value by rounding off to 6.0 kW.

Based on a total heat generation of 6.0 kW, TN presents a reasonable procedure for determining the average kW value for the inner 24 (hottest) assemblies, 0.1 kW, and the outer 64 assemblies, 0.06 kW. A maximum assembly decay heat value of 0.115 kW was also obtained by TN using decay heat plots generated with ORIGEN results.

In conclusion, the reviewers feel that the decay heat values in the SARP were obtained in a correct and prudent manner using an adequate computational tool (ORIGEN), which was verified against an NRC Regulatory Guide. The requirements of the Regulatory Guide pertaining to initial cobalt content and the uncertainty associated with BWR fuel were adhered to.

6.2 CALCULATIONAL VERIFICATION

The validity of the total decay heat load of 6.0 kW was first verified using tables and figures in Regulatory Guide 3.54 and in the ORNL report upon which the guide was based.[15] A further check was provided by the two SAS2 depletion calculations referred to in Sect. 5.2. These calculations indicated a total decay heat value of 5.1 kW after incorporation of the 15% increase for BWR fuel. The two SAS2 cases were performed using the average depletion and decay characteristics of the inner and outer fuel regions (see SARP, Chap. 5). These runs indicated average heat loads (with 15% increase for BWR fuel included) of 0.05 kW for outer region assemblies and 0.084 kW for inner region assemblies. These calculations thus verify the adequacy of the values presented in the SARP.

A separate ORIGEN-S[16] calculation was also performed for the BWR fuel assembly with the highest burnup (assembly C10 with a burnup of 24,997 MWD/MTU and 0.121 MTU/assembly per Table 5.1 of the SARP). This calculation provided a maximum assembly decay heat value of 0.113 kW (after the 15% increase for BWR fuel), which agrees well with the 0.115

kW value provided in the SARP. Table 6 summarizes the compa values presented in the SARP and those calculated by ORIGEN-S the SAS2 sequence or stand-alone).

Table 6. Comparison of decay heat values calculated at ORNL with values in the TN-BRP SARP[a]

	Decay Heat (kW)	
	SARP	ORNL
Total cask contents	6.0	5.1
Inner assembly average	0.1	0.084
Outer assembly average	0.06	0.05
Maximum assembly value	0.115	0.113

[a]SARP values from Chap. 3, Appendix A, of Ref. 1.

7. TN-BRP THERMAL REVIEW

An independent review of Chap. 3.0, "Thermal Evaluation," of the TN-BRP SARP[1] and related materials was performed by Engineering personnel of Martin Marietta Energy Systems, Inc. Preliminary submissions of proposed SARP text were reviewed as they were submitted during 1984. In 1985, a draft SARP and a revised draft SARP were reviewed. Comments related to the thermal evaluation contained in these documents were incorporated into the ORNL review team's comments and transmitted to TN. Responses to comments were provided by TN for some issues in separate letters and for other issues directly by modification of the SARP in subsequent submissions. These responses were also reviewed to ensure that every significant technical issue was resolved. A final SARP was received September 6, 1985, and the conclusions in Sect. 7.6 of this document were based on the review of that document. Revised design criteria were then reviewed for consistency with the SARP and with applicable regulations. Each phase of the review was conducted under the guidance provided by U.S. NRC regulations expressed in 10 CFR Pt. 71[3] and the related U.S. NRC Regulatory Guides 7.6,[17] 7.8,[18] and 7.9.[19]

In addition to the review of SARP material, a series of independent thermal analyses was conducted based on the cask design presented in the SARP. These analyses were undertaken to increase the reviewers' understanding of the cask's expected thermal behavior and to reduce the reviewers' uncertainties regarding the ability of this cask to meet regulatory requirements. These analyses were done using the HEATING6[20] code as documented in the SCALE reports[9] or by other calculational methods generally employed in engineering practice.[21]

7.1 REVIEW OF DESIGN CRITERIA

The TN-REG/TN-BRP design criteria document[22] was submitted in initial draft on January 30, 1984, and ORNL comments were transmitted on February 9, 1984. The design criteria document contained temperature operating ranges for the components of the cask. No thermal analyses were presented in this document. The expected heat load and the boundary conditions to be used in thermal analyses were specified.

7.1.1 ORNL's Comments

An estimated decay heat load of 5 kW appeared in the design criteria. ORNL suggested the use of a range for the decay heat load with minimum and maximum values determined by the degree of uncertainty in the decay heat calculation and the use of the more conservative limiting value appropriate to each subsequent calculation.

ORNL noted that the design criteria included a maximum solar heat load of 62 $Btu/h/ft^2d$, which is about one-half of the solar heat load for cylindrical surfaces given in Subpart F of 10 CFR Pt. 71.[23]

ORNL noted that the design criteria included a minimum ambient temperature of $-10^{\circ}F$ for transport, where 10 CFR Pt. 71 gives minimum ambient temperatures of $-20^{\circ}F$ (drop tests, normal transport conditions) and $-40^{\circ}F$ (cold test).

7.1.2 TN's Response

TN made no formal response to these comments. Subsequent submission of proposed text for the TN-BRP SARP included resolution of the above comments as follows.

TN began to use a range of 4.5 kW to 6.0 kW for the decay heat load, applying the more conservative extreme in evaluation of each test condition required by 10 CFR Pt. 71.

TN corrected the maximum solar heat load to 124 $Btu/h/ft^2$.

TN brought minimum ambient temperature assumptions into agreement with 10 CFR Pt. 71.

7.1.3 Issues Pending

The issues above were considered pending until the changes to the proposed SARP text (noted above) were received by ORNL's reviewers June 19, 1984. At that time the issues above were considered to be resolved.

7.2 REVIEW OF PRELIMINARY SUBMISSIONS

The TN-BRP transport/storage cask preliminary design[6] was received March 15, 1984, and ORNL comments were transmitted April 12, 1984. Proposed text for the SARP Chap. 3 was received June 19, 1984, and ORNL comments were transmitted July 23, 1984. Revised text for the SARP Chap. 3, "Thermal Evaluation" was received October 22, 1984, and ORNL comments were transmitted November 21, 1984. ORNL's comments, TN's response to comments, and pending issues at each stage of review are presented.

7.2.1 Review of Thermal Aspects of TN-BRP Preliminary Design

7.2.1.1 ORNL's Comments

ORNL questioned values of emissivity and absorptivity for the outer surface and the emissivity of the inner surface of the cask wall.

ORNL suggested modifying the basket thermal analysis to take into account preferential loading of the hottest assemblies in the basket center. SARP Fig. 8.2.1.1-1 shows the conservative fuel loading used in the final SARP and the resulting basket plate temperatures for normal transport conditions and for fire accident conditions as defined in 10 CFR Pt. 71.

ORNL asked for consideration of non-uniform axial distribution of decay heat in the spent fuel assemblies. The axial distribution of decay heat used in the final SARP is shown in SARP Fig. 8.2.1.1-2 normalized to the average decay heat value.

7.2.1.2 TN's Response

TN made no formal response but resolved these comments by incorporating changes in the proposed SARP text received June 19, 1984.

TN reduced emissivity and increased absorptivity to acceptable values on the outer and inner cask wall surfaces.

TN accounted for preferential loading of hotter assemblies in the basket center, thus making the basket thermal analysis more conservative.

TN applied a peak power factor of 1.2 to the axial distribution of decay heat in the fuel assemblies, thus increasing the conservatism of basket and fuel pin maximum temperature predictions.

7.2.1.3 Issues Pending

Based on resolution of the comments above in the June 19, 1984, submission, no comments remained pending before review of that submission.

7.2.2 Review of Thermal Aspects of TN-BRP SARP Rev. 0

ORNL's comments on the thermal evaluation, TN's response to comments, and issues pending at this stage of the review are listed.

7.2.2.1 ORNL's Comments

Transient maximum temperature criteria should be established because the thermal evaluation of the hypothetical accident fire indicated basket and fuel pin long-term maximum temperature criteria would be exceeded.

A lowest metal service temperature (LMST) should be defined and added to the design criteria document and the SARP.

Impact limiters must be proven to remain intact and in place following the hypothetical accident tests to protect the Viton seals from extreme ambient temperatures.

A thermal evaluation was needed for the enclosure added to the cask design to protect personnel from high surface temperatures. (This enclosure was subsequently dropped from the design.)

The Viton seal useful temperature range should be established.

The peak power factor of 1.2 should be used in the cask body analysis.

Characterization and documentation of the axial distribution of decay heat should be added to the SARP.

Maximum fuel pin temperature should be calculated using the fuel bundle with the highest calculated decay heat.

7.2.2.2 TN's Response

TN did not agree that maximum transient temperature criteria were needed for the basket and fuel pin evaluations.

The LMST was to be defined by material tests. Pending completion of those tests, TN deferred action on this comment. This issue was resolved by manufacturer's test data reported on February 27, 1985.

TN clarified the boundaries of containment for the cask. TN referred to Chap. 2 of the SARP, the structural analysis wherein the impact limiters were calculated to meet regulatory requirements. Agreement was reached among ORNL structural and thermal reviewers that TN's position on this issue was acceptable.

TN agreed to provide a calculation for the enclosure.

TN provided the correct working temperature range for the Viton seals and agreed to amend the design criteria document.

TN agreed to provide a revised two-dimensional analysis with a peaking factor for the cask body.

TN provided a reference to "data from Consumers Power." The correct peak power factor for spent fuel is 1.2.

TN agreed to base the calculated maximum fuel pin temperature on the maximum predicted decay heat among the BRP fuel assemblies.

7.2.2.3 Issues Pending

The response from TN on transient maximum temperature criteria was judged insufficient. In the absence of such criteria, the analyses should demonstrate compliance with the long-term temperature criteria shown in the design criteria document. This issue was resolved in the revised draft SARP (see Sect. 7.3.2).

The acceptability of the structural analysis for the impact limiters had to be determined by ORNL's structural reviewer. Pending a finding that the impact limiters would stay on in a hypothetical accident specified in 10 CFR Pt. 71, this issue was considered open. The required finding was made on February 27, 1985, and the issue was considered resolved.

TN's response to other comments was considered satisfactory, and the remaining issues were considered resolved when the SARP and the design criteria document were amended as TN proposed.

7.2.3 Review of Chap. 3, Rev. 1, "Thermal Evaluation - BRP"

A second round of comments and responses was undertaken before receipt of the draft SARP based on this revised submission. ORNL's comments, TN's response, and pending issues are as follows.

7.2.3.1 ORNL's Comments

TN was asked again to provide maximum transient temperature criteria for the basket and the fuel pin analyses. Other design criteria had been adjusted, and the changes had been justified acceptably.

The analysis of the enclosure showed a constant temperature for air inside the enclosure the same as the ambient air temperature. This was nonconservative: in fact, heating of the air in the enclosure would occur, and both the enclosure and the cask's outer surface would be hotter than shown.

The peak power factor describing the axial distribution of decay heat in spent fuel was used when evaluating the minimum cask temperature. Care should be taken that a power factor of 1.0 or less be applied to the decay heat load to calculate the minimum temperature.

The Consumers Power data that support the use of 1.2 as the correct peak power factor for the axial distribution of decay heat in TN-BRP spent fuel should be placed in the SARP, or a reference to a report of these data in the public literature should be added to the SARP.

7.2.3.2 TN's Response

TN agreed to add maximum transient temperature criteria of 800°F for the basket and 1000°F for the fuel pins to the SARP.

TN agreed to repeat the enclosure thermal analysis with more conservative assumptions.

The minimum temperature calculation was a two-dimensional analysis with an axial distribution applied to the minimum expected decay heat load. As ORNL suggested, the minimum temperature was predicted at a point on the cask outer surface far from the positions of peak decay heat release.

TN agreed to add a reference to Consumers Power's data to the SARP.

7.2.3.3 Issues Pending

TN had agreed to add maximum transient temperature criteria for the basket and fuel pins to the SARP. However, the temperatures chosen needed to be justified, preferably by reference to other documents already accepted by NRC. References or other justification for these temperature criteria remained a pending issue until the review of the revised draft SARP (described in Sect. 7.3.2). Otherwise, TN's response to comments was considered satisfactory, and the remaining issues were considered resolved when the SARP was amended as TN proposed.

7.3 REVIEW OF TN-BRP DRAFT SARP

The TN-BRP draft SARP was received February 15, 1985.[24,25] This was the first submission of a complete SARP document to ORNL reviewers. On February 27-28, 1985, a review meeting among project participants was held in Oak Ridge.[8] Detailed comments on the TN-BRP draft SARP were provided in that meeting, as documented in the letter of March 13, 1985, from L. D. Bates (ORNL) to F. J. Williams (TN).[26] On April 26, 1985, a separate set of comments on our pending technical issues was transmitted to TN. The TN-BRP revised draft SARP[7] was received from TN on May 14, 1985, and comments were returned June 19, 1985. The pending technical issues from the draft SARP were resolved in the text of the revised draft SARP. Review of the latter document resulted in comments on minor omissions, inconsistencies, and suggested improvements in the SARP. No new major issues were identified in this phase of the review. A discussion of the major technical issues and their resolution at each review phase follows.

7.3.1 Review of TN-BRP Draft SARP

The following four technical issues were considered to be unresolved following the review of the document and the review meeting held on February 27-28, 1985.

7.3.1.1 ORNL's Comments

Axial distribution of the spent fuel heat generation rate was modeled by an axial power shape taken from Consumer Power data for current BRP spent fuel. More discussion was needed including:

A. Correct references to the Consumer Power data in the text and sections "References" and "Appendices," and discussion of how the axial power shape actually used in the thermal evaluation was derived from the sparse data available from Consumer Power.

B. The fuel pin maximum transient (accident fire) temperature criterion was 1000°F. Although a reference existed for this new criterion, it had not been added to the SARP. The reference should appear in the SARP, and the new criterion should appear in the amended design criteria document.

C. The Viton seal operating temperature range was stated inconsistently within the SARP. The SARP and the design criteria document should agree on the correct operating temperature range for Viton seals.

D. The basket plate maximum transient (accident fire) temperature criterion was 800°F. No reference exists to support this criterion, but the criterion was justified based on materials properties at that temperature and on the absence of dynamic structural loads during the hypothetical accident fire test. Note that the 800°F criterion cannot be applied in normal transport or wherever dynamic structural loads must be considered according to applicable regulations.

7.3.1.2 <u>TN's Response</u>

All four technical issues above were resolved in the TN-BRP revised draft SARP without formal response by TN.

7.3.1.3 <u>Issues Pending</u>

The only issue pending at the start of the review of this revised draft SARP was the amended design criteria document which had not been submitted for review at that time. Sect. 7.4 covers the review of the amended design criteria document.

7.3.2 <u>Review of TN-BRP Revised Draft SARP</u>

This document was received by the thermal evaluation reviewers on May 14, 1985, and comments were transmitted on June 19, 1985. No new major issues were identified in this phase of the review. Previously identified outstanding technical issues were considered to be resolved based on the material presented in this revised draft. Comments covered minor omissions, inconsistencies, and suggested improvements in the SARP. A few of the comments made are repeated below.

7.3.2.1 ORNL's Comments

A discrepancy was noted in the SARP between the nonsymmetrical temperature distribution of Chap. 3 of the SARP and the symmetrical temperature distribution in Chap. 2 of the SARP for the TN-BRP basket. The text of Chap. 2 of the SARP indicated these should be identical. Actual values of temperature at any node in the basket differed only slightly, so no impact was expected in TN's conclusions based on either temperature distribution.

10 CFR Pt. 71 provides that the maximum value of insolation on vertical surfaces be one-half that on cylindrical surfaces. The SARP applied the larger value to all surfaces of the cask. This discrepancy was not considered a departure from regulations because the resulting temperature predictions are, in all cases, conservative.

