11 September 1997

Ms. Shirley Jackson, Chair
U.S. Nuclear Regulatory Commission

Dear Ms. Jackson,

In September of 1997, according to plans outlined by the Department of Energy, the Nuclear Regulatory Commission, and the Tennessee Valley Authority, the United States intends for the first time to produce tritium for nuclear weapons in a commercial nuclear power reactor, the Watts Bar I reactor in Spring City, Tennessee. This act will breach a fifty-year wall of separation between the civilian and military nuclear power industries. We are writing to ask you to prevent this ill-advised precedent.

The foundation of the wall between civilian and military nuclear activities is the Atomic Energy Act which prohibits the use of commercial facilities to produce special nuclear materials or special fissile materials for use in nuclear weapons. The Department of Energy currently indicates that its interpretation of the statute narrowly interprets its scope to address only plutonium and highly enriched uranium. This narrow "letter-of-the-law" reading ignores several crucial points:

1. In practice, the separation has been more comprehensive and has included the production of tritium, a radioactive material for nuclear weapons. The Department of Energy has always produced weapons tritium in facilities designed and operated as defense facilities, not as commercial power facilities. It is a precedent long standing.

More important, the separation of commercial and military nuclear activities is widely recognized by the international community to include more than plutonium and highly enriched uranium. Currently, according to DOE's Stephen Sohinki, three other nations are major suppliers of uranium fuel for power reactors in the US; the agreements under which these suppliers provide fuel for US power generators prohibit its use, even tangentially, as part of a larger power array in a reactor being used to produce tritium for nuclear weapons.

2. The separation of civilian and military nuclear activities is a cornerstone of US international nonproliferation policy which suddenly and completely vanishes the moment the United States loads "Tritium Producing Burnable Absorber Rods" in a commercial reactor. Removing the civilian/military barrier in the United States undermines our principled stance before the world. The activities currently planned for the Watts Bar reactor in September will send a message to the world that we could never take back—that the use of commercial nuclear power facilities for the production of nuclear weapons materials is acceptable practice. The profound nature of this shift in US nonproliferation policy cannot be overstated.

3. The production of new weapons-tritium now, for the first time since 1988, will signal to the world that the US intends to maintain an arsenal in excess of START II levels and will encourage the pursuit of nuclear weapons capability by non-nuclear nations and the further development of nuclear capability by nuclear nations. Current projections of the Department of Energy indicate that the US can maintain an arsenal with 3,500 strategic nuclear warheads (START II levels) without producing new tritium until 2015.

Clearly, this action is of profound significance and warrants careful consideration; the public, especially those who live in the shadow of Watts Bar, should be engaged in a full and meaningful discussion of this proposed action. The Nuclear Regulatory Commission should exercise its responsibilities at the highest level to see that any action is carried out in accordance not only with NRC

policies and regulations, but also in the spirit of the democracy in which we live

Chairwoman Jackson, we are asking you to take action to require the full Nuclear Regulatory Commission itself, not just the staff, approve the application of the Tennessee Valley Authority for a license amendment. Surely such a precedent-setting action as this requires the involvement of the highest level of authority and responsibility within the Commission.

Furthermore, we are asking you to delay the approval of the license amendment application until a significant public process can take place that would enable a comprehensive discussion about these actions, including a clear and public justification for this precedent-setting action.

To date, only one public meeting has been held in the Watts Bar area to discuss the proposed action; it was announced with a minimum 14 days notice during summer vacation period. It was held *after* virtually every significant decision-making milestone had passed. Nevertheless, more than eighty citizens attended the hearing and were unanimous in their disapproval of this action. For some, singificant technical questions remained unanswered in the documents provided thus far to the public. For others, the failure to provide meaningful public participation in the decision-making process was an issue. And for others, the precedent-setting nature of this action made a full and thorough discussion all the more imperative.

Those who live in the shadow of Watts Bar have expressed one further significant concern regarding this decision which will impact their lives and their region, and that concern is security. When the Watts Bar nuclear power plant loads tritium-producing rods in its operating core in September, it becomes, to put it bluntly, a bomb plant. It was never constructed to be a bomb plant; it does not have in place the level of security and control that exist at DOE weapons facilities. It has not undergone extensive review of vulnerabilities as have DOE weapons facilities. Instead, it becomes the least protected, least safeguarded, least secure weapons facility in the United States.

It is unfortunate that we live in an age where terrorism is a tool of international policy for some, but it is reality. Those who live near Watts Bar have serious and legitimate concerns that the government is placing them in increasing peril by the proposed use of a commercial power plant to produce weapons materials. Our concern is magnified by the recent upheaval in TVA's security program, including massive lay-offs and a major shift in security responsibilities. These concerns have not been adequately addressed in any documentation released to the public to date.

We hope that you will recognize the urgency with which we write and will respond to our concerns immediately.

Sincerely,

Ralph Hutchison

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NUREG-1607

Safety Evaluation Report

related to the Department of Energy's proposal for the irradiation of lead test assemblies containing tritium-producing burnable absorber rods in commercial light-water reactors

Project No. 697

U.S. Nuclear Regulatory Commission

Office of Nuclear Reactor Regulation

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NUREG-1607

Safety Evaluation Report

related to the Department of Energy's proposal for the irradiation of lead test assemblies containing tritium-producing burnable absorber rods in commercial light-water reactors

Project No. 697

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Division of Reactor Program Management
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ABSTRACT

The Department of Energy (DOE) is responsible for establishing the capability to produce tritium, an essential material used in U.S. nuclear weapons, by the end of 2005, in accordance with a Presidential decision directive.

Under the terms of the Joint DOE/NRC Memorandum of Understanding of May 22, 1996, NRC is providing review and consultation services to assist DOE in assessing and resolving technical and licensing issues associated with DOE's proposal for the production of tritium in a commercial light-water reactor (CLWR).

DOE has submitted a report, as revised, containing sufficient information for the staff to determine whether the use of a CLWR to irradiate a limited number of tritium-producing burnable absorber rods (TPBARs) in lead test assemblies (LTAs) raises generic issues involving an unreviewed safety question, as defined in 10 CFR 50.59. The NRC staff has reviewed the DOE report and has prepared this safety evaluation to address the acceptability of the proposed irradiation and whether a licensee can undertake the irradiation of these LTAs in accordance with the provisions of 10 CFR 50.59 without NRC licensing action.

This safety evaluation is being transmitted to the Commission before issuance.

As summarized in Section 10 of this safety evaluation, the staff has identified issues that require further NRC review. The staff has also identified a number of areas in which an individual licensee undertaking irradiation of TPBAR LTAs will have to supplement the information in the DOE report before the staff can determine whether the proposed irradiation is acceptable at a particular facility.

Therefore, the staff concludes that a licensee undertaking irradiation of TPBAR LTAs in a CLWR will have to submit an application for amendment to its facility operating license before inserting the LTAs into the reactor.