Temperatures 6-7°F too high were used as initial conditions for the fire transient temperature calculation in the cask body thermal evaluation. Because this difference had a small impact on the final result, and because the values actually used resulted in a more conservative, higher prediction of maximum basket and fuel pin temperatures, this calculation needs not be repeated.

7.3.2.2 TN's Response

Response to the above comments was made by revision of the revised draft SARP and release of a final SARP document. No major technical issues remained unresolved in the thermal evaluation presented in the revised draft SARP.

7.3.2.3 Issues Pending

Although the TN-BRP revised draft SARP could be improved by response to the comments transmitted on June 19, 1985, the thermal portion of applicable regulations including 10 CFR Pt. 71 appeared to be met in full by the cask design as presented in this document. At the conclusion of this review, the one outstanding issue was the status of the amended design criteria document, which had not been submitted for review (see Sect. 7.4).

7.3.3 Review of TN-BRP Final SARP

The final SARP was received by ORNL September 6, 1985. The conclusions in SARP Sect. 8.6 are made on the basis of review of the document and supporting material. No comments to TN are required. The document was reviewed and found to be substantially equivalent to the revised draft SARP with pages revised to reflect TN response to ORNL's comments of June 19, 1985.

7.3.3.1 Issues Pending

No issues were pending following receipt and review of the revised design criteria document discussed below. The SARP for the TN-BRP transport/ storage cask appears to satisfy the requirements of the NRC regulations embodied in 10 CFR Pt. 71 and related Regulatory Guides.

7.4 REVIEW OF REVISED DESIGN CRITERIA

The revised design criteria document was received July 2, 1985. A review of this document was conducted, and it was concluded that the thermal criteria contained therein are consistent with those contained in the TN-BRP revised draft SARP. This conclusion is extended to the final SARP. Comments on the revised design criteria document were transmitted July 30, 1985.

7.5 INDEPENDENT ANALYSES

Thermal analyses performed by members of the ORNL review team on models corresponding to selected aspects of the TN-BRP thermal evaluation were undertaken to increase the confidence of the reviewers in the results and/or the methodology used by TN, to familiarize the reviewers with aspects of the design and/or the thermal behavior of the cask, and to evaluate the combined impact of TN's design assumptions. The thermal analyses discussed below were undertaken and documented.

Documentation of the independent analyses discussed below will be maintained by the thermal evaluation reviewers within the framework of the quality assurance activities of Engineering Analysis, Process Engineering Division, Martin Marietta Energy Systems.

7.5.1 Preliminary Cask Body Thermal Analyses

Preliminary cask thermal analyses with SCALE[9] were performed for both steady state and 30-min fire transient. Several simplifying assumptions were used, and the results indicated agreement with trends and approximate confirmation of values reported by TN. Selected ORNL results are compared to TN's evaluation in Fig. 7.

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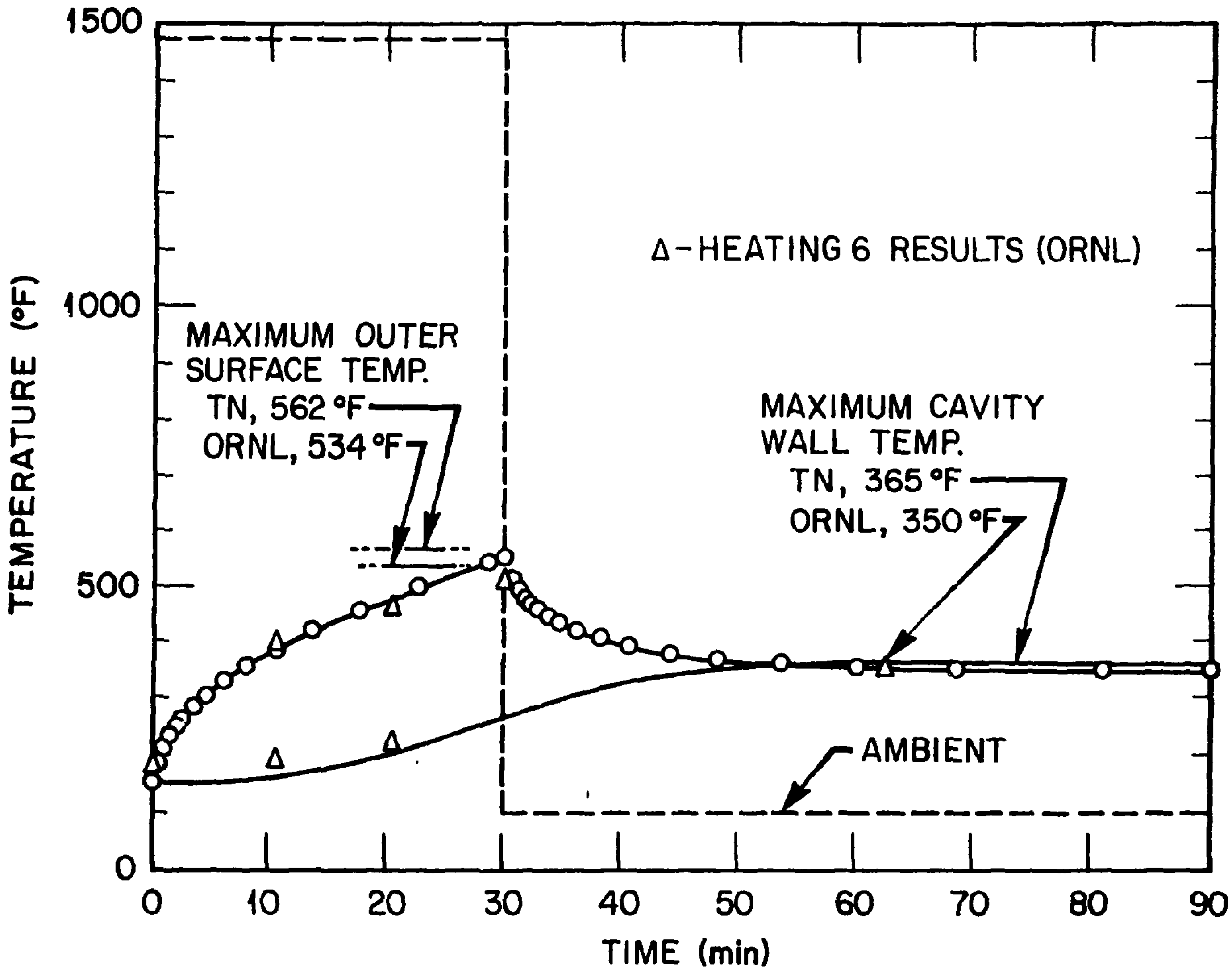

Fig. 7. Comparison of predicted time-temperature history during and following fire accident conditions for TN finite element model and ORNL finite difference model.

7.5.2 Cask Outer Surface Temperatures

Hand calculation of the cask surface temperature was performed using TN's predicted peak heat generation rate and conditions imposed by 10 CFR Pt. 71 regulations. Standard engineering practices were used. No significant discrepancies were noted between results of this analysis and TN's thermal evaluation.

7.5.3 Hand Calculation of Enclosure Effect

Hand calculation of the enclosure's effect on cask surface temperature was undertaken using several different models for the convection of air between the enclosure inner wall and cask outer wall. Results are not presented because the enclosure has been eliminated from the cask design.

7.5.4 Two-Dimensional Cask Body Thermal Analysis

Two-dimensional thermal analysis of the cask body with impact limiters was performed using the HEATING6 computer code. Axially distributed heat generation rate, detailed modeling of cask geometry, and materials properties independently checked were applied in a finite difference formulation. Good agreement with TN's results was obtained. Comparative temperature profiles are shown in Table 7.

7.6 SUMMARY

The thermal evaluation presented in the TN-BRP SARP has been found to meet the requirements of 10 CFR Pt. 71 regulations. Temperature predictions found in this document are judged to be reasonable estimates

Transnuclear Front: outside surface	CASK BODY	Transnuclear Front: inside surface	ORNL Front: outside surface	CASK BODY	ORNL Front: inside surface
171		171	172		172
171		172	172		174
171		172	174		176
172		173	175		178
173		175	176		179
174		176	177		180
175		177	178		181
176		178	178		182
177		179	179		183
177		180	179		183
178		180	180		184
178		181	180		184
179		182	181		184
179		182	181		185
180		183	181		185
181		184	181		185
181		184	182		185
181		184	182		185
181		184	182		184
181		184	181		184
181		184	181		184
181		184	181		183
181		184	181		183
181		184	180		182
179		182	180		181
179		181	179		181
179		181	179		180
178		180	179		180
178		179	179		180
178		179	179		180
178		179	179		181
178		179	179		181
179		180	179		182
179		181	179		182
180		182	180		183
180		183	180		184
181		184	181		185
182		185	181		186
183		186	183		188
184		187	184		189
185		188	185		190
185		188	186		190
186		189	186		191
187		190	187		191
187		190	187		191
187		191	188		191
188		191	188		191
188		192	188		191
188		192	188		192
189		192	189		192
	rear			rear	

Table 7. Comparison of predicted steady state cask body temperatures for the TN finite element model and the ORNL finite difference model.

of the values that may actually be experienced. The thermal performance of the TN-BRP transport/storage cask should meet the requirements of Federal regulations applicable to spent fuel shipment.

8. TN-BRP NONDESTRUCTIVE EXAMINATION REVIEW

Over the past year the subject SARP has been reviewed at both interim and final stages to ensure conformance with 10 CFR Pt. 71 in the area of nondestructive examination (NDE). Paragraph 71.85(a) of 10 CFR Pt. 71 requires that before use there be assurance of no flaws that could significantly reduce the effectiveness of the packaging. Paragraph 71.119 of 10 CFR Pt. 71 requires that special processes, including NDE, be "controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements." Paragraph 71.37(a) of 10 CFR Pt. 71 requires identification of any established codes and standards proposed for use. Additional details or recommendations on NDE are not defined in 10 CFR Pt. 71. Toward meeting these objectives, activities involved the review of interim stages of the SARP and related correspondence as well as participation in review meetings with TN personnel to ensure that the requirements were being met.

8.1 REVIEW OF TN DESIGN CRITERIA DOCUMENTS

The first review activities (February and March 1984) were on the TN initial design criteria document dated January 27, 1984, and the TN preliminary design document.[6] Both documents cited the ASME Boiler and Pressure Vessel Code, Section III, Article NC 2000 (Class 2 vessels) and the specification requirements of Section II for material requirements.

The cited ASME documents were reviewed relative to NDE requirements. This included the Section II material specifications referenced in the TN preliminary design document.

The referenced material specification for the forged shell, bottom, and lid of the casks were SA 508 or SA 350. Subsection NC 2540 for forgings and bars requires examination in accordance with the material specifications and provides guidance for magnetic particle and liquid penetrant examination when one of these is required by the rules of this subsection. SA 350 (steel forgings for piping components) identifies magnetic particle and liquid penetrant examination as supplementary requirements, applicable only when specified by the purchaser. SA 508 (steel forgings for pressure vessels) requires dimensional, visual, magnetic particle, and ultrasonic examinations.

The ultrasonic examination is to be performed by both longitudinal and angle beam techniques. (The additional examination details will not be discussed in this report.) For the approximately 9-in.-thick vessel, reliance on only a surface examination (magnetic particle or liquid penetrant) was deemed inadequate. A recommendation was made for use of volumetric ultrasonic examination.

For the trunnions and lid alignment pins, reference was made to SA 564 (steel bars and shapes), which has no requirements for NDE. This was not deemed appropriate for forgings up to 15-in. diam, and a recommendation was made that volumetric ultrasonic examination should also be used for this load-bearing member.

For the bolts for the impact limiter, lid, trunnion, and protective cover, reference was made to SA 320 (alloy steel bolting) or SA 193 (alloy steel and stainless steel bolting for high temperatures). Neither required NDE. This was considered inadequate, and recommendations were made for surface NDE such as magnetic particle or liquid penetrant examination.

Because of apparent inadequacies in the Code Class II requirements for this application, a review was made for comparison with NDE requirements for Class I. For forgings, NB 2540 (for Class I) requires ultrasonic examination. NB 2540 also requires all accessible surfaces of forgings to be examined by magnetic particle or liquid penetrant methods. The procedural requirements and acceptance standards for the surface examination are equivalent for Classes I and II. For bolting, NB 2581 (Class I) requires visual, magnetic particle or liquid penetrant, and ultrasonics for bolts more than 2 in. diam.

8.2 REVIEW OF FIRST DRAFT OF SARP

In May 1984, the first edition of the TN-BRP SARP[7] was reviewed relative to NDE requirements. Most of the cited requirements in the draft SARP were the same as noted above in the design criteria documents, and the review comments were repeated. In addition, as shown in Dwg. 3010-150-3 of the draft SARP, the shell is joined to the bottom with a butt weld. ASME Boiler and Pressure Vessel Code, Section III, Subsection NC 5211 specifies radiographic examination. (If the weld is quench and tempered, magnetic particle or penetrant examination is required after hydrostatic testing.) The minimum requirements of the Code do not require ultrasonic examination of the weld (although the current trend is for pressure vessel manufacturers to use ultrasonics to examine the welds). ORNL recommends ultrasonic examination of the butt weld of the cask to provide improved assurance of the weld quality and integrity. These comments were conveyed through appropriate channels to TN.

Subsequently in July 1984, by both telephone and letter communication, TN contacted ORNL stating that the Procurement Specification for the cask imposed the following NDE requirements:

1. The forgings for the shell, bottom, lid, and trunnions were to be examined in accordance with ASME specifications SA 654 (for steel bars and shapes) including the examinations for ASME Boiler and Pressure Vessel Code, Section III, Class I forgings. The ultrasonic examinations are specified in SA 388, which requires that all forgings be examined by the straight beam technique. The acceptance criteria specifies (for the straight beam examination) no indication equal to, or larger than that from a 1/4-in. diam flat-bottom hole. SA 388 also requires that all ring forgings and hollow forgings be examined using the angle beam technique with an acceptance criteria of no indication equal to, or larger than that from a calibration notch, 1/4 in. deep by 1 in. long.
2. The shell-to-bottom weld is to be examined by radiographic, ultrasonic, and magnetic particle or liquid penetrant methods in accordance with ASME Code, Section V (NDE) and Section III, Subsection NC 5000.

It was agreed that these requirements in the purchase specification met the intent of the ORNL comment related to NDE requirements.

8.3 REVIEW OF TN POSITION PAPER ON USE OF ASME CODE

Also submitted by TN in July 1984, was a position paper.[27] This paper discussed the use of the ASME Code [Section III, Subsection NC (with modifications)] for design, fabrication, and inspection of shipping casks as a supplement to (and method of implementation of) 10 CFR Pt. 71 and the U.S. NRC Regulatory Guide 7.6.[12] The modifications included invoking Class I (Subsection NB) requirements for NDE of forging and bolting materials and the addition of ultrasonic examination requirements for the welds. Because the cited 10 CFR Pt. 71 and Regulatory Guide 7.6 do not contain sufficiently detailed guidance to ensure adequate NDE for the casks, it seemed reasonable to adapt portions of the ASME Code to provide such guidance. Details of the upgrading to Class I NDE requirements for forgings, bolting, and welds were addressed above relative to the Procurement Specifications. The acceptance standards for ultrasonics, radiography, and magnetic particle or liquid penetrant methods were the same for Classes I and II. The requirement for ultrasonic examination of the weld exceeded the requirements for either Class I or II.

The position paper also documented the TN intent to require that the cask fabricator be an ASME-authorized supplier of components (N certificate holder) and to use a third-party Authorized Nuclear Inspector. Use of personnel with such experience should enhance the confidence in the work performed (if it is specified in the requirements and proper examination details are in the fabrication examination procedures). In September 1984, a letter was submitted noting that ultrasonic examination of welds is not required by Section III of the ASME Code; therefore, pre-existent ASME-approved procedures might not be anticipated. It was recognized that the ORNL responsibility was limited to design aspects of the casks, with fabrication and examination to be the responsibility of others. However, ORNL recommended that the responsible parties ensure that adequate examination procedures be implemented by having a review of the procedures and performance by persons with good technical knowledge in NDE technology.

8.4 REVIEW OF INTERIM DRAFTS OF SARP SECTIONS

During the priod from November 1984 to January 1985, ORNL reviewed interim revised drafts of sections of the SARP. In general, the NDE technical requirements (noted above) had been incorporated, but occasionally without reference to the governing documentation. In addition, Chap. 8 of the SARP required the application of liquid penetrant or magnetic particle examination of lid lifting lugs and trunnions after load tests. ORNL recommended that approved written procedures be referenced and used. These shortcomings were noted in correspondence and in a review meeting (February 1985)[8] with DOE, EG&G Idaho, TN, and ORNL personnel.

8.5 REVIEW OF FINAL DRAFT OF SARP AND CONCLUSIONS

In May 1985, revised sections of the SARP were reviewed for NDE content. In general, the requested modifications had been made. Recommendations were repeated for documentation references to surface examination techniques to be used after load tests on lifting, lugs, and trunnions. As noted earlier, ORNL has not reviewed the detailed NDE procedures and test results. However, if the NDE requirements cited in the SARP are properly implemented, that phase of the design and fabrication of the BRP cask should be adequate for the proposed one-time transportation of spent fuel and to meet the requirements for NDE imposed by 10 CFR Pt. 71 and Regulatory Guide 7.6.

9. TN-BRP STRUCTURAL REVIEW

9.1 OVERVIEW

An independent review of Chap. 2, "Structural Evaluation," of the TN-BRP SARP[1] and related materials was performed. The review activities began in 1984 and continued through 1985. The review consisted of receiving portions of the SARP, thoroughly reading the submitted material, comparing the reported results with the appropriate regulations or design criteria, performing independent calculations for checking purposes, submitting comments for consideration by TN, and consideration of the comments of others that had reviewed the same material. During the review activity, all comparisons with regulations were made by reference to 10 CFR Pt. 71,[3] U.S. NRC Regulatory Guides 7.6[17] and 7.8,[18] applicable sections of the ASME Boiler and Pressure Vessel Code, and ASTM Standards.

9.2 REVIEW FINDINGS

Chap. 2 of the SARP addresses the structural aspects of the cask in the major areas of containment, fuel support, lifting and restraint, and impact protection. Each of these areas will be addressed separately below. During the review process, significant design changes were made as a result of needs identified by TN and those identified by the review process. It was not possible due to time available to perform a detailed analysis of all portions of the cask. At the present time, the review of mechanical integrity is not a mature technology. The design of all portions of the cask is not covered by codes or standards. For the containment function exclusive of seals and bolting. U.S. NRC Regulatory Guides 7.6 and 7.8 serve as codes of acceptable performance, supplemented by the ASME Boiler and Pressure Vessel Code. There are no similar guidelines for the acceptability of lifting and restraint systems, and impact protection. The reviewers were prohibited from having direct contact with the NRC at the time of this review. The review process was thus based on judgements of personnel with experience in design of casks and submittal of SARPs but could not directly benefit by contact with the NRC.

9.3 CONTAINMENT VESSEL

TN has provided analytical demonstrations that the cask meets 10 CFR Pt. 71 and Regulatory Guides 7.6 and 7.8. This was accomplished by use of the computer program ANSYS[28] and a series of hand calculations. The following paragraphs provide a comparison between the TN-BRP SARP and ORNL reviewers' calculations.

The stresses in the cask ends were checked by simplified hand calculations. The stress in the cask bottom due to 150 psi internal pressure was found by the reviewers to be 1,508 psi vs. 1456 psi (SARP p. 2.A.1-43). Stress at 80 g axial impact and 45 psi and excluding the lower impact limiter was found by the reviewers to be 17,407 psi vs 28,700 psi (SARP p. 2.A.1-47). Stress in the lid was found by the reviewers to be 2,500 psi and 30,493 psi under 150 psi and 80 g impact, respectively, versus 2,355 psi and 18,599 psi as specified at cross section 1-1 on Table 2.A.1-16 (SARP p. 2.A.1-83).

Stresses induced in the cask walls by the trunnions were checked using Bijlaard's methods. Maximum membrane stress was found by the reviewers to be 2,044 psi and maximum membrane and bending was 17,025 psi vs. reported stresses of 1,959 psi and 18,842 psi respectively (SARP p. 2.A.1-90).

Stress in the cask walls due to 150 psi internal pressure was checked and found by the reviewers to be 433 psi (hoop), 217 psi (axial), and 367 psi (radial). Reported stresses were 584 psi (hoop), 217 psi (axial) and 150 psi (radial) (SARP p. 2.A.1-42). Stress due to 25 psi external pressure was found by the reviewers to be 123 psi and was negligible as specified at cross section 19 in the SARP (SARP p. 2.A.1-77). Stress during 30-ft impact was found by the reviewers to be 4,662 psi vs. 3,107 psi (SARP p. 2.A.1-45) and 8,874 psi vs. 7,905 psi (SARP p. 2.A.1-48).

9.4 FUEL SUPPORT

The fuel is supported by a basket constructed of a stainless steel alloyed with boron. TN has provided analytical models of the mechanical performance of the basket. The major requirement for the basket is to provide positioning of the fuel and the moderating constituent, boron. The analysis must demonstrate that the basket does not permit excessive motion and that the general topology is retained. While specific criteria for fuel motion or basket topology were not stated, the ORNL structural reviewers and the ORNL criticality reviewers discussed the adequacy of TNs design at length and agreed that the limited basket distortion was acceptable (see Sect. 4.2, p. 13 of this report).

A check was made on the capacities of the basket plate assemblies under various g loadings. Simplifying assumptions were made and the results of calculations compared to the finite element analysis results in the SARP. The maximum plate load under 5 g conditions was 3,668 lbs vs. SARP values of 4,250 lbs (SARP p. 2.A.2-75). The maximum load under 120 g conditions was 87,976 lbs vs. an adjusted value at 120 g of 91,680 lbs (SARP Sect. 2.A.2-91 for 100 g). Using a 31,000 psi yield stress allowable, the maximum g-load capacity was found to be 95 g which exceeds the maximum transverse acceleration of 80 g.

Individual plates under support conditions of one-end fixed and one-end simply supported were checked for maximum buckling stress considering a full 7.12 in. length. A critical buckling stress of 28,273 psi was found. When this stress is applied (no spread or lateral restraint) to the minimum bearing area, the maximum acceleration capacity of 86.8 g which exceeds the maximum expected transverse acceleration of 80 g.

The function of the basket assembly is to maintain separation of the fuel elements. Some localized plastic deformation is acceptable. A check was made of maximum deformation under 120 g-load conditions. The maximum deflection under elastic conditions was .058 in. Local stress levels are above the ultimate bending capacity of the plate but below the ultimate shear capacities. This indicates inelastic deformations greater than the calculated elastic deformations would be expected at the conservative 120 g-loading level. This may be compared to the maximum finite element SARP results of .063 in. on an interior plate (SARP p. 2.A.2-90) and .107 in. on an exterior plate. A nominal gap of

.14 in. exists initially between the fuel element and adjacent plates. Under conditions of 100 g acceleration in two simultaneous directions, adjacent deformed plates would not touch a fuel element. It is therefore felt that the existing egg crate plate design is adequate.

9.5 LIFTING AND RESTRAINT

The lifting and restraint functions are provided by four trunnions that are bolted to the cask body. TN has provided a series of hand calculations for the design of the trunnions and bolts. A similar series of calculations were made by ORNL.

Transportation stresses in the trunnions were checked under the same conditions in the SARP. Assuming loads are ultimately resisted only by the preloaded bolts, assuming no credit for friction, shear stress was found by the reviewers to be 54,926 psi and maximum tension stress was 51,975 psi vs. 28,900 psi and 78,300 psi (SARP p. 2.A.3-19) respectively.

The stress intensity was found to be 116.15 ksi and the allowable intensity, utilizing actual material values, was found to be 121.63 ksi at 200°F (SARP p. 2.A.1-68). The reported stress intensity value was 97.4 ksi (SARP p. 2.A.3-19). Trunnion stresses were checked and found very close to the reported values.

9.6 IMPACT PROTECTION

The cask is protected from impact by a composite structure of balsa and redwood encased in carbon steel and with removable aluminum spacers. The design of this structure was performed by TN utilizing a proprietary computer program, ADOC. The SARP provides an overview of the procedures incorporated into this program and the resulting performance of the limiter in terms of force, deflection, and time over a range of drop angles and material properties. In addition, the predictions of ADOC are compared with simplified analytical models and scale model tests. The reviewers have compared the prediction of ADOC with the simplified models and experiments and with a similar program developed in the course of the review. The results of ADOC and the material properties used were found to be conservative and appropriate for design.

9.7 CONCLUSIONS ON STRUCTURAL REVIEW

The structural evaluation section of the SARP was the most modified and last received portion of the SARP. Only limited portions of this chapter of the SARP are addressed by codes and standards or by a mature design procedure. As such, judgement was called for on the part of the reviewer in terms of weighing the analysis provided against the performance basis of 10 CFR Pt. 71. After considerable review and discussion internal to ORNL and in conjunction with TN, an understanding was developed for all relevant aspects of the SARP. In some cases, such as the direct use of the ASME Code in place of the Regulatory Guides 7.6 and 7.8, the reviewer ignored what was considered to be irrelevant material. In the trunnion analysis, the use of friction and details of the bending load induced tension were judged to be unacceptable and an alternative analysis was performed which provided the reviewers with confidence in the design. The above are stated only to indicate that the SARP as a document is not developed to an expected final state. It does, however, provide sufficient evidence that a review can be conducted leading to an affirmative conclusion on the adequacy of the cask in terms of the ability to satisfy all appropriate regulatory requirements.

10. TN-BRP CONTAINMENT REVIEW

10.1 OVERVIEW

An independent review of SARP Chap. 4, "Containment," and the sections and appendices related to the lid closure seals and bolts from SARP Chap. 2, "Structural Evaluation," has been performed. The review activities began in 1984 and continued through 1985. The review consisted of receiving portions of the SARP, thoroughly reading the submitted material, comparing with appropriate regulations or criteria, performing independent calculations for checking purposes, submitting comments for consideration by TN, and consideration of the comments of others that had reviewed the same material. During the review activity, all comparisons with regulations were made by reference to 10 CFR Pt. 71, ANSI N14.5,[29] and U.S. NRC Regulatory Guide 7.4.[30] The design criteria from the SARP is contained in Chap. 4, Sects. 4.2 and 4.3.

10.2 REVIEW FINDINGS

The SARP provides analytical and empirical evidence that the contents of the cask will be adequately contained under all prescribed conditions. This evidence is provided in terms of a demonstration of the mechanical integrity of the seals, bolting and closure flanges, provision of suppliers performance specifications for the seals, determination of permissible leak rates, and demonstration that the permissible leak rates are greater than the expected leak rate.

As with the "Structural Evaluation," chapter of the SARP, the methodology for demonstration of adequacy of containment by analysis is not a mature technology. TN chose to design the containment system by reference to procedures of the ASME Boiler and Pressure Vessel Code. While these procedures are well recognized as adequate in many circumstances, their applicability for use in cask design has not been generally accepted. The approach taken by the review required a detailed examination of the stress analysis of the containment system. This design changed significantly over the review period. Because of the time available and the changes being made, a completely independent analysis of the mechanical integrity of the containment system was not possible. Instead, a series of confirming hand calculations were made. These calculations addressed the loading condition, load paths, and material capability. The review was focused on the question of general agreement between TN and ORNL calculations and determination that the state of stress in the bolts and flanges was below yield. It was found that general agreement was obtained. The stress condition in the bolts reported by TN was above yield for a small portion of some bolts. This is due to lateral loading of the lid causing a bending distortion in some of the bolts. Since the closure integrity is based on the elastomeric seal, the small amount of yielding is not expected to cause a loss of containment.

The SARP indicates that the main closure will be subjected to a 45 psig internal pressure and 80 g axial impact under accident conditions. For these conditions, the maximum load per bolt was calculated to be 3,016 lb/bolts and 121,666 lb/bolt versus 3,450 lb/bolt and 131,303 lb/bolt (per SARP pp. 2.A.6-126 and 2.A.1-152C.) This loading would result in a momentary seal loss on the metal Helicoflex seal but containment would be preserved by the Viton O-ring. Under normal conditions no loss of seal integrity was calculated.

10.3 CONCLUSIONS ON CONTAINMENT REVIEW

The closure system of the cask has been adequately shown to meet the prescribed design criteria and regulatory requirements in the judgement of the reviewers.

11. TN-BRP MATERIALS REVIEW

The review of materials section for the TN-BRP SARP[1] has focused on the requirements of 10 CFR Pt. 71[3] related to prevention against brittle fracture. That document requires casks to withstand accident conditions that may occur at an initial temperature of −20°F. At that temperature, many steels are subject to brittle fracture, and susceptibility of the steel is dependent on many factors. One goal of this review was to establish a procedure which would minimize the potential for brittle fracture of the cask. Since the fracture toughness of ferritic steels is dependent on operating temperature, the procedure should necessarily define temperature conditions within which the cask body can be transported. One published document addressing material toughness criteria for ferritic steel shipping casks is NUREG/CR-1815[31], which was prepared for the Transportation Certification Branch, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission (NRC). The NRC has, in fact, published a draft U.S. NRC Regulatory Guide based on that report. However, the information was developed for containers 4 in. thick or less. To the best of ORNL's knowledge, the provisions of that report have not been adopted by the NRC. A subsequent report applicable to containers greater than 4 in.-thickness, NUREG/CR-3826[32], was published in July 1984.

The posture recommended for this application (a one-time shipment considering transportation only) was operation of the casks at a temperature at or above that at which the material attains 100% ductile fracture as measured by standard Charpy V-notch testing. The dynamic fracture toughness versus temperature relationship given in NUREG/CR-3826 indicates, for 9-1/2 in. thickness, that the lower temperature limit for fully plastic behavior would be approximately NDT + 120°F. That is probably quite realistic as an approximation of the temperature at which many structural steels exhibit the onset of fully ductile behavior (100% shear) in a Charpy V-notch impact test. In fact, out of four common structural steels tested at ORNL (A508 Class 1 forging, A537 Classes 1 and 2 plates), the onset of 100% shear occurred at about T + 120°F for the forging and one plate, T + 90°F for another plate, and T + 160°F for the third plate. Thus, it is important to recognize that substantial differences occur even among steels of similar chemical composition. It is important that the Charpy V-notch absorbed energy be sufficiently high to demonstrate high resistance to fracture even on the upper shelf. By tightening the ASTM specification on elements such as sulfur and phosphorus, for example, one can obtain substantial improvements in material toughness in terms of transition temperature and upper-shelf energy levels.

The same comments apply to the weld metal and heat-affected zones of the weldments. Thus, the minimal testing required is drop-weight NDT of the base metal and weld metal; Charpy V-notch impact testing of the base metal, weld metal, and heat-affected zones; tensile testing of weld metal and base metal; and hardness testing of all three components. The toughness tests should be performed over a temperature range and at intervals to allow for construction of the full Charpy V-notch curve of brittle to fully ductile behavior. The results should include total absorbed energy, mils lateral expansion, and percent shear. This kind of information will allow for a minimal assessment of the material's resistance to brittle fracture as well as determination of the lowest temperature at which fully ductile behavior in a Charpy impact test is achieved. A recommendation regarding limiting temperatures for transport can then be defined.