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ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards
AISI	American Iron and Steel Institute
ALARA	as low as reasonably achievable
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATR	Advanced Test Reactor
ATWS	anticipated transient without scram
BOL	beginning of life
BPRA	burnable poison rod assembly
BWR	boiling-water reactor
CLWR	commercial light-water reactor
CMTR	certified material test report
CW	cold-worked
DBA	design-basis accident
DBLOCA	design-basis loss-of-coolant accident
DOE	Department of Energy
DORT	discrete ordinate transport (code)
EFPD	effective full-power day
EOL	end of life
ETR	Engineering Test Reactor
FCL	facilities (security) clearance
FSAR	final safety analysis report
GVR	gas volume ratio
HFIR	High Flux Isotope Reactor
IGSCC	intergranular stress corrosion cracking
LBLOCA	large-break loss-of-coolant accident
LTA	lead test assembly

MCNP	Monte Carlo N-Particle (Transport Code Version 4A)
MPH	Materials Property Handbook
MOU	memorandum of understanding
NDE	nondestructive examination
NPZ	nickel-plated Zircaloy-4
NRC	Nuclear Regulatory Commission
OBE	operating-basis earthquake
ODCM	offsite dose calculation manual
PIE	post-irradiation examination
PNNL	Pacific Northwest National Laboratory
PRF	permeation reduction factor
PWR	pressurized-water reactor
QA	quality assurance
RCS	reactor coolant system
SAR	safety analysis report
SBLOCA	small-break loss-of-coolant accident
SCC	stress corrosion cracking
SRM	staff requirements memorandum
SS	stainless steel
SSE	safe-shutdown earthquake
TGSCC	transgranular stress corrosion cracking
TPBAR	tritium-producing burnable absorber rod
TS	Technical Specifications
TVA	Tennessee Valley Authority
WABA	wet annular burnable assembly

1 INTRODUCTION

On December 4, 1996, the Department of Energy (DOE) submitted a report prepared by Pacific Northwest National Laboratory (PNNL), PNNL-11419, "Report on the Evaluation of the Tritium Producing Burnable Absorber Rod Lead Test Assembly" (the DOE report), to present technical information related to irradiation of tritium-producing burnable absorber rods (TPBARs) in a commercial light-water reactor (CLWR). DOE submitted Revision 1 to this report on March 3, 1997, in order to respond to the staff's requests for additional information of January 3 and 13, 1997.

1.1 Background

Tritium, an essential material in U.S. nuclear weapons, is an isotope of hydrogen that decays at a rate of approximately 5 percent per year (a 12.3-year half-life). The United States has not produced tritium since 1988, when DOE closed its production facility at Savannah River. Current, short-term tritium needs are being met by recycling tritium from dismantled U.S. nuclear weapons. Resumption of tritium production will be essential for maintaining the U.S. nuclear weapons stockpile and the U.S. nuclear deterrent.

DOE's Dual-Path Strategy for the Production of Tritium

DOE is responsible for establishing the capability to produce tritium by the end of 2005, in accordance with a Presidential decision directive. DOE has selected a dual-path strategy to meet the schedule. One path is the accelerator production of tritium. If DOE adopts an accelerator design utilizing a tungsten target (as is currently contemplated), it may pursue that option without Commission approval because the NRC does not have statutory authority to regulate accelerators or DOE production facilities.

The other path is one that could require NRC oversight. DOE proposes to produce tritium in CLWRs, either through acquisition of reactor(s) under Government ownership or by contracting for target irradiation services at a plant under private ownership. Production of tritium in an NRC-regulated CLWR would involve NRC oversight.

Regardless of which option is selected as the primary approach for tritium production, DOE intends to complete confirmatory testing, fabricate the first core load of targets, and develop a new extraction capability as a contingency to meet national defense requirements. Tritium extraction would take place at DOE's Savannah River Plant and would not involve oversight by NRC.

Joint DOE/NRC Memorandum of Understanding

On May 22, 1996, the Secretary of Energy and the Chairman of the Nuclear Regulatory Commission signed a Joint DOE/NRC Memorandum of Understanding (MOU). This MOU establishes the basis for NRC review and consultation concerning DOE's possible use of CLWRs for producing tritium. It supplements an earlier MOU between DOE and NRC (dated February 24, 1978) and relates solely to NRC's review of and consultation on DOE's proposal for tritium production in CLWRs. The MOU acknowledges that an issue exists involving the use of civilian commercial reactors to support military requirements but stipulates that NRC will not be involved, either in a policy or a technical role, in resolution of that issue. The MOU also stipulates that NRC will not be involved in the decision on whether to use an accelerator or a CLWR to produce tritium.

Under the terms of the MOU, NRC is providing review and consultation services to assist DOE in assessing and resolving technical and licensing issues associated with CLWR production of tritium (including physical security, security clearance, and environmental issues) in order to support a Secretarial decision on the primary and backup tritium production approaches in late 1998.

Finally, the MOU contemplates that the NRC will recover costs associated with this program through a reimbursable agreement between the two agencies. Therefore, the cost of this review will not be split among NRC licensees to be paid as part of the annual fee under 10 CFR Part 171 to cover NRC overhead, general, and administrative costs.

CLWR Production of Tritium

DOE has developed a design for burnable poison rods using lithium, rather than boron, in pressurized-water reactor (PWR) fuel assemblies. As a result of irradiation by neutrons in the reactor core, some of the lithium in the target rods is converted to tritium. The irradiated burnable poison rods can then be removed from the fuel assemblies and shipped to another location (Savannah River Plant) for tritium extraction. The first phase of the tritium program that requires the involvement of NRC is a lead test assembly (LTA) demonstration. LTA irradiation would serve as a confirmatory test of the design for TPBARs that DOE has developed over the past 10 years.

DOE expects that LTAs will be available for irradiation in the core of a CLWR in late summer 1997. At the reactor involved in the LTA demonstration (Watts Bar, Unit 1), 32 target rods (8 each in 4 LTAs, with 1 LTA inserted in each quadrant of the core) will be irradiated for one fuel cycle.

The second phase of DOE's tritium production program that will require NRC review is DOE's submittal of a topical report for production irradiation in mid-1998. The staff will initiate review

of that report concurrently with the irradiation of the LTAs and anticipates that it will document its review in a safety evaluation report to be issued in early 1999. DOE has stated that, because the primary purpose of the LTA demonstration is to build confidence among prospective licensees, completion of the LTA demonstration is not an essential precursor to submittal of the topical report. The NRC staff agrees that it could initiate review of the topical report independent of the LTA demonstration. However, the staff may need information from the LTA demonstration before it can complete its review of the production topical report. The NRC staff will send the Commission its safety evaluation on the production phase topical report before the staff issues its safety evaluation.

The third and final phase of DOE's tritium production program, which may require NRC's review is the actual production of tritium. Under one of the DOE options being considered, this review would be conducted, not at the request of DOE, but as a result of a request by a licensee for amendment of its facility operating license to authorize use of up to 3300 TPBARs in each core reload. A license amendment is required in order to make changes to the plant technical specifications and to address any unreviewed safety questions pertaining to such use. A request for a license amendment authorizing irradiation of burnable poison rods for production of tritium is expected to be received at the beginning of 2000. A request for a license amendment will be noticed in the *Federal Register* and will be the subject of an opportunity for hearing. If a hearing is requested, the Commission will be notified if the staff intends to make a "no significant hazards consideration" finding (which would allow the amendment to become effective before the conclusion of a hearing).

Regardless of which dual-path strategy is chosen, the first core loading of TPBARs will be fabricated during 2002 and 2003 as part of DOE's target demonstration program. Also, the licensing activities to support CLWR production of tritium will be completed. Should CLWR production be chosen, the TPBARs will be irradiated, cooled, and shipped in 2004 and 2005 to support the Presidential decision directive's requirement for production of the first tritium gas at Savannah River by the end of 2005.

SECY-96-212

In SECY-96-212, the staff described DOE's proposal for the CLWR production of tritium and presented its approach for reviewing DOE's proposal under the terms of the joint MOU of May 22, 1997. The staff proposed to consider whether irradiation of LTAs containing TPBARs could be accomplished under the provisions of 10 CFR 50.59 without NRC licensing action.

In its staff requirements memorandum (SRM) of December 10, 1996, the Commission approved the staff's review approach. However, the Commission directed the staff to hold a series of public meetings to give the public an opportunity to comment on the technical issues during the LTA phase and to inform the public of the staff's activities early in the evaluation process. The initial meeting was held at NRC Headquarters on February 25, 1997. The next public meeting

directed by the Commission is expected to be held in the vicinity of the LTA host facility selected by DOE (Watts Bar) in the summer of 1997, before the TPBAR LTAs are inserted into the reactor. Finally, the staff will hold similar local public meetings before TPBARs are inserted in any particular NRC-licensed facility for the production phase of DOE's CLWR tritium program.

DOE's report, as revised, contains sufficient information for the staff to determine whether the use of a CLWR to irradiate a limited number of TPBARs in LTAs raises generic issues involving an unreviewed safety question. The staff has reviewed the DOE report and has prepared this safety evaluation to address the acceptability of the proposed irradiation and whether a licensee can undertake irradiation of the LTAs under the provisions of 10 CFR 50.59 without NRC licensing action. This safety evaluation is being transmitted to the Commission before the safety evaluation is issued.

Independent of its review of the DOE report, the staff is conducting vendor-related activities with respect to quality assurance (QA) plans and fabrication inspections in order to give DOE insights on how the NRC will review the production phase report.

1.2 Purpose

As described in SECY-96-212, the original purpose of the DOE report was to provide sufficient information for the NRC staff to determine whether use of a CLWR to irradiate a limited number of TPBAR LTAs raised generic issues involving an unreviewed safety question. Should the staff determine that no generic unreviewed safety questions are involved in irradiating TPBAR LTAs in a CLWR, a licensee undertaking such irradiation would be permitted to proceed under the provisions of 10 CFR 50.59 without NRC licensing action, subject to plant-specific evaluations confirming that no unreviewed safety question exists and that no change in a technical specification is needed.

The original report addressed the issue of TPBAR LTA irradiation generically and presented several plant-specific analyses for an unspecified Plant A and Plant B. On February 7, 1997, DOE announced the selection of Watts Bar as the facility that would conduct the one-time confirmatory test of components that could be used in the production of tritium. After selecting Watts Bar as the facility that will carry out out the confirmatory TPBAR LTA irradiation, and in response to the staff's requests for additional information, DOE submitted a revised report. The revised report no longer addresses the TPBAR LTA irradiation in generic terms, but presents analyses and data based solely on the Watts Bar facility. For that reason, the staff shifted the focus of its review from a generic evaluation of potential unreviewed safety questions to a more specific evaluation addressing TPBAR LTA irradiation at Watts Bar.

The staff's review of the DOE report and the staff's conclusions regarding the applicability of the provisions of 10 CFR Part 50.59 in implementing the proposed TPBAR LTA irradiation are

documented in this safety evaluation.

1.3 Scope

The staff has evaluated DOE's report, submitted by letter dated December 4, 1996, and revised by letter dated March 17, 1997. The staff has also considered information submitted by DOE in letters of February 7 and 14, 1997, and March 7 and 12, 1997. These letters responded to the staff's requests for additional information dated January 3 and 13, 1997 and to the staff's letters of February 4 and 24, 1997, providing guidance on benchmarking for the VIPRE amd PHOENIX codes. The staff has also reviewed classified versions of the DOE report that were submitted by letters dated December 4, 1996, and March 3, 1997, containing confidential restricted data. None of the information in this safety evaluation is classified.

1.4 Organization of This Safety Evaluation

The format of this safety evaluation follows that of the DOE report (PNNL-11419) as closely as possible. The staff has added Section 10 to summarize the results of its review. Section 10 of this safety evaluation also summarizes the remaining plant-specific issues that will have to be addressed in the TeNnessee Valley Authority's application for an amendment to the facility operating license for Watts Bar to permit TPBAR LTA irradiation.

2 TRITIUM-PRODUCING BURNABLE ABSORBER ROD LEAD TEST ASSEMBLY DESIGN

In Chapter 2 of its report, the Department of Energy (DOE) describes (1) the mechanical design of the tritium-producing burnable absorber rod (TPBAR) lead test assembly (LTA) and its acceptability, (2) the surveillance program, and (3) the testing and inspection program.

2.1 LTA Design Description

In Section 2.1 of its report, DOE describes the design features, materials, and operation of the TPBAR. The TPBAR LTA is designed to meet the operating requirements of a large four-loop Westinghouse reactor under Condition I, II, III, and IV events,[1] as defined in the Watts Bar Final Safety Analysis Report.

The LTA consists of a Westinghouse hold-down assembly with 8 TPBARs and 16 thimble plugs as shown in Figure 2-1 of the DOE report. The TPBAR will be inserted into a fresh 17x17 Westinghouse standard fuel assembly that has no control rod assembly. The external dimensions of the TPBAR are similar to those of the standard Westinghouse burnable poison rod assembly (BPRA). Design characteristics of the TPBAR, the conventional BPRA, and wet annular burnable assemblies (WABAs) are compared in Table 2-1 of the DOE report: the TPBAR is dimensionally similar to both the BPRA and the WABA. Because the TPBARs are installed in the standard Westinghouse guide thimble, the diameter of TPBARs is similar to that of the BPRA and the WABA. Because of the length of the absorber's poison (142 in.) (360.7 cm) and overall length of the rods (152.35 in.) (387 cm), the TPBAR is physically more similar to the BPRA (rod length = 152.59 in. [387.6 cm], poison = 142 in.) than the WABA (rod length = 149.83 in. [380.6 cm], poison = 134 in. [340 cm]). The dimensions listed in Table 4-1 of the DOE report vary slightly from the dimensions presented in Table 2-1 of the DOE report.

On the basis of the comparison of dimensions between the TPBAR and the conventional BPRA and the use of standard Westinghouse design components for the LTA hold-down assemblies, the staff concludes that TPBARs are similar in form to BPRAs. The staff's evaluation as to whether the TPBAR is similar in function to the BPRA is in Sections 3 and 4 of this safety evaluation, which relate to the nuclear and thermal-hydraulic design of TPBARs.

The LTA is designed for a large four-loop Westinghouse pressurized-water reactor (PWR) and is compatible with the fuel assembly, reactor vessel internals, reactor coolant chemistry, refueling

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[1] Condition I = normal operation and operational transients; Condition II = faults of moderate frequency; Condition III = infrequent faults; Condition IV = limiting faults

system and tools, and spent fuel storage facility. The LTA is a removable reactor core component, installed inside a fuel assembly that has no reactor control rod assembly.

The TPBAR LTA design consists of subcomponents clad with American Iron and Steel Institute (AISI) Type 316 stainless steel (316 SS). The 316 SS tubular cladding gives structural strength and acts as the pressure barrier between the TPBAR internals and the reactor coolant system (RCS). The inner surface of the cladding is coated with a permeation-resistant aluminum barrier. The TPBAR internals consist of a plenum subassembly, 12 pencils, and a lower getter disk. A pencil consists of a Zircaloy-4 liner tube surrounded by absorber pellets. The liner and absorber pellets are contained in a getter tube. The getter tube is made from nickel-plated Zircaloy-4 (NPZ). The nickel plating maintains the getter effectiveness by preventing oxidation of the Zircaloy-4; the oxide film would become a permeation-resistant film.