TN originally proposed to use the criteria for a minimum operating temperature outlined in Appendix R, Subsection NC, Sect. III, of the ASME Boiler and Pressure Vessel Code. These criteria provide a graphical procedure for determining the permissible LSMT. The LSMT increases with the thickness of the component so that a 9-in. thickness requires a LSMT of about NDT + 75°F (NDT is the nil-ductility temperature determined from the ASTM drop-weight test). The Appendix R procedure and Subsection NC requirements, however, are not necessarily designed to give a LSMT in the Charpy V-notch upper-shelf temperature regime. The temperature at which upper-shelf (meaning fully ductile) behavior is achieved is dependent on the specific material and, as mentioned earlier, can vary from heat to heat, depending on thickness, chemistry, heat treatment, etc. Additionally, the requirements of Subsection NC were not, to ORNL's knowledge, intended to apply to the kinds of service loadings that might be experienced by a shipping cask.

As stated earlier, the basic tenet of the ORNL toughness criteria is operation of the cask structural parts at or above the onset of the Charpy V-notch impact upper-shelf temperature. That is, the temperature at which, or above, the Charpy specimens exhibit 100% shear fracture, or fully ductile fracture. Specifying the temperature at which 100% shear fracture is attained is equal to specifying no brittle fracture. A TN response stated acceptance of the criterion in principle and offered specific guidelines to determine that temperature. The ORNL reviewers agreed with most of the TN statements outlined in the response; however, they disagreed with the specific aspect of the allowance of less than 100% shear fracture.

The procedure proposed and accepted by TN for determination of the LSMT is as follows:

The specimen orientation should have the longitudinal axis in the transverse direction (transverse to the major working directions) and, further, the crack should propagate in the longitudinal direction (parallel to the major working direction). The test specimens should be removed at a depth in the component not closer to the surface than 1/4 of the thickness. For the weldment tests, specimens should be oriented transverse to the direction of welding with crack propagation in the direction of welding. Locations of heat-affected zone specimens should follow the same requirements as those for base materials, and those of weld metal should not be located closer than 1/2 in. of the surface.

It is precisely because of material variability that ORNL proposed the requirement that at least three specimens tested at the same temperature exhibit no evidence of brittle fracture (i.e., 100% shear). The requirements for determination of the LSMT are as follows:

1. Three specimens shall be tested at a temperature predicted to result in 100% shear fracture.
2. If all three specimens exhibit 100% shear, that temperature qualifies as the LSMT; if not, two of the specimens must exhibit 100% shear, while the third must exhibit at least 95% shear to qualify for retest at the same temperature.

3. If retest requirements are met, two additional specimens may be tested at the same temperature; both shall exhibit 100% shear to qualify that temperature as the LSMT.
4. If the retests do not qualify, a higher temperature shall be selected, and the above procedure repeated until successful qualification.

Additionally, ORNL agreed that the final LSMT would be that determined by either the Subsection NC procedure or that determined by the above Charpy V-notch testing procedure, whichever provides the highest temperature.

All tests shall be conducted with material in the final heat-treated condition to include postweld heat treatments.

The above procedure is more restrictive than that suggested in the TN letter. However, in the absence of more sophisticated, quantitative fracture mechanics analyses and testing, a conservative procedure should be required to minimize the potential for brittle fracture. The fact that the more severe constraints of the thick-section cask can result in an increased potential for brittle fracture serves as the motivation for such conservatism.

Regarding the acceptance criteria for Charpy energy, 75 ft-lb was suggested as the minimum Charpy V-notch impact upper-shelf energy for the material comprising the shipping cask body and heads. For purposes of this situation, the upper-shelf energy shall be determined at the lowest LSMT. The establishment of a minimum Charpy V-notch energy as the basis for prevention of brittle fracture is certainly not new, but it is somewhat arbitrary because the Charpy V-notch impact test is essentially a qualitative measure of toughness. There are various correlations between

Charpy V-notch energy and fracture toughness for materials of various strength levels, but they are approximations with large degrees of uncertainty, which is a driving force in employing conservatisms.

Nonetheless, in the absence of quantitative fracture toughness information for the materials of interest, correlations for this application were used. A material static yield strength of 50 ksi was assumed, which, using a method developed by George Irwin,[33] translates to a dynamic yield strength of about 77.5 ksi. It was assumed that the NDE procedures would allow for the capability detect planar defects 0.25 in. deep and larger. As a measure of conservatism, this value was doubled to establish a minimum critical flaw size of 0.50 in. The flaw size chosen is similar to that contained in Section XI of the ASME Code. A simple calculation for a semi-infinite plate with the above critical flaw depth assuming dynamic yield level stresses results in a stress intensity of about 100 ksi $(in.)^{1/2}$. Then, using the Barsom-Rolfe correlation:[34]

$$K_{Id}^2 = A * E * CVN ,$$

where

K_{Id} = dynamic fracture toughness, psi $(in.)^{1/2}$,

CVN = Chapry V-notch impact energy, ft-lb,

A = constant of proportionality, A = 4 and A = 5 bound data used for correlation,

E = Young's modulus, $\sim 30 \times 10^6$ psi.

CVN energy values of 67 ft-lb (A = 5) and 83 ft-lb (A = 4) are obtained. The value midway between those correlation results was selected as 75 ft-lb.

The required minimum K_{Id} value of 100 ksi $(in.)^{1/2}$ is very close to that which would result from a calculation using a procedure similar to that described in NUREG/CF-3826. For a 9.62-in.-thick container, they recommend a K_{Id}/σ_{yd} ratio of about 1.3 for the most conservative flaw aspect ration. For σ_{yd} of 77.5 ksi, that ratio would yield a K_{Id} of 100.75 ksi $(in.)^{1/2}$. Thus, the two methods of calculation yield similar results.

The data package supplied by Kobe Steel for the TN-BRP cask demonstrated compliance with the above requirements. For the various portions of the BRP cask, the highest temperature at attainment of 100% ductile fracture is $-40^{\circ}F$. Using the ASME Code, Subsection NC, criteria, the LSMT would be $-54^{\circ}F$. Therefore, the established LSMT of $-40^{\circ}F$ is appropriate. Additionally, the Charpy upper-shelf energies are all above 150 ft-lb, far in excess of the required 75 ft-lb.

It is the opinion of the ORNL reviewers that the materials selected and tested for the TN-BRP cask meet the requirements of 10 CFR Pt. 71.

12. TN-REG PACKAGE DESCRIPTION

The following is a brief overview of the TN-REG package description.

TN-REG package is composed of a cylindrical vessel fabricated from a forged carbon steel cylinder with an internal diam of 71.75 in. and a wall thickness of 9.25 in. with an integrally-welded forged carbon steel bottom having a thickness of 8.25 in. The overall length of the basic vessel is 174.50 in. The cask body is sealed with a disk shaped forged steel lid. This lid is 82.25 in. diam with a bolting flange at its outer edge. The maximum thickness of the lid is 8.50 in. reducing to 4.25 in. at the bolting flange. The lid is attached to the cask body by 48 1-5/8 in. diam bolts. The lid sealing is accomplished by one metallic and one Viton O-ring.

The major design features for the TN-REG are similar to the TN-BRP (see Sect. 3). The fuel is shipped dry in an inert gas (nitrogen) atmosphere. Heat dissipation from the cask is via convection and radiation with no forced cooling or cooling fins. The design pressure for the cask body is 150 psig at a temperature of 200°F. The cask body surfaces are metal spray coated with the exception of the sealing surfaces which are stainless steel clad by weld overlay.

The cask body contains three penetrations for research data collection. Two of these penetrations are for gas sampling and one is for pressure and temperature instrumentation. During transport these penetrations will be sealed via a bolted closure and double Viton O-ring. The cask lid contains two penetrations. One penetration is a vent port and the second is an access port which is used in pressurizing the cavity with inert gas during storage or for introducing cooling water prior to returning the cask to a fuel pool for fuel transfer. These penetrations are also protected by stainless steel bolted covers with a single Viton O-ring in conjunction with a metallic O-ring.

The cask shell is machined for the attachment of four lifting trunnions for cask handling. One pair of trunnions is located near the lid and is used for vertical handling. The second pair is located near the cask bottom and is used for rotation of the cask during handling. The trunnions are machined from stainless steel and are attached with 14 1-1/2 in. diam socket head bolts. The trunnions are separated by 106 in.

The TN-REG contains an interlocking borated stainless steel fuel basket to accommodate 40 PWR fuel assemblies from the R. E. Ginna plant. Front and rear impact limiters are provided for the package. These impact limiters are composed of balsa wood and redwood encased in a carbon steel container. The outside diameter of the limiters is 131 in. with an end thickness of 26 in. and a side thickness of 20 in.

Additional details on the TN-REG cask described may be obtained by reference to the TN-REG SARP.[2]

13. TN-REG CRITICALITY SAFETY REVIEW

13.1 SUMMARY OF REVIEW PROCESS

The review process for the criticality, shielding, and decay heat analyses for the TN-REG is equivalent to that described for the TN-BRP. The reader is referred to Sect. 4.1 for a more detailed overview of this process.

As with the TN-BRP, the review was expedited by maintenance of a close design/review relationship during the preparation of the TN-REG SARP. In April 1984, TN submitted the preliminary design and supporting information for the TN-REG cask.[35] Comments on the nuclear and thermal aspects of the preliminary design were compiled and forwarded through the Task Manager in May 1984. Following this exchange, TN began submitting draft portions of the SARP for review and comment.[36,37,38] In April 1985, the first complete SARP was submitted to ORNL followed by a comment meeting and a revised SARP submittal in August 1985. The final TN-REG SARP[2] was issued by TN in October 1985 and is the reference for the findings and conclusions described herein.

The review process included a combination of reviewing/evaluating submitted material, evaluating assumptions and procedures, and performing verifying calculations. The content of the SARP was specifically reviewed to ensure the cask met the requirements of 10 CFR Pt. 71. All analyses performed in support of the criticality, shielding, and decay heat sections were done using various modules of the SCALE computational system.[9]

13.2 REVIEW OF SARP CONTENT

The TN-REG cask was designed to hold 40 Westinghouse 14 x 14 PWR fuel assemblies. The fuel assembly characteristics required for criticality safety review or analysis are provided in Figs. 1.3 and 6.3 and Tables 6.1 and 6.2 of the SARP. The identification numbers for the assemblies are shown in Table 5.1 of the SARP. This information was obtained from the operators of the R. E. Ginna reactor (Rochester Gas and Electric) and the fuel fabricator (Westinghouse). The criticality safety review was performed based on the supplied fuel assembly descriptions.

The review of Chap. 6 of the SARP indicates that TN generated an acceptable set of calculational benchmarks for their codes and subsequently used these calculational tools in a proper manner to ensure a conservative k-eff value was obtained per the requirements of 10 CFR Pt. 71. Specifically, TN (1) searched for and found that the optimum water moderation occurred at or near full density (Table 6.4 of SARP), (2) appropriately considered the absence of burnable poison (BP) rods in certain assemblies (see Table 6.1 of the SARP), (3) took credit for the presence of available BP rods, but not for any neutron poison that they might contain, (4) appropriately considered slight movements of the flux trap walls, (5) assumed an infinite length of active fuel, (6) assumed an infinite array of the casks, and (7) assumed initial fuel enrichments with no credit for burnable poisons or fuel depletion. The computer codes used by TN for cross-section processing (NITAWL) and evaluation of the effective multiplication factor (KENO IV) are widely recognized as acceptable tools for this type of analysis. The 27-group cross-section set, based on

ENDF/B-IV, also represents a validated data library for criticality analysis. These codes and the cross-section set are all part of the SCALE package[9] developed by NEAD review staff.

With the assumptions and codes specified above, TN obtained a value of 0.931 $\pm$ 0.004 for the effective multiplication factor (k-eff). This value [illegible] acceptable upper limit typically used in criticality safety assessment of transport casks, i.e., k-eff + $2\sigma \leq 0.95$. Although the k-eff value reported by TN appears reasonable and is verified by confirmatory analysis (see Sect. 13.3 of this report), the KENO-IV input provided in Appendix 6.A.1 of the SARP does not appear to be the one used to obtain the report value. The primary reasons for this conclusion are that the input contains comment cards with the wrong problem description and also indicates only 18,000 histories were run, the same number which provided a σ of 0.006 in the last draft SARP calculation.[39] <u>The correct KENO IV input and output should be placed in the SARP prior to approval by DOE.</u>

The criticality model was changed in going from the last draft SARP to the final SARP because in attempting to verify the fuel assemblies in the West Valley pool, West Valley Nuclear Services (WVNS) discovered an additional assembly with no BP rods present. Thus, Table 6.1 and the calculational model of the SARP were altered in the final SARP to indicate eight assemblies with only eight BP rods and two assemblies (I.D. C17 and C40) with no BP rods present. This verification project was performed by WVNS and the findings were reported verbally to C. V. Parks of the ORNL review team by J. A. Eggert of WVNS. DOE should seek written confirmation of the verification process and findings from WVNS prior to approving the SARP or cask loading scheme shown in Fig. 7-4 of the SARP. The loading pattern in this figure is acceptable from both criticality and shielding considerations. However, again DOE needs to ensure that administrative procedures are in place at WVNS to load the cask in accordance with the specified loading pattern.

The calculated k-eff value shown above did not consider any deformation or movements of the basket. However, consultation with the ORNL structural reviewer confirmed the SARP contention that any deformation or movements of the basket during normal or accident conditions do not compromise the integrity of the basket or its ability to keep fuel assemblies within their respective compartments. The opinion of the criticality reviewers is that the minor deformations or movements of the basket indicated by Chap. 2 of the SARP are not significant and would not alter the k-eff value beyond the 2 uncertainty limit. TN also included a section in the SARP (Sect. 6.4.2.2) to address the potential decrease in the flux trap width during an accident due to local bending of the basket plates. Since the bending provides only a slight decrease in the flux trap width, TN chose to vary the water density in the flux trap (to 0.9 g/cm^3) rather than the actual plate width. The reviewer judged this to be an acceptable scheme for evaluating small changes in the flux trap width. Although the actual numbers are not presented, TN claims k-eff shows "virtually no change" from the normal condition calculation.

In conjunction with the SARP review, a review of the TN report E-6781 concerning boron verification in the basket was also completed. This report does a good job of summarizing the efforts to ensure the boron content in the basket and was satisfactory to the NEAD review staff. However, a review by persons familiar with the chemical testing procedures and by QA/AC personnel is recommended. One shortfall of the final SARP is that this report is not referenced in the SARP section on boron verification (SARP Sect. 8.1.11) nor are the methods and procedures of the report included in the SARP. It is recommended that the report or a reference to it be added to the SARP.

13.3 CALCULATIONAL VERIFICATION

As with the TN-BRP review, a detailed review and check of the submitted KENO IV input would be a tedious, time-consuming, and perhaps error-prone project. However, since assurance of subcritical conditions is imperative, it was decided to develop an independent model of the cask and fuel contents and perform analyses at ORNL to verify criticality safety of the cask. Analyses were performed both for transport and loading conditions. Loading conditions were considered because the analyses were also used to support the criticality safety report written at the West Valley site for the DOE Safety Officer.