The Zircaloy-4 liner inside the absorber pellets scavenges free oxygen and water vapor by reacting to form an oxide on its surface. The reaction of the tritiated water vapor with the liner releases tritium, which is then absorbed by the getter. The liner also provides mechanical support to keep the absorber pellets from relocating.

The upper getter disk and an attached getter tube house a stainless steel plenum spring located above the top pencil in the cladding tube. This subassembly provides an axial force to restrain the pencils during handling and shipping operations and allows for axial growth of the pencils caused by irradiation, hydriding, and thermal growth of the pencils while in the reactor. The upper disk subassembly and the lower getter disk maintain low tritium partial pressure at the ends of the TPBAR to minimize tritium leakage through uncoated weld preparation zones of the cladding and end plugs.

The TPBAR is sealed using a 316 SS top plug and a 316 SS bottom plug welded to the cladding tube. Before the final closure is welded shut, the TPBAR is evacuated and repressurized to 1 atmosphere with helium.

2.2 Mechanical Design Evaluation

In Section 2.2 of its report, DOE has established and evaluated a number of criteria for the TPBAR. DOE has specified that swelling or shrinking of internal TPBAR components must be accommodated by the TPBAR design. On the basis of the specified tolerances and clearances, and considering the extensive documentation of the selected materials behavior in the reactor environment, DOE states that the design adequately addresses swelling and shrinking of the TPBAR components for the design irradiation lifetime. The swelling and shrinking of each TPBAR component is discussed in the sections that follow.

2.2.1 Cladding and Top and Bottom End Plugs

Section 2.2.1 of DOE's report states that the structural integrity of the TPBAR will be maintained during Conditions I through IV, and throughout shipping and handling, with the exception of the large-break loss-of-coolant accident (LBLOCA). The cladding, end plugs, and associated welds form the pressure boundary of the TPBAR. The integrity of this pressure boundary during Condition I, II, III, and IV events is discussed next.

Stress-Strain

In Section 2.2.1.1 of its report, DOE states that the TPBAR cladding stresses and the end plug weld stresses will not result in cladding collapse, excess ovality, or cracking over the irradiation life of the TPBAR. The structural members (cladding and top and bottom end plugs) of the LTA were designed using stress and fatigue criteria and methodology consistent with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (ASME Code, Section III, Division I, Subsection NG, Article 3220, 1995.) The external pressure criteria of the code were excluded because the LTA is not a reactor core structural component. Also, strength values used to calculate the TPBAR stresses are based on materials data because the material properties of American Society of Testing and Materials Standard A771 Type 316 stainless steel (ASTM A 771 316 SS) are not included in the code. The stress correlation shown in the DOE report is used to evaluate the discontinuity stress at the weld junction between the cladding and end plug.

DOE states that the highest loads on the BPRA or TPBAR are caused by worst-case operating pressures or by handling and shipping loads. Handling and shipping loads exceed the loads encountered during seismic events. Therefore, operating-basis earthquake (OBE) and safe-shutdown earthquake (SSE) loads were not analyzed in the cladding stress analysis and are bounded by the loads analyzed by DOE.

DOE has analyzed the cladding for the most conservative pressure, temperature, and dimensional tolerances for Conditions I, II, III, and IV. For each design condition, the internal design pressure was assumed to be the worst case internal pressure (accounting for non-ideal gas behavior) at the temperature of concern. The factor of safety for each design condition exceeds the requirements of the ASME Code.

DOE states that the results indicate that, except for the LBLOCA (where the TPBARs are assumed to fail), the lowest factor of safety based on yield strength is during the hydrostatic test at 1.25 times the reactor design pressure. Stress analyses of the TPBAR produced the following results:

- Critical buckling pressures were verified by experiment to be greater than the RCS design pressure and temperature of 2500 psia (17.2 MPa) and 660 °F (347 °C). The lowest

factor of safety based on pressure is 2.3 (critical buckling pressure divided by the measured pressure).

- The TPBAR was designed to prevent collapse or excess ovality from the effects of pressure, external temperature, and irradiation-induced creep.

- The TPBAR was designed not to collapse under hydrostatic pressure test conditions.

- A pressurized TPBAR was designed to withstand a 4-g axial and a 6-g lateral shipping and handling load at the end of life (external pressure of 14.7 psia [0.1 MPa] and internal pressure of 1420 psia [9.8 MPa] at 72 °F [22 °C]), with a factor of safety of 4.9.

On the basis of cladding stress calculations, DOE states that cladding breach is not expected during a small-break loss-of-coolant accident (SBLOCA). However, because high cladding pressures occur at elevated temperatures during an LBLOCA, it is likely that the TPBAR cladding would fail under postulated accident conditions. Burst testing of specimens indicates that the cladding will burst at about 1500 °F (815.5 °C) and 5230 psia (36.1 MPa), compared to a predicted LBLOCA temperature of 2200 °F (1204 °C) with a differential pressure across the cladding that would exceed 5230 psia (36.1 MPa). Chapter 6 of the DOE report assesses the effects of a TPBAR rupture.

DOE states that cold-worked (CW) 316 SS cladding is stable at the irradiation temperatures and neutron fluence encountered during the in-core residence period for the TPBAR, 650 °F (343 °C) and 5×10^{21} n/cm^2 (E>1MeV). The irradiation creep and volumetric swelling strains are less than 2 percent. Nominal changes in cladding diametric dimensions due to irradiation creep are plotted in Figure 2-4 of the DOE report and are less than 0.0004 in. (10.2 μm). This is much less than the design limit on cladding strain of 1 percent.

The staff concludes that the method used to analyze the stresses on structural members is conservative as long as the margins specified in Subsection NG of Section III of the ASME Code are satisfied. However, DOE used the 1995 edition of the code, but the staff has only endorsed the 1989 edition. (A comparison of Article NG-3220 in the 1995 edition with Article NG-3220 in the 1989 edition indicates that they are identical.) A licensee that uses this analysis must submit a relief request to use the later edition.

The staff further concludes that reliance on ASTM A 771 for the purchase of the cladding does not satisfy the requirements of 10 CFR Part 50, Appendix B. The quality assurance (QA) program described in ASTM A 771 needs to be supplemented to include conformance with NQA-1 and 10 CFR Part 50, Appendix B.
DOE's analysis provides reasonable assurance that the cladding and top and bottom end plugs are designed consistent with the ASME Code for both static and fatigue loads. DOE's conclusion that the OBE and SSE loads need not be analyzed since the worst-case pressures and handling and shipping loads exceed the loads induced by the OBE and by the SSE is acceptable.

DOE's analysis, experimental data, and operating experience offer reasonable assurance that the cladding will not be affected for Conditions I, II, and III. DOE's experimental data indicate that the cladding is expected to fail during an LBLOCA (Condition IV). On the basis of the design of the Westinghouse four-loop reactor, the fuel bundles and TPBAR cladding temperature could reach 2200 °F (1204 °C) during a postulated LBLOCA, much higher than the temperature at which the cladding is expected to fail. The consequences of the cladding failure are discussed in detail in Section 6.3.3 of this safety evaluation.

Cladding Collapse

In Section 2.2.1.2 of its report, DOE states that the cladding will be free- standing and will not collapse as a result of external pressure or creep for a design life of 550 effective full-power days (EFPDs), corresponding to an 18-month fuel cycle. DOE describes external pressure tests of barrier-coated cladding in Chapter 5 of its report. DOE states that these tests demonstrate that the cladding is strong enough to resist mechanical buckling from the reactor coolant pressure. DOE also states that the calculated change in ovality of a TPBAR as a function of time, neutron flux, and uniform external pressure caused by cladding creep shows that the TPBAR cladding resists collapse through creep buckling.

On the basis of its review of Section 2.2.1.2 of DOE's report, the staff concludes that DOE has demonstrated through analysis of experimental data that the design factors of safety for Subsection NG are met. This, along with DOE's operating experience, gives adequate assurance that the cladding will remain free-standing and will not collapse because of external pressure or creep for the design life.

Vibration Fatigue, Design Cycle Fatigue, and Fretting Wear

Section 2.2.1.3 of DOE's report states that neither the TPBAR nor its associated guide thimble will fail because of vibration fatigue, design cycle fatigue, or fretting wear resulting from reactor coolant flow-induced vibration. Reactor coolant flowing axially through the annulus between the TPBAR and the fuel assembly guide thimble imposes bending stresses that cause the TPBAR to vibrate. The maximum credible vibration stress was calculated to be an alternating stress that is bounded by the gap between the TPBAR and the guide thimble. This stress is significantly less than the endurance limit of 24,000 psi (165.5 MPa) specified by the ASME Code and, therefore, the number of cycles a TPBAR may be subjected to without failure is well in excess of 1×10^{11}. To exceed 1×10^{11} cycles during an 18 month fuel cycle (550 EFPDs) would require the TPBAR to oscillate at 2100 Hz. Tests have shown that a BPRA constrained within a guide thimble oscillates at less than 1 Hz. A TPBAR and BPRA are dimensionally the same and are similar in weight and stiffness, and should exhibit similar frequencies of oscillation. BPRAs used in PWRs have not experienced failure from vibration fatigue. Therefore, the staff concludes that failure of a TPBAR as a result of vibration fatigue is not plausible.

Flow-induced vibration of a TPBAR within a guide thimble could cause the contacting surfaces to wear. The TPBAR and a BPRA are dimensionally similar and are similarly constrained by the guide thimble while vibrating. DOE states that experience and available test data for BPRAs, including austenitic SS clad BPRAs, have shown the wear to be acceptable. The similarity in resistance to wear of 304 SS and 316 SS further ensures that the wear for the LTA will be acceptably small. DOE's conclusions are consistent with the absence of BPRA failures by these mechanisms. The cladding was evaluated for design cycle fatigue failure caused by changes in pressure and temperature during the reactor duty cycle, using the ASME Code. The staff concludes that, as long as the cladding satisfies the conditions of Article NG-3222.4(d), it will have the ability to withstand the cyclic service, and an analysis in accordance with Article NG-3222.4(d) is not required. The design cycle fatigue evaluation is based on the transient conditions and design cycles for Watts Bar, shown in Table 2-5 of the DOE report.

On the basis of its review of Section 2.2.1.3 of DOE's report, the staff concludes that DOE has provided reasonable assurance that the TPBARs will not fail as a result of such flow-induced effects as vibration fatigue, design cycle fatigue, or fretting wear based on calculated frequencies of vibration, previous experience with burnable poison assemblies, and previous experience with stainless steel cladding. This conclusion is supported by actual operating experience with stainless steel cladding on fuel assemblies in several plants, including the Consumers Power Company's Palisades plant.

Chemical Properties of the Cladding

Section 2.2.1.4 of DOE's report states that corrosion and erosion of the TPBAR outer surface will not cause material transfer into the reactor coolant in excess of rates applicable to other reactor internal components. The cladding is resistant to chemical attack from the chemical species normally present in the reactor coolant. Because 316 SS has not been extensively used for corrosion studies, data for the uniform corrosion of 304 SS were used to estimate the cladding wastage from corrosion by the reactor coolant. Based on the corrosion rates for 304 SS in PWRs and in the Engineering Test Reactor (ETR), DOE estimates that the corrosion rate for the TPBAR 316 SS cladding is less than 0.0001 in. (2.5 μm) per year. A conservative value of 0.0003 in. (7.6 μm) for an 18-month fuel cycle (550 EFPDs) was applied to the TPBAR. As discussed in Section 5 of this safety evaluation, 316 SS is more corrosion - resistant than 304 SS. Consequently, the wastage estimate used in the design evaluation is conservative for 316 SS. TPBARs are designed to be free of crevices; therefore, crevice corrosion is of no concern.

Stress corrosion cracking (SCC) in 300-series stainless steel requires sensitization, an aggressive environment, and high stresses; it may be aggravated by neutron fluences, hydrogen, and high temperatures. DOE states that the formation of oxidizing species is effectively suppressed in PWR coolant. Austenitic stainless steel is not susceptible to SCC in PWR coolant, because of the low oxygen concentration (less than 100 ppb). SSC is discussed in more detail in Section 5 of this safety evaluation. No significant chemical reaction is expected between the 316 SS TPBAR cladding or end plugs and the reactor coolant. DOE states that experience with SS-clad

fuel and BPRAs in PWRs indicates that, given the current PWR water chemistry, crud deposition is acceptably low.

Experience shows that erosion of austenitic SS clad BPRAs is insignificant. The wear resistance of 316 SS further ensures that the erosion of the LTAs will be acceptably small.

The staff concludes that DOE has presented operating and experimental data, which provide reasonable assurance that austenitic stainless steels, including 316 SS, are resistant to SCC in PWR environments. This is particularly true of the cladding of TPBARs that are only exposed to one operating cycle. There is also considerable evidence that austenitic stainless steels are highly resistant to erosion. The cladding on the reactor vessels of PWRs and the piping for the primary loop are constructed using austenitic stainless steels. High corrosion rates have not been observed, nor has erosion corrosion been reported in the piping or on the cladding. Also, stress corrosion cracking has not been reported for these materials in PWR environments.

2.2.2 Absorber Pellets

The thermal and physical properties of absorber pellets are summarized in Chapter 5 of the DOE report. In Section 2.2.2 of its report, DOE states that structural integrity of absorber pellets will be maintained while producing tritium. The next two sections address the chemical properties and the stability of the absorber pellet. These discussions lead to the conclusion that the structural integrity of absorber pellets is acceptable except for localized structural damage at the breach site during a postulated LBLOCA, and will be maintained during all Condition I, II, III, and IV events.

Chemical Properties of the Absorber Pellets

In Section 2.2.2.1 of its report, DOE states that the absorber pellets do not react with the TPBAR components. In the event of a cladding breach, water ingress would dissolve a microscopic layer of lithium from the surface of absorber pellets; otherwise, the absorber pellets are insoluble in the coolant water. Lithium is produced by irradiation of boron; hence, it is always present in the primary system. The small additional amount of lithium that might be introduced into the primary system as a result of cladding breach is expected to have little effect on materials in contact with the primary coolant.

Stability of the Absorber Pellets

In Section 2.2.2.2 of its report, DOE states that the strength of the absorber pellets enables them to resist fracture during TPBAR handling and to resist cracking from substantial thermal cycling during reactor operations. Thermal expansion and swelling for absorber pellets are described in the Materials Property Handbook (MPH). Lithium aluminate is a high-temperature ceramic material that is very stable at elevated temperatures. Thermal expansion and swelling strains are accommodated by the TPBAR design. No densification or significant phase change of the

absorber pellets is predicted over the range of temperatures encountered during Conditions I through IV.