The NEAD review staff performed the calculations using the CSAS25 analysis sequence within the SCALE computational system.[9] The CSAS25 sequence uses BONAMI-S and NITAWL-S for cross-section processing and resonance self-shielding and subsequently accesses KENO V.a for the criticality analysis.

The model developed for the analyses includes a pin-by-pin description of each assembly in the cask. Guide tubes, burnable poison (BP) rods, and instrument tubes are modeled explicitly. The entire cask (not just a quadrant) was modeled and loaded with the 40 REG assemblies. Axially, only the fuel region of an assembly was modeled, and the active fuel length of

144 in. was assumed for the total assembly height. The borated steel basket was modeled with the same height as the assemblies. The SCALE 27-group cross-section library was used for all calculations.

The basket loading configurations used for the confirmatory criticality analyses are shown in Figs. 8 - 12. The loading configuration of Fig. 8 is that prescribed in Chap. 7 of the August SARP submittal[39] which had only one assembly without a BP cluster, while Fig. 10 shows the loading configuration assumed by NEAD review staff after being informed by WVNS that two (instead of one) assemblies had no BP rod cluster. C rvative case loadings relative to Figs. 8 and 10 are shown in Figs. 9 and 11, respectively. Only after the final SARP submittal was the actual ading configuration used by TN available for calculation. This loading attern is slightly different from that assumed in Fig. 10 and is shown in Fig. 12. Although Figs. 11 and 12, respectively, provide the correct conservative case and intended loading of the cask, results corresponding to Figs. 8-10 are also provided because they show reactivity effects that apply to, but were not later demonstrated for, the final configurations of Figs. 11-12.

The first calculational set models an infinite square array (void between casks) of closed, water-filled casks per the conditions of 10 CFR Pt. 71. The results presented in Table 8 indicate that (1) the k-eff values show little sensitivity to the boron content in the basket between 1.5 wt % and 1.7 wt %, (2) full density water provides the optimum moderating conditions, and (3) removal of all BP clusters (case REG4) or assuming the conservative case loading scenario (case REG2P, Fig. 11

ORNL-DWG 86-11266

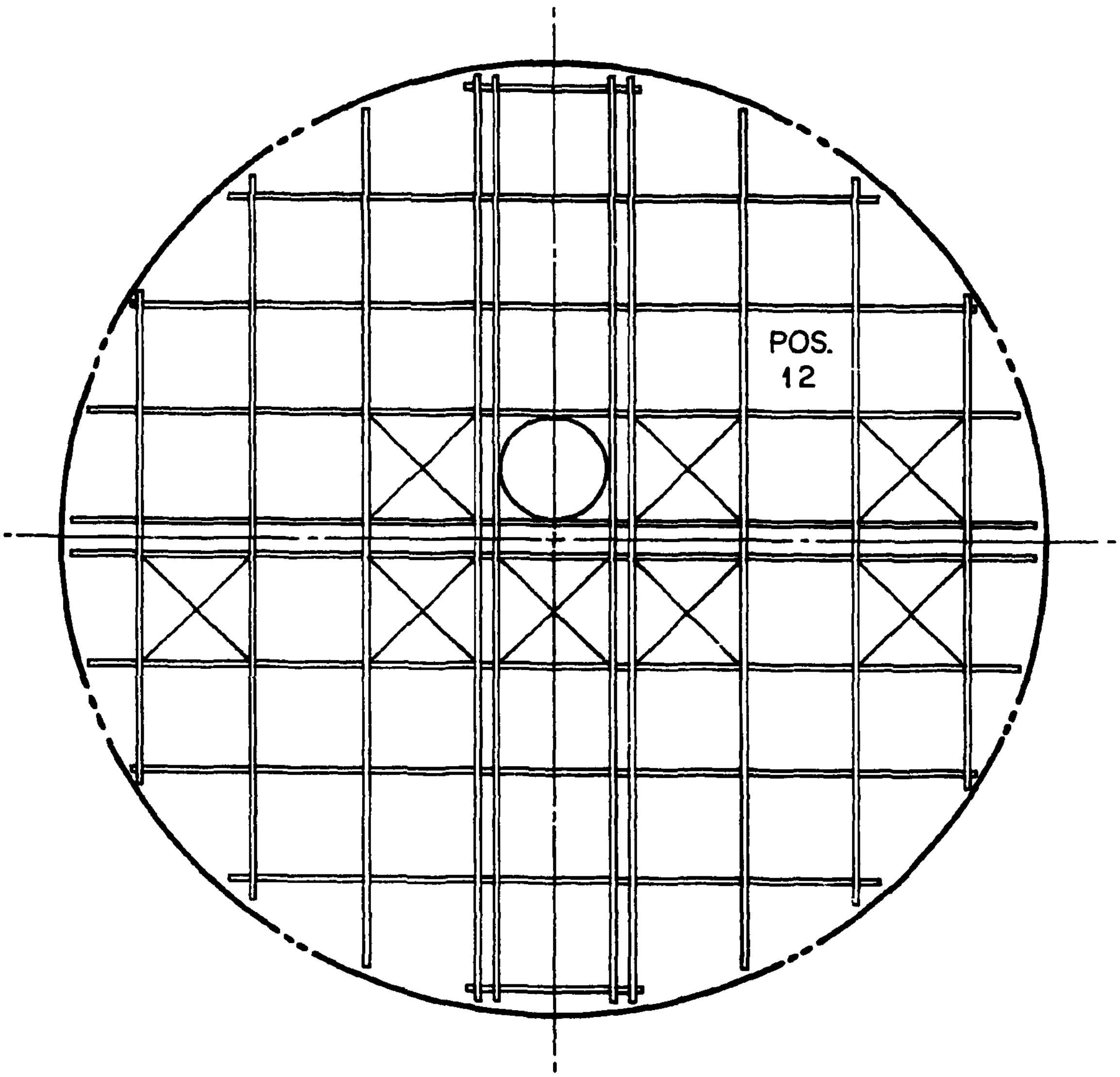

Fig. 8. TN-REG Fuel Basket Loading Configuration for August 1985 draft SARP. O indicates position of assembly with no BP rods. X indicates position of assembly with only 8 BP rods. All other basket compartments contain assemblies with full BP rod cluster.

ORNL-DWG 86-11265

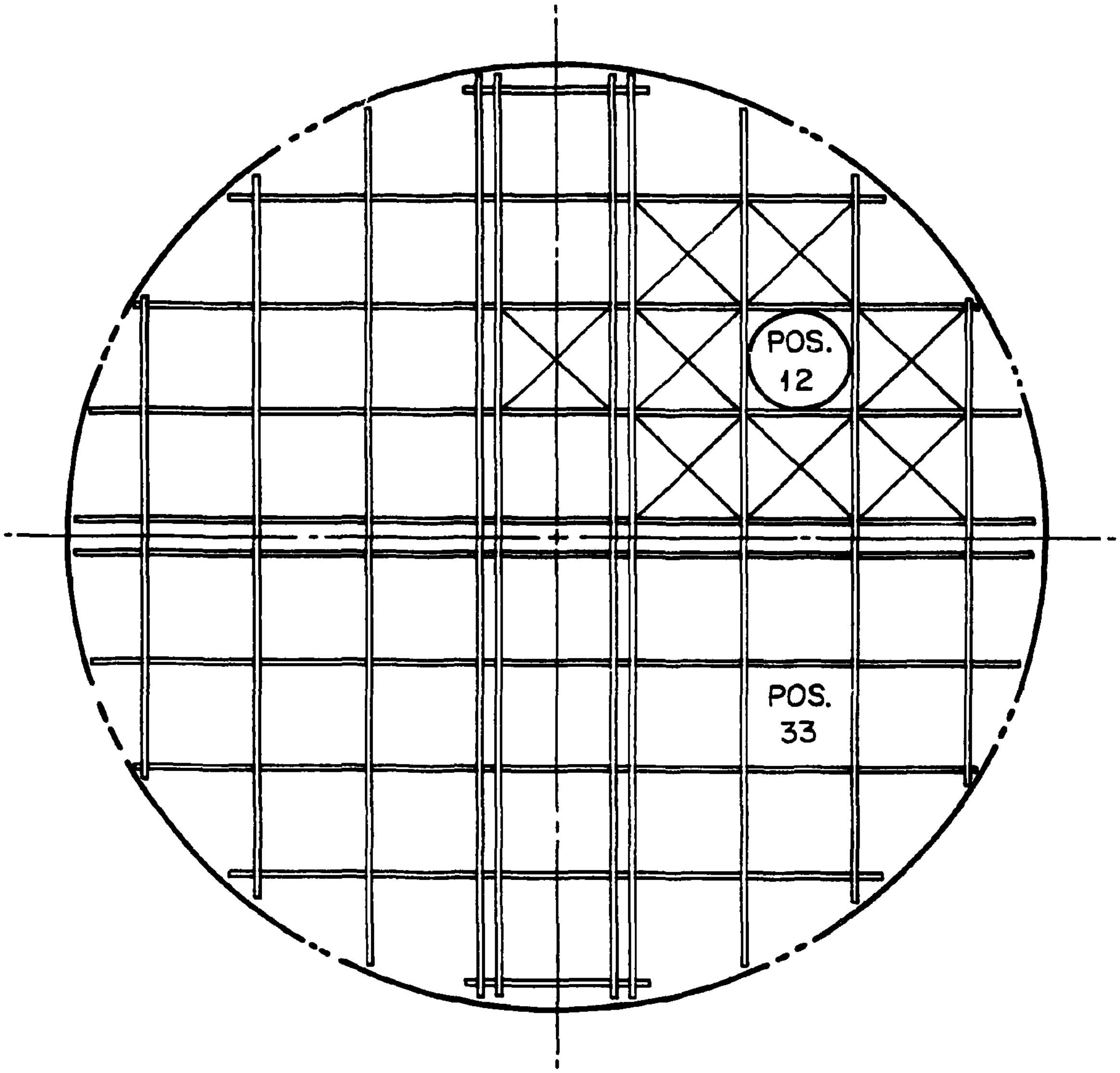

Fig. 9. TN-REG Worst Case Fuel Basket Loading Configuration for one assembly with no BP rods. O indicates position of assembly with no BP rods. X indicates position of assembly with only 8 BP rods. All other basket compartments contain assemblies with full BP rod cluster.

ORNL-DWG 86-11262

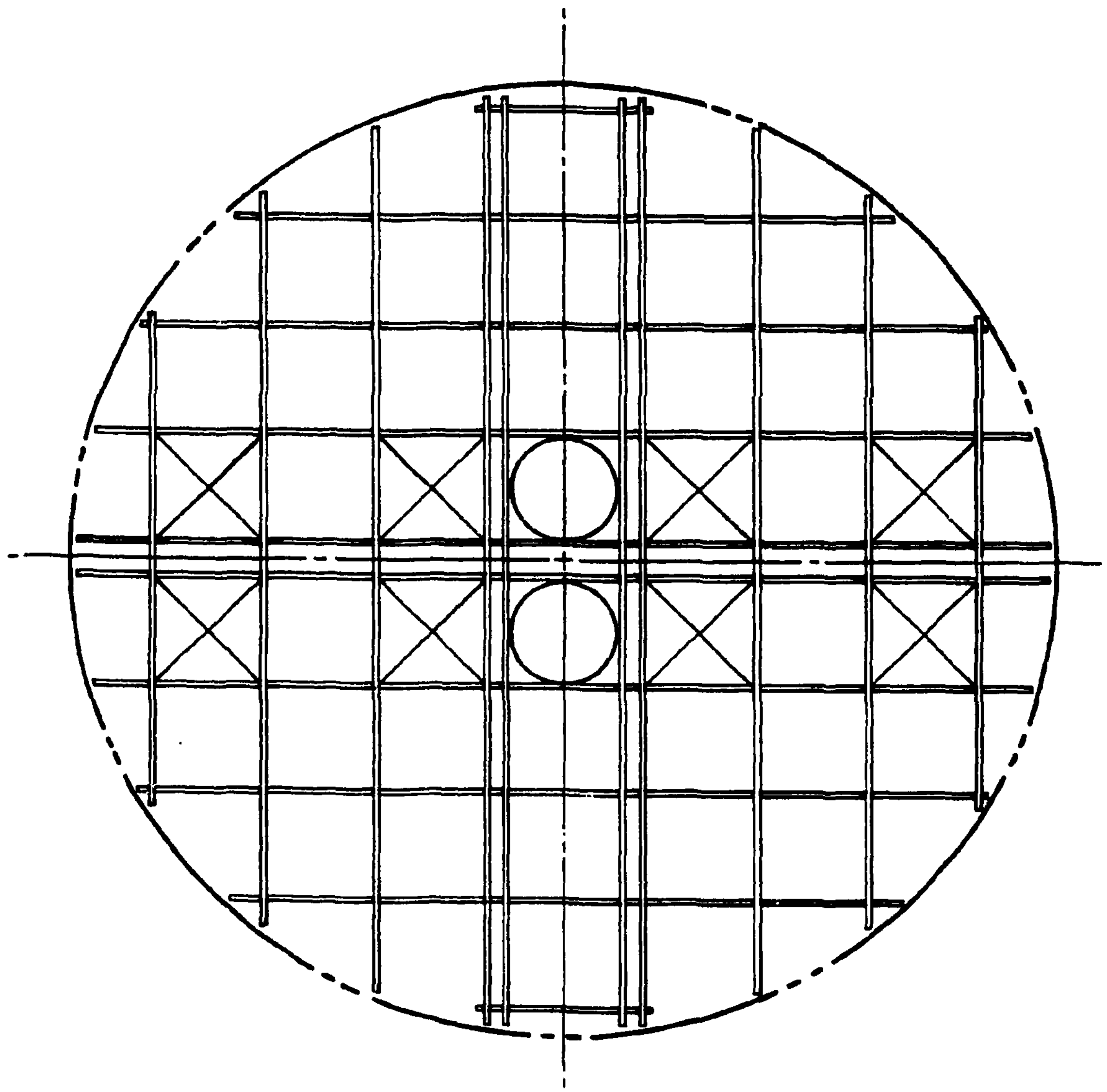

Fig. 10. ORNL Assumed TN-REG Fuel Basket Loading Configuration for two assemblies with no BP rods. O indicates position of assembly with no BP rods. X indicates position of assembly with only 8 BP rods. All other basket compartments contain assemblies with full BP rod cluster.

ORNL-DWG 86-11264

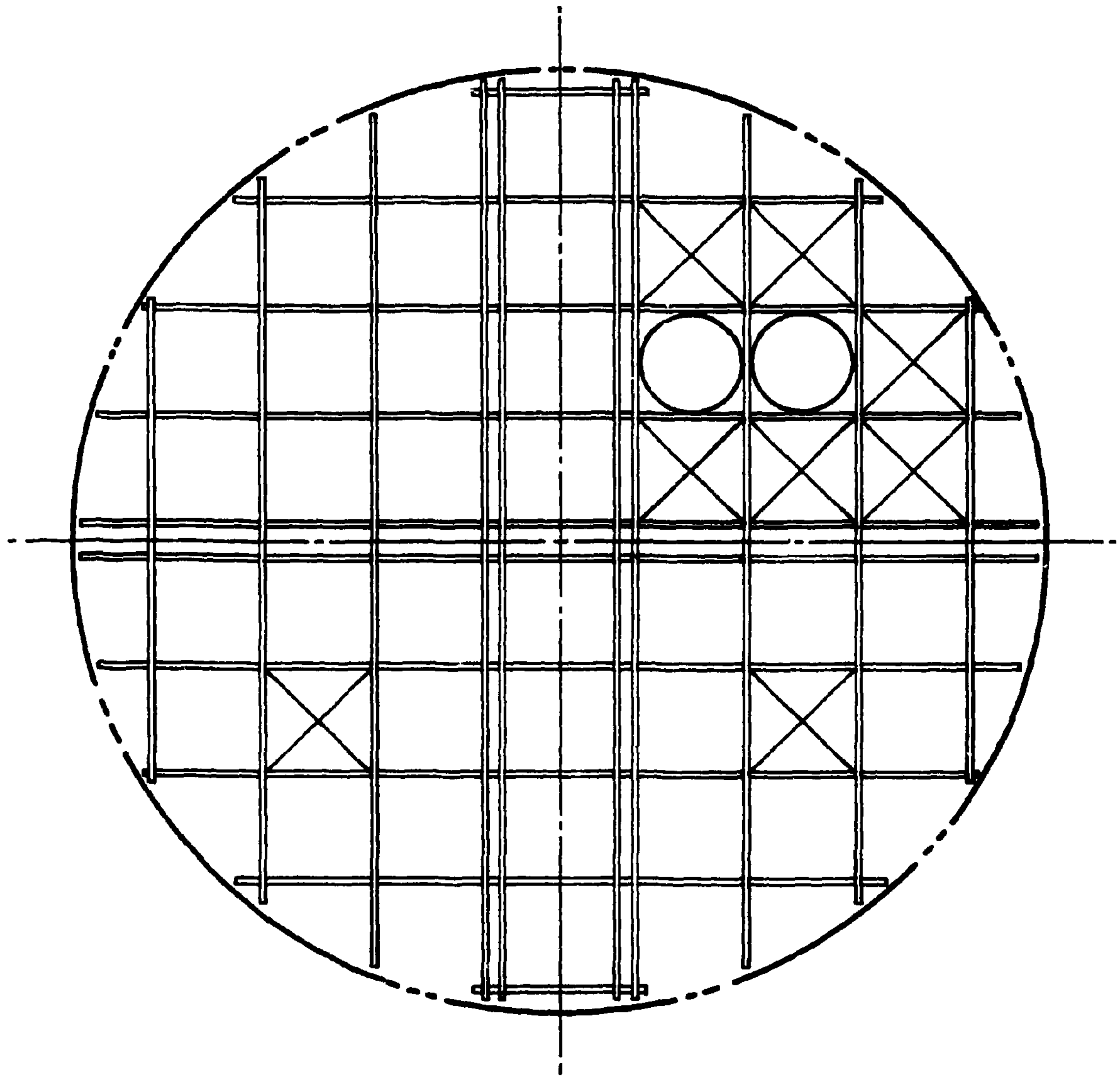

Fig. 11. TN-REG Worst Case Fuel Basket Loading Configuration for two assemblies with no BP rods. O indicates position of assembly with no BP rods. X indicates position of assembly with only 8 BP rods. All other basket compartments contain assemblies with full BP rod cluster.

ORNL-DWG 86-11263

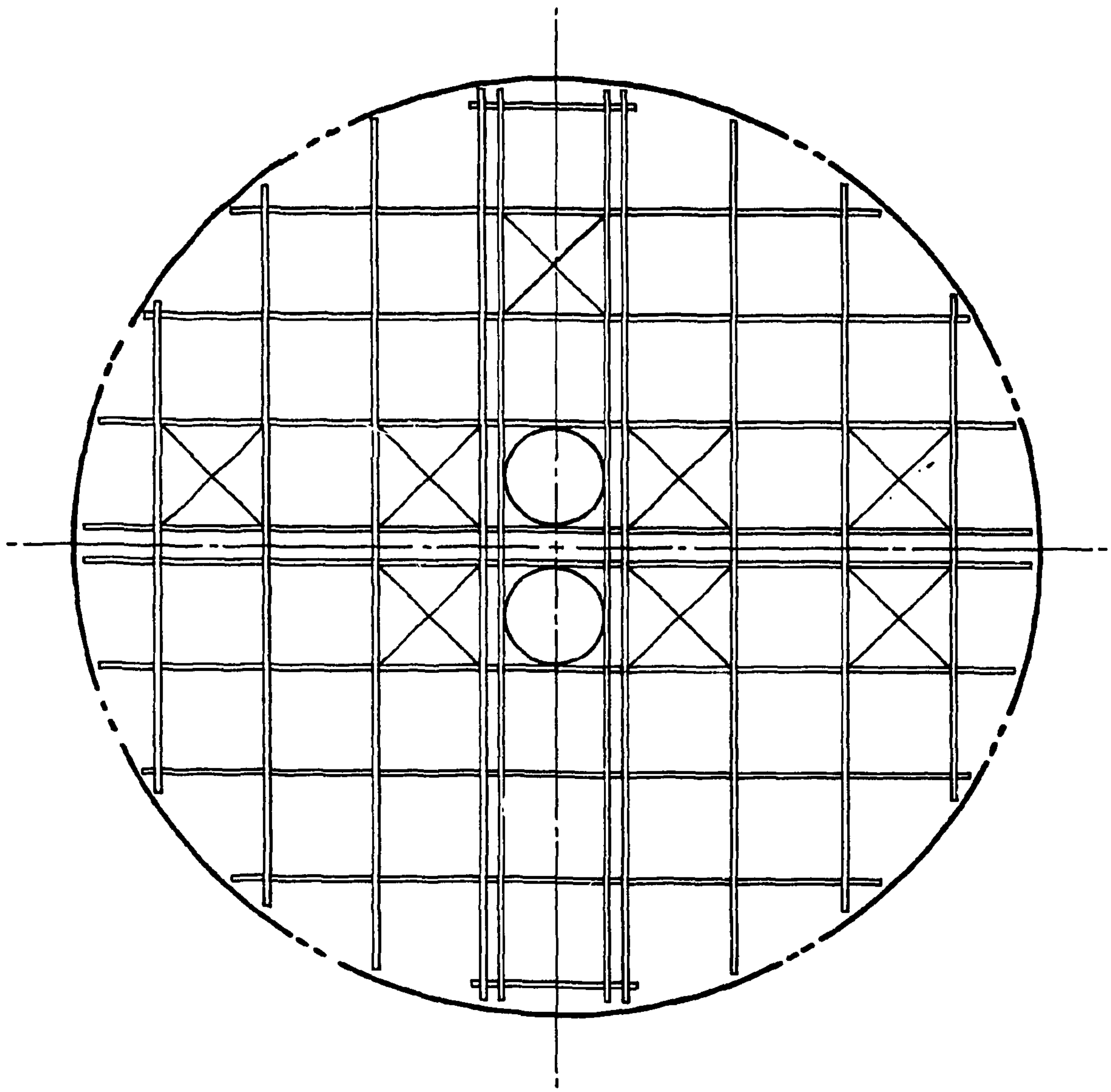

Fig. 12. TN-REG Fuel Basket Loading Configuration for final SARP. O indicates position of assembly with no BP rods. X indicates position of assembly with only 8 BP rods. All other basket compartments contain assemblies with full BP rod cluster.

Table 8. Criticality analysis results for an infinite square array of TN-REG closed casks

Case	Loading pattern	Water density, g/cm^3	Boron wt %	Multiplication factor[a]
REG1	Fig. 8	1.0	1.7	0.933 ± 0.004
REG5	Fig. 8	1.0	1.6	0.936 ± 0.004
REG6	Fig. 8	1.0	1.5	0.933 ± 0.004
REG7	Fig. 8	0.95	1.7	0.923 ± 0.004
REG7	Fig. 8	0.9	1.7	0.895 ± 0.004
REG9	Fig. 8	0.7	1.7	0.829 ± 0.004
REG10	Fig. 8	0.5	1.7	0.727 ± 0.004
REG11	Fig. 8	0.1	1.7	0.519 ± 0.004
REG12	Fig. 8	1.0	1.7	0.457 ± 0.004
REG2	Fig. 9	1.0	1.7	0.940 ± 0.004
REG1P	Fig. 10	1.0	1.6	0.941 ± 0.004
REG2P	Fig. 11	1.0	1.5	0.948 ± 0.004
REG21	Fig. 12	1.0	1.7	0.935 ± 0.004
REG3	All assemblies with 8 BP rods	1.0	1.7	0.938 ± 0.004
REG4	All assemblies with no BP rods	1.0	1.7	0.962 ± 0.004

[a]All k-eff values are for 30,000 histories.

loading) provides a k-eff + 2σ value greater than 0.95. Case REG21 is comparable to and provides reasonable agreement with the TN calculation in the SARP.

The second calculational set models various loading scenarios with a single cask in an infinite pool of water. The results for this set of calculations are shown in Table 9. The calculated k-eff values indicate that (1) there is no positive reactivity change associated with the removal of an assembly from the center of a quadrant, (2) the accident scenario with an assembly lying across the open cask does not increase the k-eff value, and (3) a single open or closed cask in an infinite pool of water is less reactive than an infinite array of closed casks.

As evident by the results of cases REG2P and REG4, if the worst case loading pattern is assumed or if all the BP rods are removed from the assemblies, the calculated k-eff + 2σ value is greater than the design criteria limit of 0.95 specified in Ref. 17. Although the scenarios postulated by these two cases may seem unrealistic, these calculations definitely serve to demonstrate that DOE must ensure that the cask loading pattern of Fig. 7-4 in the SARP is strictly adhered to and that the presence of the BP clusters is confirmed by WVNS. The administrative controls and verification developed to meet the above requirements should, in the opinion of the reviewers, be part of the SARP or Certificate of Compliance since they are required to ensure the design criteria are not exceeded.

Table 9. Criticality analysis results for a TN-REG cask in an infinte pool of water[a]

Case	Loading configuration	Multiplication factor[b]
REG13	Fig. 8, open cask	0.929 ± 0.004
REG14	Fig. 9, open cask	0.935 ± 0.004
REG13P	Fig. 10, open cask	0.932 ± 0.004
REG14P	Fig. 11, open cask	0.933 ± 0.004
REG14PA	Fig. 11, closed cask	0.9345 ± 0.002
REG20	Fig. 12, open cask	0.934 ± 0.004
REG15	Fig. 8, w/assembly across top[c]	0.928 ± 0.004
REG16	Fig. 9, w/assembly across top[c]	0.926 ± 0.004
REG15P	Fig. 10, w/assembly across top[c]	0.922 ± 0.004
REG16P	Fig. 11, w/assembly across top[c]	0.934 ± 0.004
REG17	Fig. 8 w/position 12 empty, open cask	0.922 ± 0.004
REG18	Fig. 9 w/position 12 empty, open cask	0.924 ± 0.004
REG19	Fig. 10 w/position 33 empty, open cask	0.917 ± 0.004

[a]All calculations performed with 1.7 wt% boron in the basket and full water density.

[b]All k-eff values are for 30,000 histories except case REG14PA which had 90,000 histories.

[c]Assembly laying across top of open cask contains no BP rods.

The final conclusion drawn from these analyses is that the TN-REG design as presented in the SARP assures a subcritical configuration during loading and transport when the cask is loaded with the fuel for which it was designed. The calculations also serve to confirm the validity of the k-eff values presented in the SARP.

14. TN-REG SHIELDING REQUIREMENTS REVIEW

14.1 REVIEW OF SARP CONTENT

Chap. 5 of the SARP[2] presents the shielding evaluation performed by TN to ensure that the cask would meet the dose requirements specified in 10 CFR Pt. 71.[3] This chapter of the SARP provides (1) a description of the available cask shielding, (2) the irradiation characteristics of the fuel contents, (3) a good description of the procedures for generating the radiation sources, (4) necessary information regarding the calculation of cask dose rates, and (5) and adequate evaluation of the dose from the cask penetrations. The evaluated dose rates and corresponding 10 CFR Pt. 71 limits are shown in Table 5.2 of the SARP. This table indicates that the available shielding for the TN-REG cask is adequate to satisfy the 10 CFR Pt. 71 limits for rail shipment with the designated fuel contents.

The final shielding calculations performed by TN for the SARP were done using well-established codes and cross-section libraries. TN used the ORIGEN code[10] for the fuel depletion analysis while the BUGLE-80 coupled cross-section set[11] was used with the ANISN[12] code to perform the radiation transport and surface dose evaluations. Graphs from Ref. 40 and the calculated surface dose were used to obtain dose rate values at varying distances from the cask. The effective ^{59}Co impurity in the fuel assemblies was calculated using an established and accepted procedure and with documented information supplied by the fuel vendor and included in the SARP (ref. 4 of Appendix 5.A.3 of the SARP). Assumptions used by TN in terms of the peaking factor employed (1.2), use of one-dimensional analysis methods, and the homogenization of the fuel have been found acceptable and/or conservative. The methodology and models used for generating the radiation sources, performing the transport calculations, and evaluating the dose rates are reasonable and acceptable procedures. The above statement holds for both the cask body analysis and the analysis performed on the cask penetrations.

As with the criticality review, the NEAD review staff reviewed the shielding evaluation assuming the fuel contents specified in the SARP to be correct. The contents of the TN-REG cask is limited to the specific 40 PWR fuel assemblies identified in Table 5.1 and described in Figs. 1.3 and 6.3 and Tables 6.1–6.2 of the SARP. The irradiation data specified in Table 5.1 of the SARP is particularly important to the shielding evaluation and any significant changes could invalidate the validity of the calculated doses. However, it appears that TN has used reliable sources (reactor utility and West Valley) to obtain the irradiation data.

Another issue that needs the attention of DOE and West Valley is the fuel loading pattern specified in Fig. 7.4 of the SARP. Administrative procedures need to be in place to ensure that the cask is loaded in accordance with the approved specified pattern. In addition to the criticality concerns noted earlier, the loading pattern shown in the SARP is also required because the fuel assemblies with the highest burnup (highest radiation sources) were placed in the cask center for the shielding analyses (see Sect. 5.3.1.1 and Fig. 5.1 of the SARP).

14.2 CALCULATIONAL VERIFICATION

Although the evaluation procedures and calculational tools used by TN were judged to be acceptable, it was decided that selected verification analyses would increase the confidence of reviewers in the results and methodology used and serve to better familiarize the reviewers with the details and assumptions used in the SARP evaluation. Therefore, after receiving the final SARP in October 1985, verifying calculations were performed using the SAS2 and SAS1 modules of the SCALE system[9] and employing the basic methodology and procedures presented in the SARP. Only reasonable agreement was expected with the analysis because (1) different cross sections, flux-to-dose conversion factors, and ORIGEN data libraries were used and (2) the mesh spacing, angular quadrature, and (in some cases) material number densities were different. A comparison of the partial results obtained at ORNL and the corresponding results reported in the SARP are provided in Tables 10 and 11. Note that the ORNL radial results also include an axial peaking factor value of 1.2.

The differences in the respective analyses (as cited above) and the uncertainty (cross-section data, methods, and assumptions) associated with any shielding analysis of this type led to the conclusion that the TN results presented in the SARP appear reasonable in comparison to those calculated by the NEAD review staff.

Table 10. ORNL calculated maximum dose rates for normal transport compared with SARP values[a]

Location		Total dose rate (millirem/h) SARP	ORNL	10 CFR Pt. 71 limit
Package surface:	side	38.6	44.5	200
	top	8.9	8.7	200
	bottom	20.8	23.8	200
2m from vehicle:	side	9.3	9.8	10
2m from package:	top	3.0	3.5	10
	bottom	7.0	9.5	10

[a]SARP values taken from Table 5.2 of Ref. 2.

Table 11. ORNL calculated maximum dose rates for accident conditions compared with SARP values[a]

Location[b]		Total dose rate (millirem/h) SARP	ORNL	10 CFR Pt. 71 limit
Package surface:	top	45.1	43.1	
	bottom	117.0	115.4	
1m from package:	top	31.6	29.2	1000
	bottom	82.0	79.5	1000

[a]SARP values taken from Table 5.2 of Ref. 2.