Experience with irradiation of absorber pellets has shown excellent stability up to a gas volume ratio (GVR) of 239, based on theoretical pellet density, or 216 GVR, based on actual pellet density given in the DOE report. As discussed in Section 5 of the safety evaluation, absorber pellets were irradiated in the Advanced Test Reactor (ATR) to 239 GVR with only minor microcracking that had no effect on the structural integrity of the pellets. Absorber pellet disintegration, major cracking, and relocation is not expected below the design goal of 215 GVR. As indicated in Table 2-6 of the DOE report, the maximum calculated GVR is 209. The average GVR is 174.

The staff concludes that DOE has presented analysis and operating experience that gives reasonable assurance that the absorber pellets will maintain integrity during tritium production.

2.2.3 Getters and Liners

The thermal and physical properties of the getters and liners are discussed in Chapter 5 of the DOE report. Section 2.2.3 of the DOE report addresses the chemical and mechanical aspects of TPBAR design.

Chemical Properties of the Getters and Liners

In Section 2.2.3.1 of its report, DOE states that the getters and liners do not react with the other TPBAR components. DOE states that the Zircaloy-4 getter and liner are insoluble in the reactor coolant

Stability of the Getters and Liners

In Section 2.2.3.2 of its report, DOE states that dimensional changes in Zircaloy-4 getters and liners are caused by thermal expansion, irradiation growth, and hydride-induced swelling. DOE states that the irradiation growth of the Zircaloy-4 getters and liners at end of life (EOL) is less than 0.5 percent; therefore, the irradiation stability of the getter materials is acceptable. Hydriding cannot deform the cladding or the pellets because the hydrided getter is brittle and weaker than the cladding and pellets. The TPBAR dimensional design accommodates this growth and the swelling from hydriding.

The staff concludes that DOE has presented presented sufficient operating experience in an environment comparable to a PWR primary coolant to give reasonable assurance that the Zircaloy-4 getter and liner materials will experience no problems for the TPBAR design life of one cycle.

2.2.4 Plenum Spring

Section 2.2.4 of the DOE report states that the plenum spring will have sufficient preload and spring rate to prevent movement of the pencil column stack during fabrication, shipping and handling, considering a 4-g axial acceleration loading at beginning of life (BOL). DOE states that the spring is made from 302 SS and is similar in design to springs used in BPRA rods and fuel rods. The spring load stress has been established to be less than 60 percent of the yield stress, providing a safety factor of 1.66 after consideration has been given to tolerance stackup, internal and external pressure, thermal and radiation growth, compressed height of the spring, and pencil buckling. On the basis of a conservative safety margin and satisfactory commercial reactor experience with the material in this application, the spring is expected to provide the bearing load required for shipping and handling. No credit is taken for the spring in operational or reactor accident analysis.

Chemical Properties of the Plenum Spring

Section 2.2.4.1 of the DOE report states that the plenum spring is constructed of 302 SS and does not react with the other TPBAR components. The spring is only slightly soluble in the reactor coolant. In the event of a cladding breach, a very small quantity of SS would dissolve in the reactor coolant.

Stability of the Plenum Spring

Section 2.2.4.2 of the DOE report states that the dimensional changes in the plenum spring result from thermal expansion and irradiation growth. These phenomena are described in Chapter 5 of the DOE report.

The staff concludes that 302 SS is a high carbon stainless steel. The higher carbon content produces a higher yield and greater tensile strength, but a lower resistance to intergranular stress corrosion cracking (IGSCC). However, the 302 SS plenum spring is normally not in contact with the primary coolant because it is located within the sealed getter. Further, the PWR environment is not expected to cause SCC even if the primary solution comes in contact with the spring for part of one operating cycle.

2.2.5 TPBAR Analytical Models

Section 2.2.5 of the DOE report summarizes the analytical models used to calculate TPBAR operating temperatures, rod internal total pressure, pellet tritium release, gettering (process of chemically binding the tritium in hydrided form), and resulting tritium partial pressure.

The software used to calculate the TPBAR performance parameters is MATHCAD by Mathsoft Corporation. MATHCAD is an interactive spreadsheet, which permits calculations to be displayed and annotated, and which displays the results in an ongoing logical stream. In this

way, axial peak values, such as peak getter loading and peak tritium release, can be identified.

The modeling in MATHCAD is based on ex-reactor gettering rates and cladding permeation data, and is supported by some additional burnable absorber test data. DOE states that the models may contain large uncertainties for some situations. The uncertainty in modeling test rods for some phenomena is, therefore, relatively large. These uncertainties are accommodated

in the conservatism of the TPBAR design. The MATHCAD model will be updated whenever post-irradiation examination (PIE) data become available.

DOE will need to submit additional documentation to show that the MATHCAD model is conservative, since DOE points out that the uncertainty in modeling some phenomena is relatively large. This documentation could consist of results obtained for other applications using MATHCAD and compared with actual operating service.

TPBAR Component Operating Temperatures

Section 2.2.5.1 of the DOE report states that heat is generated in the TPBAR from two sources: the $^{6}Li[n,\alpha]^{3}H$ reaction in the absorber pellets, which produces 4.8 MeV of energy per disintegration, and gamma heating in the cladding, getter, liner, and the pellets. The heating from hydriding of the liner is negligible.

The TPBARs reside in guide thimbles within the fuel assembly, and are cooled by reactor coolant that flows up the annulus between the TPBAR and the guide thimble. The coolant in the annulus is heated slightly by the TPBAR, but gains significantly more heat from the guide thimble, which is heated by gamma radiation and heat transfer from the coolant outside the guide thimble. The coolant temperature rises from 559 °F (293 °C) at the bottom of the TPBAR to 620 °F (327 °C) at the top of the TPBAR.

Calculation of TPBAR Internal Pressure

Section 2.2.5.2 of the DOE report states that the internal pressure of the TPBAR is determined by the internal gas concentration and the gas temperature. Essentially all of the tritium generated in the TPBAR is absorbed by the getter and liner; therefore, the internal pressure is due to the helium generated in the TPBAR. The generation of helium in the absorber pellet results from the $^{6}Li[n,\alpha]^{3}H$ reaction and can be equated to the ^{6}Li depletion. The limiting design criterion for the internal gas pressure at 675 °F (357 °C) is 3000 psia (20.7 MPa).

The staff has reviewed Section 2.2.5 of the DOE report and concludes that DOE must present additional information to confirm that the MATHCAD analytical model is conservative when it is used to calculate TPBAR temperatures and pressures.

2.2.6 TPBAR Performance

TPBAR Bowing Caused by Thermal Effects, Radiation, Coolant Flow, and Creep

Section 2.2.6.1 of the DOE report states that the TPBAR must be sufficiently straight to allow insertion into a fuel assembly and must maintain dimensional integrity to allow removal from an irradiated fuel assembly without excessive force. DOE states that significant bowing of the TPBAR is precluded by the uniformity of its circumferential temperatures during irradiation, combined with the very small thermal creep, irradiation-induced creep, and swelling strains under the low stresses, temperatures, and neutron fluences encountered. TPBARs are restrained by the guide thimble so that the bowing is limited to what is permitted by the width of the annular region between the outer surface of the TPBAR and the inner surface of the guide thimble. This amount of bowing is accommodated by the TPBAR design without damaging the components. Analyses were performed to verify that the changes in internal component dimensions resulting from thermal, irradiation, coolant flow, and creep effects did not cause interferences between components. On the basis of BPRA experience and the analysis of TPBAR bowing, the thermal, irradiation, coolant flow, and creep effects are small enough not to inhibit the insertion of an LTA into an unirradiated fuel assembly or the removal of an LTA from an irradiated fuel assembly.