[b]Package is without impact limiters for accident results.

15. TN-REG DECAY HEAT GENERATION REVIEW

15.1 REVIEW OF SARP EVALUATION

The methodology used to obtain the decay heat values for the thermal evaluation is presented in Chap. 3, Appendix 3, of the SARP.[2] TN used the fuel burnup and decay characteristics of Table 5.1 in the SARP to calculate heat generation values via the ORIGEN code.[10] Prior to the analysis, TN ran ORIGEN to enable comparison with results available in U.S. NRC Regulatory Guide 3.54.[14] Table 3.A.3-1 of the SARP shows the comparison between the Regulatory Guide values and those from ORIGEN.

To obtain the total heat generation, the REG fuel was grouped by discharge date and an ORIGEN analysis performed using the average burnup associated with each discharge date. The decay heat value from each ORIGEN run was multiplied by the total MTU for the discharge group and "normalized" to the Regulatory Guide values by factors of 1.01 to 1.04. The total calculated decay heat was 5.11 kW. TN further raised the total decay heat value by rounding off to 5.5 kW.

Based on a total heat generation of 5.5 kW and Fig. 3.A.3-1 of the SARP, TN presents a reasonable procedure for determining the average kW value for the inner 12 (hottest) assemblies, 0.166 kW, and the outer 28 assemblies, 0.125 kW. A maximum assembly decay heat value of 0.19 kW was also obtained by TN using decay heat plots generated with ORIGEN results (see Fig. 3.A.3-1 of SARP).

In conclusion, the reviewers feel that the decay heat values in the SARP were obtained in a correct and prudent manner using an adequate computation tool (ORIGEN) which was verified against a Regulatory Guide. The requirements of the Regulatory Guide pertaining to initial cobalt content were adhered to.

15.2 CALCULATIONAL VERIFICATION

The validity of the total decay heat load of 5.5 kW was first verified using tables and figures in Regulatory Guide 3.54[14] and in the ORNL report upon which the guide was based.[15] A further check was provide by the SAS2 depletion calculations used in Sect. 14.2 for the shielding source terms. These depletion calculations were performed using the two fuel groups in Table 5.1 of the SARP that had the highest average burnups. The calculations indicated a total cask heat load of 4.8 kW and an average assembly heat load of 0.107 kW for the outer 18 assemblies (9.7 GWD/MTU average burnup) and 0.129 kW for the inner 22 assemblies (11.5 GWD/MTU average burnup). These calculations indicate the adequacy of the total and assembly average values presented in the SARP.

A separate SAS2 calculation was also performed for the PWR fuel assembly with the highest burnup and shortest decay time (assembly C23 with a burnup of 14293 MWD/MTU and 0.382 MTU/assembly per Table 5.1 of the SARP). This calculation provided a maximum assembly decay heat value of 0.174 kW which agrees well with the 0.19-kW value provided in the SARP. Table 12 summarizes the comparison of values presented in the SARP and those calculated by ORNL.

Table 12. Comparison of decay heat values calculated at ORNL with values in the TN-REG SARP[a]

	Decay heat, kW	
	SARP	ORNL
Total cask contents	5.5	4.8
Inner region average/assembly	0.166	0.129[b]
Outer region average/assembly	0.125	0.107[b]
Maximum assembly value	0.19	0.174

[a]SARP values from Chap. 3, Appendix A, of Ref. 2.

[b]The number of fuel assemblies and average burnup values used for the inner and outer regions differs from that of the SARP but serve to provide a reasonable confirmation of their adequacy.

16. TN-REG THERMAL REVIEW

An independent review of Chap. 3.0, "Thermal Evaluation," of the TN-REG SARP[2] and related materials was performed. Design criteria were initially reviewed by ORNL. Preliminary submissions of proposed SARP text were reviewed as they were submitted during 1984. In 1985, a draft SARP and a revised draft SARP were reviewed. Comments related to the thermal evaluation contained in these documents were incorporated into ORNL's review team comments and transmitted to TN. Responses to comments were provided by TN for some issues in separate letters and for other issues directly by modification of the SARP in subsequent submissions. These responses were also reviewed to assure that every significant technical issue was resolved. The conclusions were based on the review of the revised draft SARP submitted on August 16 and amended on August 22, 1985. Revised design criteria were then reviewed for consistency with the SARP and with applicable regulations. Each phase of the review was conducted under the guidance provided by U.S. NRC regulations expressed in 10 CFR Pt. 71 and the related U.S. NRC Regulatory Guides 7.6,[17] 7.8,[18] and 7.9.[19]

The TN-REG SARP is similar in content to the TN-BRP SARP. One set of design criteria was applied to both packagings. Therefore, the review of design criteria applies equally well to either cask.

In addition, preliminary submissions and draft SARPs for TN-REG were generally submitted for review after the corresponding submission for the TN-BRP SARP had been reviewed. The two casks are very similar in design and requirements. Frequently, the submission for the REG cask incorporated

TN's response to comments made on the corresponding submission for the TN-BRP SARP. The discussion of TN's response to comments on the TN-REG already includes resolution of every major comment on TN's thermal evaluation made by ORNL reviewers. Therefore, the separate treatment of TN's resolution of comments for the TN-REG SARP is abbreviated here.

Finally, no independent thermal analyses were conducted on the TN-REG cask design. A series of independent analyses of the TN-BRP cask design was conducted to increase the reviewers' understanding of the casks' thermal behavior and to reduce reviewers' uncertainties regarding the casks' compliance with regulations. The results of independent analyses on the TN-BRP cask design are thought generally to apply to both designs.

16.1 REVIEW OF PRELIMINARY THERMAL EVALUATION

The thermal aspects of the preliminary design[35] (received April 13, 1984) for the TN-REG transport/storage cask were reviewed. Informal discussion of comments with TN occurred on May 8, 1984. Comments on the corresponding TN-BRP document[6] were generally applicable to the TN-REG report (see Sect. 7). A summary is provided below of the specific comments.

16.1.1 ORNL's Comments

The 30-min fire transient analysis and other analyses required by 10 CFR Pt. 71 are missing from and should be added to the document. Three criteria for maximum temperatures are set in the design criteria document:

1. maximum fuel pin temperature $\leq 707^{\circ}F$,
2. maximum basket temperature $\leq 650^{\circ}F$, and
3. maximum metallic seal temperature $\leq 700^{\circ}F$.

Calculations showing compliance with each criterion should be included.

Decay heat axial distribution along the length of the fuel assemblies should be applied in the cask body, basket, and fuel pin thermal evaluations.

Radial distribution of the assemblies (hottest toward the center of the cask) should also be taken into account.

Whenever the SARP departs from the most conservative interpretation of 10 CFR Pt. 71 requirements, justification should be cited, including references to the appropriate regulatory guide or SARP for a previously licensed cask.

More information should be added on the basket analysis, including boundary conditions, material properties, and justification for simplification of the thermal model as conservative.

All codes used should be documented by either (1) a reference to a report in the public domain or (2) a full description of the Code's assumptions and methodology.

The maximum fuel pin temperature should be calculated using the fuel assembly with the maximum predicted decay heat, presumed to be loaded at the hottest point in the basket. The correlation showing best agreement with experimental data should be identified and used in this calculation.

16.1.2 TN's Response

Subsequent SARP submissions starting June 19, 1984, applied a peak power factor of 1.2 to the axial distribution of decay heat in the fuel assemblies and accounted for radial distribution of the assemblies. Missing information was supplied. By submissions of October 22, 1984, use of the peak power factor was extended to the cask body, and the correct maximum predicted decay heat was being used to calculate maximum fuel pin temperature. The issue of correct values for maximum basket temperature, maximum fuel pin temperature, and the matching temperature criteria were resolved in the text of the revised draft SARP (see Sect. 16.1.5).

16.1.3 Review of Proposed TN-REG SARP Chap. 3.0, Rev. 0

Proposed text for the thermal evaluation, Chap. 3.0 of the TN-REG SARP, was received August 6, 1984. The document was reviewed and comments were made. This document was substantially similar to the corresponding section of the TN-BRP SARP on which comments has been prepared. Those comments were considered applicable to the TN-REG SARP, and TN had not had the opportunity to incorporate responses to the earlier comments into this submission.

16.1.4 Review of Addendum 8 - REG, Chap. 3.0, Rev. 1

The thermal aspects of the document received November 19, 1984, were reviewed. Comments resulting from review of Addendum 8 of TN-REG SARP follow.

16.1.4.1 ORNL's Comments

The maximum basket temperature criterion has gone from 650°F to 700°F to 800°F. This criterion should not be a moving target, and the final value should appear with justification in both SARP and design criteria document.

The maximum fuel pin temperature design criterion of 707° is violated during a transient. A change in the criterion or a separate transient criterion should be included with justification in both SARP and design criteria document.

The maximum fuel pin temperature design criterion of 707° is violated during a transient. A change in the criterion or a separate transient criterion should be included with justification in both SARP and design criteria document.

More information is needed regarding thermal coupling between the basket and cask body.

An axial distribution of decay heat exists. Therefore, a reasonable maximum value of decay heat should be used in maximum temperature calculations, and a minimum value of decay heat should be used in minimum temperature calculations.

16.1.5 Review and Results of Review for TN-REG Draft SARP

The TN-REG draft SARP[36,37,38] was received April 11, 1985. A review of thermal aspects of the entire document was done. A SARP review meeting[42] was held among participants in the Dry Cask Transport/Storage Demonstration Project including ORNL, TN, Nuclear Fuel Services, EG&G (Idaho), and DOE. ORNL's comments were provided to TN, and TN proposed resolutions to the comments. Following the meeting, a formal summary of comments on thermal aspects were made. The single issue for which action by TN was still required involved the correct criterion for the basket plate temperature. This issue remained pending until the release by TN of the TN-BRP revised draft SARP.

16.1.5.1 ORNL's Comments

Table 2-10 of the SARP, taken from U.S. NRC Regulatory Guide 7.8,[18] required several notes explaining changes in regulations since the table was produced.

The LSMT should be added to Chap. 2.0 of the SARP.

As defined in 10 CFR Pt. 71, solar insolation induces a 12-h heat load of 2950 Btu/ft^2 on horizontal flat surfaces, 1475 Btu/ft^2 on curved surfaces, and 737 Btu/ft^2 on nonhorizontal flat surfaces. Given TN's cask design, TN's use of 1475 Btu/ft^2 throughout the thermal evaluation is unnecessarily conservative. No action was required of TN.

References to reports in the public domain or actual sources should be added to the SARP for (1) the axial decay heat peaking factor of 1.2, (2) the use of 800°F as the maximum basket plate temperature criterion, and (3) specific power for REG fuel during operations which generated the spent fuel being transported.

16.1.5.2 TN's Response

The requested notes and references were incorporated in the revised draft SARP.

16.1.6 Review and Results of Review for TN-REG Revised Draft SARP

The TN-REG revised draft SARP[39] was received August 23, 1985, and amended pages were received August 29, 1985. A review of thermal aspects of the entire document was performed. The primary findings of this review were that all previous comments requiring TN's response had been resolved to the satisfaction of the ORNL thermal reviewers. No new major issues were identified in the course of this review. Finally, the SARP as presented in this draft appears to meet the thermal portion of NRC requirements set forth in 10 CFR Pt. 71 regulations.

Comments on thermal aspects of the TN-REG revised draft SARP covered minor omissions, inconsistencies, and suggested improvements in the SARP. A summary of these comments is included below.

16.1.6.1 ORNL's Comments

The water spray quench test condition given in 10 CFR Pt. 71 is covered adequately in the SARP Sect. 2.6.5, "Water Spray," but is not mentioned in the SARP Sect. 2.1.2.1, "Containment Vessel." ORNL suggests that the SARP Sect. 2.1.2.1 be amended.

Chap. 2.0, Appendix 3, Sect. 6.2, "Trunnion Flange and Bolts," of the SARP refers to a bolt preload, F_p, with units of inches instead of pounds.

TN has retained the (conservative) use of 1475 Btu/ft^2 value for solar heat load during a 12-hour period on flat vertical surfaces on the impact limiters versus the 737 Btu/ft^2 shown in 10 CFR Pt. 71 regulations. No action on TN's part is required in this instance since none of TN's conc ions regarding the thermal evaluation of the cask design would be affected.

Appendices 1 - 4 of Chap 4.0 of the SARP have a nonstandard page numbering scheme. ORNL suggests the pages in these appendices be renumbered.

16.1.6.2 TN's Response

No formal response by TN was required.

16.2 SUMMARY OF TN-REG THERMAL REVIEW

The thermal evaluation presented in the TN-REG SARP has been found to meet the requirements of 10 CFR 71 regulations. The thermal performance of the TN-REG transport/storage cask should meet the requirements of federal regulations applicable to spent fuel shipment.

17. TN-REG NONDESTRUCTIVE EXAMINATION REVIEW

The subject SARP[2] was reviewed at both interim and final stages to assure conformance with 10 CFR Pt. 71[3] in the area of NDE. Paragraph 71.85(a) of 10 CFR Pt. 71 requires that prior to use there be assurance that there are no flaws that could significantly reduce the effectiveness of the packaging. Paragraph 71.119 of 10 CFR Pt. 71 requires that special processes including NDE be "controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements." Paragraph 71.37(a) of 10 CFR Pt. 71 requires identification of any established codes and standards proposed for use. Additional details or recommendations on NDE are not in 10 CFR Pt. 71. Toward meeting these objectives, activities involved the review of interim stages of the SARP and related correspondence as well as participation in review meetings with TN personnel to assure that the requirements were being met. After review of written documentation from TN, written comments were provided for compilation with other comments and transmission to TN.

17.1 REVIEW OF TN DESIGN CRITERIA DOCUMENTS

The first review activities (in February and April 1984) were on early drafts of the TN design criteria document[22] and the supporting information.[6] Both documents cited the ASME Boiler and Pressure Vessel Code, Sect. III, Article NC-2000 (Class 2 vessels) and the specification requirements of Sect. II for material requirements. The cited ASME documents were reviewed relative to NDE requirements. This included the requirements of Sect. II for material requirements. The cited ASME documents were reviewed relative to NDE requirements. This included the Sect. II material specifications referenced in the supporting information. After review, comments were provided noting that the examination requirements of the ASME Code calls for written procedures, a reasonable approach. The adequacy of the examination will depend on the details of the procedures as related to the actual fabricated hardware. Identification was needed on the person(s) to provide approval of the procedures.

The referenced material specifications (including NDE requirements) for the forged shell, bottom, and lid of the casks, as well as the trunnions and lid alignment pins and the bolts for the impact limiter, lid, trunnion, and protective cover were the same as for the TN-BRP cask. The review comments noted in Sect. 8.1 (this report) were repeated. In addition to the specification requirements, recommendations were made for (1) volumetric ultrasonic examination for the trunnions and the shell, bottom, and lid of the cask, and (2) surface examination of bolts with magnetic particle or liquid penetrant methods.

17.2 REVIEW OF FIRST DRAFT OF SARP

In July 1984, the first draft of the TN-REG SARP[41] was reviewed relative to NDE requirements. Most of the cited requirements in the draft SARP were the same as noted above in the design criteria documents and the review comments were repeated. In addition, as shown in Dwg. 3010-150-23 of the draft SARP, the shell is joined to the bottom with a butt weld. ASME Boiler and Pressure Vessel Code, Section III, Subsection NC-5211 specifies radiographic examination. (If the weld is quenched and tempered, magnetic particle or penetrant examination is required after hydrostatic testing.) The minimum requirements of the Code do not require ultrasonic examination of the weld (although the current trend is for pressure vessel manufacturers to use ultrasonics to examine the welds). We recommended ultrasonic examination of the butt weld of the cask to provide improved assurance of the weld quality and integrity. These comments were conveyed through channels to TN.