The flow through a guide thimble containing a BPRA or a TPBAR is a function of the guide thimble and rod cross-sectional areas. The external dimensions of the TPBAR are similar to those of a BPRA; therefore, guide thimbles containing either a TPBAR or a BPRA will have similar flow rates. Dimensional changes throughout the fuel cycle have an insignificant impact on flows. Therefore, the contribution to bowing of the TPBAR by reactor coolant flow is considered negligible, considering the structural strength of the TPBAR.

Compatibility of the TPBAR Internal and Cladding Materials

In Section 2.2.6.2 of its report, DOE states that the TPBAR components are mechanically, chemically, and metallurgically compatible during PWR irradiation conditions. Metallurgical liquidus interactions between components do not occur below 1760 °F (960 °C). Melting of the getter was not detected below 1832 °F (1000 °C) during transient heating tests. Specific melting temperatures for TPBAR component materials are presented in the MPH. The absorber pellet melting temperature of 3182 °F (1750 °C) exceeds all anticipated and design-basis temperatures.

The Advisory Committee on Reactor Safeguards (ACRS) questioned this DOE conclusion at DOE's March 7, 1997, presentation to the ACRS. The ACRS requested DOE to submit additional evidence to support the conclusion. ACRS has also requested information on thermal compatibility of coatings on the cladding, metal-metal interactions, and intermetallic interactions during design-basis accidents.

ACRS provided a preliminary assessment dated March 17, 1997, of the metal-metal interactions and intermetallic interactions during design basis accidents and concluded that the temperatures would not be high enough so that metal-metal or intermetallic interactions would be possible.

The staff likewise concluded that the temperatures would be too low to initiate any of these interactions based on examination of relevant phase diagrams. Nevertheless, DOE has agreed to respond to the ACRS questions. The staff will review this information following its submittal by DOE.

Water-Logging Rupture

As a result of experience with an irradiation of an iridium capsule at the Oak Ridge High Flux Isotope Reactor (HFIR), the staff asked DOE to prepare an analysis of the potential for water logging rupture of a TPBAR. DOE has provided its analysis in Section 2.2.6.3 of its report.

- Potential for Chemical Interaction

  Chemical reactions internal to the TPBAR include burnup-induced release of tritium and moisture from the lithium aluminate absorber pellets, oxidation of the liner, and hydriding of the getters. The TPBAR design requires that these reactions be limited to minimize internal pressurization with tritium gas and steam.

  Oxidation of the 316 SS cladding by the PWR coolant is discussed in Section 2.2.1.4 of the DOE report. Oxidation of the coated inner surface of the cladding is limited by the quantity of oxygen and moisture released from the lithium aluminate absorber pellets and remaining after reaction with the Zircaloy-4 liner.

  Breach of the TPBAR cladding is unlikely. In the event that a TPBAR is breached, water is expected to partially dissolve the aluminide barrier, releasing insignificant amounts of Al_2O_3, water-soluble $AlCl_3$, and other barrier constituents. Lithium aluminate is insoluble in water. A microscopic layer of lithium may be leached from the surface of the absorber pellets. However, given the high density and stability of the absorber pellets, and the fact that they are contained within a getter tube within the cladding, the possibility of pellet dissolution is extremely remote.

  In the event of a sudden temperature transient with a water-logged TPBAR, the low level of heat generation in the TPBAR would cause pressure changes to be sufficiently slow to allow the internal TPBAR pressure to equalize with the RCS pressure without further cladding damage or ejection of internal material. Also, the water would not boil because of the low heat generation and the increase in heat transfer caused by the replacement of helium inside the TPBAR with water. Radiological consequences associated with a postulated breached TPBAR are presented in Chapter 6 of the DOE report.

- Water-Logged TPBAR in Dry Cask Storage

  If a water-logged TPBAR is placed in dry cask storage, there is a potential for an increase in TPBAR temperature and pressure as a result of internal heat generation of the TPBAR.

A concern is that the water in the TPBAR could boil and cause overpressurization. However, the TPBAR generates less than 3 W of heat 150 hours after shutdown. An analysis of the TPBAR stored in a dry cask shows that the maximum temperature increase of the TPBAR due to internal heat generation is less than 3 °F and boiling will not occur in the TPBAR.

Mechanical Interaction Between Absorber Pellets and Cladding

In Section 2.2.6.4 of its report, DOE states that pellet-cladding interactions do not occur in the TPBAR because: (1) cladding creepdown is insufficient to close the gap between the cladding and the getter, (2) the getter encloses the pellets and thereby restricts pellet movement, (3) the annular pellets surround the liner, which further restricts the movement of the pellets, (4) the pellets are dimensionally stable, and (5) design clearances were selected to ensure that interference does not occur.

Failure and Burnup Experience

In Section 2.2.6.5 of its report, DOE states that a review of the failure and burnup experience during testing of absorber pellets and tritium target test rods is provided in Tables 2-5 and 2-6. No failures were observed.

TPBAR Component and Cladding Temperatures

In Section 2.2.6.6 of its report, DOE states that TPBAR component and cladding temperatures are compatible with the operating environment of Watts Bar.

Potential Effect of Sudden Temperature Transients

In Section 2.2.6.7 of its report, DOE states that sudden temperature changes during startup, shutdown, or power spikes do not cause significant thermal or differential thermal expansion stresses, because the TPBAR component walls are thin and the component thermal time constants are much less than the duration of the transient.

On the basis of DOE's calculations, test results, and past experience in DOE operating facilities, the staff concludes that DOE has provided reasonable assurance that the TPBAR components are mechanically, chemically, and metallurgically compatible during PWR irradiation conditions. In addition, the commercial nuclear industry has operating experience with austenitic stainless steel cladding in PWR environments at several plants, including Consumers Power Company's Palisades plant, and has not experienced problems with the stainless steel cladding after several years of service. There is also considerable operating experience with austenitic stainless steel reactor vessel cladding and austenitic stainless steel piping in PWR environments that indicates that austenitic stainless steel components are compatible with these environments.

2.3 Surveillance Program

In section 2.3 of its report, DOE states that an LTA surveillance program is not planned since the LTAs will only be irradiated for one cycle. Additionally, the current monitoring program at

Watts Bar should be abie to identify anomalies if they were to occur. The staff believes that the Watts Bar surveillance program should oe adequate for one cycle of operation with TPBAR LTAs installed in the core.

2.4 Testing and Inspection Plan

In Section 2.4 of its report, DOE states that no special testing or monitoring program is necessary. Standard start-up tests, flux mapping, and power monitoring will be performed in conjunction with Watts Bar's operating procedures.
In Section 2.4.4 of its report, DOE discusses the visual examination of the TPBAR LTAs after their removal from the core. The visual examination will be for obvious damage to TPBARs, which would then require special handling procedures.

2.5 Conclusions

The staff has reviewed the design of the TPBAR and has concluded that as long as the stresses on structural members meet the margins specified in Subsection NG of Section III of the ASME Code, the design will be conservative. DOE has presented sufficient analyses, test data, and operating experience data to give reasonable assurance that the TPBARs will be compatible with the environment in the core of a PWR. In addition, there is a large amount of operating data in-core and in the primary coolant system that indicates that austenitic stainless steels are compatible with PWR environments.

DOE presented experimental data and analyses which indicate that TPBAR cladding integrity will be maintained during Condition I, II, and III. The cladding will likely be breached during an LBLOCA at Condition IV. The consequences of this breach are discussed in Section 6.4.3 of this safety evaluation.