Subsequently, in July 1984, by both telephone and letter communication, TN contacted ORNL stating that the procurement specification for the cask imposed the following NDE requirements:

1. The forgings for the shell, bottom, lid, and trunnions were to be examined in accordance with ASME specifications SA-654 (for steel bars and shapes) including the examinations for the ASME Code, Section III, Class I forgings. The ultrasonic examinations are specified in SA-388, which requires that all forgings be examined by the straight-beam technique. The acceptance criteria specified (for the straight-beam examination) indication equal to or larger than that from a 1/4-in.-diam flat-bottom hold. SA-388 also requires that all ring forgings and hollow forgings be examined using the angle-beam technique with an acceptance criteria of no indication equal to, or larger than that from a calibration notch, 1/4 in. deep by 1 in. long.
2. The shell-to-bottom weld is to be examined by radiographic, ultrasonic and magnetic particle or liquid penetrant methods in accordance with the ASME Code, Section V (NDE) and Section III, Subsection NC-5000.

We agreed that these requirements in the purchase specification met the intent of the comments related to NDE requirements in the draft SARP.

17.3 REVIEW OF TN POSITION PAPER ON USE OF ASME CODE

In July 1984, TN submitted a position paper,[27] that discussed the use of the ASME Code [Section III, Subsection NC (with modifications)] for design, fabrication, and inspection of shipping casks as a supplement to (and method of implementation of) 10 CFR Pt. 71 and the Regulatory Guide 7.6.[17] Our review and comments on the position paper are found herein in Sect. 8.3.

17.4 REVIEW OF INTERIM DRAFTS OF SARP SECTIONS

During the period from November 1984 to April 1985, we reviewed interim revised drafts of sections of the SARP. In general, the NDE technical requirements (noted above) had been incorporated, but occasionally without reference to the governing documentation. In addition, Chap. 8 of the SARP required the application of liquid penetrant or magnetic particle examination of lid lifting lugs and trunnions after load tests. We recommended that approved written procedures be referenced and used.

17.5 REVIEW OF FINAL DRAFT OF SARP AND CONCLUSIONS

In August 1985 revised sections of the SARP were reviewed for NDE content. In general, the requested modifications had been made. Recommendations were repeated for documentation references to surface examination techniques to be used after load tests on lifting, lugs, and trunnions. As noted earlier, we were not privileged to review the detailed NDE procedures and test results. However, if the NDE requirements cited in the SARP are properly implemented, that phase of the design and fabrication of the REG cask should be adequate for the proposed one-time transportation of spent fuel and to meet the requirements for NDE imposed by 10 CFR Pt. 71 and Regulatory Guide 7.6.

18. TN-REG STRUCTURAL REVIEW

18.1 OVERVIEW

An independent review of Chap. 2, "Structural Evaluation," of the TN-REG SARP[2] and related materials was performed. The review activities began in 1984 and continued through 1985. The review was performed in conjunction with, and in the same manner as that of the TN-BRP SARP[1] of Sect. 9.1 of this report. All comparisons with regulations were made by reference to 10 CFR Pt. 71, U.S. NRC Regulatory Guides 7.6[17] and 7.8,[18] applicable sections of the ASME Boiler and Pressure Vessel Code, and ASTM Standards.

18.2 REVIEW FINDINGS

Chap. 2 of the SARP addresses the structural aspects of the cask in the major areas of containment, fuel support, lifting and restraint, and impact protection. Each of these areas was addressed separately as in Sect. 9.2 for the TN-REG cask, and the same comments are applicable.

18.3 CONTAINMENT VESSEL

TN has provided analytical demonstrations that the cask meets 10 CFR Pt. 71 and Regulatory Guides 7.6 and 7.8. This was accomplished by use of the computer program ANSYS[28] and a series of hand calculations. The following paragraphs provide a comparison between the TN-REG and ORNL reviewers' calculations.

The stresses in the cask ends were checked by hand calculations. The stress in the cask bottom due to 150 psi internal pressure was found by the reviewers to be 2,585 psi vs. 2,062 psi (SARP p. 2.A.1-45). Stress at 95g axial impact and 45 psi and excluding the lower impact limiter was found by the reviewers to be 32,885 psi vs 32,663 psi (SARP p. 2.A.1-53). Stress in the lid was found to be 4,020 psi and 53,803 psi under 150 psi an 95 g impact respectively vs. 2,331 psi and 34,090 psi as specified for cross section 1-1 on table 2.A.1-19 (SARP p. 2.A.1-88).

Stresses induced in the cask walls by the trunnions were checked using Bijlaards methods. Maximum membrane stress was found by the reviewers to be 8,162 psi and maximum membrane and bending was 18,832 psi vs. stresses of 8,680 psi and 30,340 psi respectively (SARP p. 2.A.1-115).

Stress in the cask walls due to 150 psi internal pressure was checked and found by the reviewers to be 665 psi (hoop), 258 psi (axial), and 408 psi (radial). These stresses in the SARP were 665 psi (hoop) and 258 psi (axial) (SARP P. 2.A.1-48). Stress due to 25 psi external pressure was found by the reviewers to be 136 psi and was a maximum of 134 psi at cross section 22 (SARP p. 2.A.1-9-). Stress during 30-ft impact was found by the reviewers to be 5,314 psi vs. 3061 psi and 3,043 psi (SARP p. 2.A.1-52).

18.4 FUEL SUPPORT

The fuel is supported by a basket constructed of a stainless steel alloyed with boron in a manner similar to the TN-BRP cask. TN has provided analytical models of the mechanical performance of the basket. The major requirement for the basket is to provide positioning of the fuel and the moderating constituent, boron. The analysis must demonstrate that the basket does not permit excessive motion, and that the general topology is retained. While specific criteria for fuel motion or basket topology were not stated, the ORNL structural reviewers and the ORNL criticality reviewers discussed the adequacy of TNs design at length and agreed that the limited basket distortion was acceptable (Sect. 13.2, p. 86 of this report).

A check was made on the capacities of the basket plate assemblies under various g loadings. Simplifying assumptions were made and the results of calculations compared to the finite element analysis results in the SARP. The maximum plate load under 5 g conditions was 5,481 lbs vs. 6,953 lbs (SARP p. 2.A.2-86). The maximum load under 75 g conditions was 82,215 lbs vs. a value at 75 g of 70,968 lbs (SARP p. 2.A.2-103). Using a 31,000 psi yield stress allowable, the maximum g-load capacity was found by the reviewers to be 69 g which is in acceptable agreement with the reported maximum transverse acceleration of 75 g.

Individual plates under support conditions of one-end fixed and one-end simply supported were checked for maximum buckling stress considering a full 8 3/8 in. length. A critical buckling stress of 28,362 psi was found. When this stress is applied (no spread or lateral restraint) to the minimum bearing area, the maximum acceleration capacity is 66.5 g which is in acceptable agreement with the reported expected transverse acceleration of 75 g.

The function of the basket assembly is to maintain criticality separation of the fuel elements. Some localized plastic deformation is acceptable. A check was made of maximum deformation under 75 g-load conditions. The maximum deflection under plastic conditions is limited to the spacer depth of .058 in. Local stress levels are above the ultimate bending capacity of the plate but below the ultimate shear capacities. This indicates inelastic deformations greater than the calculated elastic deformations would be expected at the conservative 75 g-loading level. This may be compared to the maximum finite element SARP results of .075 in. on an interior plate (SARP p. 2.A.2-102) and .262 in. on an exterior plate. A nominal gap of .143 in. exists initially between the fuel element and adjacent plates. Under conditions of 75 g acceleration in two simultaneous directions, adjacent deformed plates would touch a fuel element and support would be uniform. It is therefore felt that the existing egg crate plate design is adequate.

18.5 LIFTING AND RESTRAINT

The lifting and restraint functions are provided by four trunnions that are bolted to the cask body. TN has provided a series of hand calculations for the design of the trunnion and bolts. A similar series of calculations were made by ORNL.

Transportation stresses in the trunnions were checked under the same conditions in the SARP. Assuming loads are ultimately resisted only by the preloaded bolts, shear stress was found by the reviewers to be 54,091 psi and maximum tension stress was 43,368 psi vs. 11,900 psi and 84,200 psi (SARP p. 2.A.3-19) respectively.

The stress intensity was found to be 116.6 ksi and the allowable intensity, utilizing actual material values, was found by the reviewers to be 121.63 ksi at 200°F. The reported stress intensity value was 67 ksi (SARP p. 2.A.3-18). Trunnion stresses were checked and found close to the reported values.

18.6 IMPACT PROTECTION

The cask is protected from impact by a composite structure of balsa and redwood. This structure is in fact, the same as that utilized for the TN-BRP cask as detailed in Sect. 9.6 of this report, without the aluminum spacers. The comments of Sect. 9.6 are applicable for the TN-REG review.

18.7 CONCLUSIONS ON STRUCTURAL REVIEW

The conclusions on the structural evaluation of the TN-BRP SARP[2] are identical to those stated in Sect. 9.7, p. 66 of this report.

19. TN-REG CONTAINMENT REVIEW

19.1 OVERVIEW

An independent review of Chap. 4, "Containment," of the SARP[2] and the sections and appendices related to the lid closure seals and bolts from Chap. 2, "Structural Evaluation," of the SARP has been performed. The review activities began in 1984 and continued through 1985. The review consisted of receiving portions of the SARP, thoroughly reading the submitted material, comparing with appropriate regulations or criteria, performing independent calculations for checking purposes, submitting comments for consideration by TN, and consideration of the comments of others that had reviewed the same material. During the review activity, all comparisons with regulations were made by reference to 10 CFR Pt. 71,[3] ANSI N14.5,[29] and U.S. NRC Regulatory Guide 7.4.[30] The design criteria from the SARP is contained in Chap. 4, Sects. 4.2 and 4.3.[22]

19.2 REVIEW FINDINGS

The comments and findings expressed in Sect. 10.2, p. 69 of this report on the TN-BRP containment review are also applicable to the TN-REG as regarding to analysis methodology and the closure integrity.

The SARP indicates that the main closure will be subjected to a 45 psig internal pressure and 95 g axial impact under accident conditions. For these conditions, the maximum load per bolt was calculated to be 3,834 lb/bolts and 158,064 lb/bolt versus 14,251 lb/bolt and 135,323 lb/bolt (74 g and 150 psi) (SARP p. 2.A.1-63 and 2.A.1-59.) This loading would result in a momentary seal loss on the metal Helicoflex seal but containment would be preserved by the Viton O-ring. Under normal conditions no loss of seal integrity was calculated.

19.3 CONCLUSIONS ON CONTAINMENT REVIEW

The closure system of the cask has been adequately shown to meet the prescribed design criteria and regulatory requirements in the judgement of the reviewers.

20. TN-REG MATERIALS REVIEW

The material specifications and requirements for the TN-REG cask are equivalent to those for the TN-BRP cask discussed in Chapter 11. The reader is referred to that chapter for more detailed discussions regarding the approach and techniques utilized in the review. The following discussion addresses additional specifics related to the TN-REG cask.

As with the review of the TN-BRP, the review of materials selection was focused on the requirements of 10 CFR 71 related to the prevention of brittle fracture. This document requires the cask to withstand accident conditions that may occur at an initial temperature of -20°F. The approach for the review of the TN-REG cask assumed a one-time only shipment which could occur at a temperature at or above that at which the material attains 100% ductile fracture with standard Charpy V-notch testing. This requirement applies equally to the weld metal and the heat-affected zones of the weldments.

The minimum recommended testing included drop-weight NDT of the base metal and weld metal; Charpy V-notch impact testing of the base metal, weld metal, and heat affected zones; tensile testing of weld metal and base metal; and hardness testing of all three components. The toughness tests shall cover a temperature range with sufficient intervals to allow for construction of the full Charpy V-notch curve of brittle to fully ductile behavior. The results will include total absorbed energy, mils lateral expansion, and percent shear. The objective of the testing is to provide sufficient information to allow for a determination of the lowest service metal temperature (LSMT) at which fully ductile behavior is achieved and use this as a limiting condition for transport.

The TN-REG SARP gives -20°C as the LSMT in both Chapters 1 and 2. That value is in agreement with the Kobe Steel Company data package. However, on pages 1-2 and 2-1, it is stated that, since Regulatory Guide 7.8[18] requires accident conditions to be evaluated at an ambient temperature of -20°F, Transnuclear considers that there is no need for any ambient temperature restrictions on cask shipment.

Regulatory Guide 7.8 is used in conjunction with Regulatory Guide 7.6[17] and applies to casks made of stainless steel. Because of the previously discussed propensity of ferritic steels for brittle fracture (dependent on temperature), the cask body and lids should be maintained at -20°C or higher. Perhaps decay heat or insulation will allow that temperature to be attained in the event of lower ambient temperatures. ORNL's recommendation is that the cask should not be transported if the cask body or lids are at a temperature below -20°C.

The basket material is specified in SARP Tables 2-12 and 2.A.2.1 as boron stainless steel with 1.7 wt % Boron. Increasing boron content in the range of 1 to 2 wt % degrades toughness. This issue must be given appropriate consideration consistent with the application of the specific material in the context of the requirements for the structural design of the package (See Section 18.4).

21. CONCLUSIONS

This report has summarized the details of the technical evaluations completed during the SARP reviews of both the TN-BRP[1] and the TN-REG[2] spent fuel shipping casks. The summaries included individual sections on the package description, criticality safety, shielding, heat generation, thermal analyses, nondestructive examination, structural and containment analyses, and materials concerns. As noted in the Introduction, this report and the reference material represents an "interim status" as additional revisions and discussions have occurred during NRC review of the subject casks.

Based on the evaluations presented herein, it is the opinion of the ORNL reviewers that the cask designs, as presented to ORNL by TN, have been developed using accepted techniques and procedures, and the designs meet the technical requirements of 10 CFR Pt. 71[3] and are acceptable for the issuance of a one-time shipment DOE Certificate of Compliance for transportation as intended by the supporting DOE program.

This recommendation for certification is based on all the assumptions as described in Sect. 2 of this document and is predicated on data described herein. This is not a guarantee of NRC acceptability, but does represent a knowledgeable interpretation of the equivalent NRC standards as applied and interpreted by the ORNL reviewers based both on technical competence and experience in similar work both with the DOE and NRC.

It was recognized during the course of the review that there are not definite standards for the design of cask internal structures that are critical to satisfying the performance factors of 10 CFR Pt. 71. In particular, issues such as the fracture toughness of the basket plates with the quoted boron concentrations must be considered as judgemental decisions on the part of the reviewers.

During the course of the technical evaluations, recommendations were compiled regarding work which was beyond the scope of the ORNL effort or representing concerns which should be verified. For convenience, these recommendations are summarized below.

1. ORNL recognizes that the respective SARPs upon which this review was based are not of regulatory quality; and, in some cases, ORNL's opinions are based on knowledge of facts not adequately represented in the SARPs. For external review, the SARPs should be upgraded to acceptable standards.
2. A review of procedures and quality control for the boron concentration in the cask baskets should be conducted.
3. Verification of removal of the cobalt rods from the 9 x 9 and 11 x 11 assemblies to be shipped in the TN-BRP should be completed prior to loading of the TN-BRP.
4. Adequate NDE must be implemented by a review of procedures and performance by individuals with appropriate knowledge and expertise.
5. For proper criticality and shielding safety, the cask loading pattern of the TN-REG must be strictly adhered to and confirmed via administrative procedures at WVNS, and the presence of the burnable poison clusters must be confirmed.

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