During its review of Chapter 2 of the DOE report, the staff identified a number of areas in which the Tennessee Valley Authority will have to present additional analyses as part of its application for an amendment to the facility operating license for Watts Bar before the staff can reach a conclusion of acceptability. These include the following:

(1) DOE has not addressed the use of the 1995 Edition of the ASME Code. A relief request will be required by the host plant for the use of the 1995 code since the NRC staff has only endorsed up to the 1989 Edition of the ASME Code.

(2) DOE has not addressed the conformance of the design with 10 CFR Part 50, Appendix B and NQA-1 because the cladding was ordered to conform to ASTM A 771. This will have to be resolved before the TPBARs can be loaded into a PWR core.

(3) DOE has not addressed the issues of the effect of thermal cycling on the components of the TPBAR and metal-metal and intermetallic interactions during a design-basis accident.

(4) DOE will need to present additional documentation to show that the MATHCAD analytical model is conservative when it is used to calculate TPBAR temperatures and pressures.

3 NUCLEAR DESIGN DESCRIPTION

In Chapter 3 of its report, the Department of Energy (DOE) discusses the effects of the tritium-producing burnable absorber rod (TPBAR) lead test assemblies (LTAs) in terms of nuclear design, power distribution, reactivity control, and reload safety analysis. Since the TPBARs will replace some of the burnable poison rods in the reload core, DOE proposes to demonstrate through scoping analyses that the TPBAR is similar in nuclear characteristics to burnable poison rod assemblies (BPRAs) and will satisfy the same nuclear design requirements. DOE states that the nuclear design criteria will be assessed in the core reload evaluation using NRC-approved methodologies. This chapter investigates whether the TPBARs have nuclear properties similar to BPRAs and wet annular burnable assemblies (WABAs) and whether the lithium-based absorbers have any sensitivities to gaps or fabrication tolerances that need to be considered in the reload analysis. Chapter 3 also compares the various neutronics codes – WIMS-E, PHOENIX-L, and MCNP – to assess any special modeling sensitivities that need to be considered. The analyses are presented as scoping studies and as supporting evidence for the reload safety evaluation, rather than as a direct assessment of the general design criteria. In order to establish the acceptability of operation with TPBAR LTAs in the reactor core, the reload analysis must demonstrate that the facility remains in compliance with 10 CFR Part 50. This will be verified during the staff's review of the Tennessee Valley Authority's (TVA's) application for an amendment to the facility operating license for Watts Bar.

3.1 Effects on Reactor Nuclear Design

In Section 3.1 of its report, DOE states that the TPBAR LTAs will have minimal impact on the commercial core. The primary model used in the neutronics scoping studies of the TPBARs is the WIMS-E computer code, a two-dimensional, multi-group, integral-transport model. Although not an NRC-approved methodology, WIMS-E was benchmarked by Pacific Northwest National Laboratory (PNNL) in a study of the light-water reactor concept for a DOE production reactor. The model used design characteristics of 17x17 fuel assemblies and large Westinghouse pressurized-water reactors (PWRs). WIMS-E was compared to MCNP (Monte Carlo N-Particle) Transport Code Version 4A for benchmarking purposes. Each code uses an independent set of nuclear cross-sections and different calculation methodologies. The Monte Carlo technique is generally considered the most accurate method for computing reactivity. The comparison demonstrates the adequacy of the WIMS-E model of the TPBAR. Therefore, differences in the calculated reactivity are expected and considered to be small. The DOE report states that a complete three-dimensional model of the host reload core with the LTAs will be performed by TVA and Westinghouse using an NRC-approved core design methodology.

The DOE report proposes that mimicking, to the extent feasible, the behavior of BPRAs ensures that the TPBARs will have minimal impact on the overall core design. This mimicking would be

accomplished by using a limited number of TPBARs in any one fuel assembly, by using a limited number of LTAs in the core, and by placing LTAs in core regions that are not limiting with respect to core thermal-hydraulic performance.

However, the DOE report does not contain a comparison of the reactivity characteristics of the TPBARs with the BPRAs. Instead, a comparison of the infinite medium multiplication factor (k_∞) for TPBARs and WABAs as a function of burnup is shown in Figure 3-1 of the DOE report. In this case, the close comparison between these two designs is a general indication that other core design parameters are also similar. This analysis illustrates that differences are small enough to be accommodated within the range of core-to-core variations that are customarily handled in fuel cycle design. However, the scoping analysis does not present a basis for ensuring that all core design limits are satisfied. The staff concludes that the Watts Bar license amendment request must contain a comparison of the reactivity characteristics of the TPBAR to the BPRAs in order to demonstrate that the TPBARs are functionally similar to the BPRAs.

3.2 Effects on Power Distribution

In Section 3.2 of its report, DOE evaluates the sensitivity of flux peaking on pellet gaps and fabrication tolerances. The revised DOE report states that the impact of TPBARs on overall power distribution will be similar to the impact of BPRAs and WABAs currently used in PWRs. TPBAR absorber pellets are contained in pencils, which are stacked in a column in the TPBAR. The interfaces between the pencils result in gaps between segments of absorber pellet material. Each gap produces a small local axial power peak in the adjacent fuel rods. Gaps are affected by manufacturing tolerances, temperature, and irradiation.

The peak pellet gap is calculated with DORT, a discrete ordinate transport code. This method should accurately represent the effect of an absence of absorber on the surrounding fuel pins. The staff notes that the maximum gap was calculated to be less than 400 mils. A 400-mil gap in the absorber pellet stack results in a relatively small local power peak of 4.5 percent in the surrounding fuel pins. As part of its application for an amendment to the facility operating license for Watts Bar, TVA must demonstrate that the effect of the 400-mil maximum gap on the Watts Bar core is acceptable.

An analysis of fabrication tolerances using the WIMS-E model assessed the effect of variations in TPBAR dimensional tolerances, ^{6}Li loading tolerances, and impurity specifications. Power peaking as a result of TPBAR fabrication tolerances was less than 1 percent. This peaking is small compared to other flux perturbation effects. Since it is assumed that the LTAs will not be placed in peak locations, the staff believes that peaking effects of less than 1 percent caused by fabrication tolerances are not likely to exceed fuel design limits, based on past experience with other reactor cores. The staff will verify that the peaking effects due to fabrication tolerances will not cause the fuel design limits to be exceeded during the staff's review of TVA's application for an amendment to the facility operating license for Watts Bar.

3.3 Effects on Control Requirements

In Section 3.3 of its report, DOE discusses the overall reactivity contribution of ^{6}Li in the LTA and its similarity to that of regular burnable absorber rod assemblies. The staff notes that the most significant difference in the behavior of the TPBAR is the decay of tritium to a strong absorber, ^{3}He. As discussed in the January 22, 1997, public meeting, the effect of tritium decay during a long shutdown near the end of a cycle might result in more negative reactivity in the TPBARs than in a comparable WABA or BPRA. The DOE report indicates that the tritium decay is being included in the PHOENIX-L upgrade, which is discussed in Section 3.4 of this safety evaluation, below. The staff believes that the Watts Bar reload analysis should consider a case that assesses the maximum negative worth of the TPBAR LTA. This case could be near the end of cycle following a long shutdown rather than the usual beginning-of-life case. Because of the number and proposed location of LTAs in the prototypical irradiation, the staff would expect the effect to be small and that no limiting conditions would be introduced. However, this will be confirmed during the staff's review of TVA's application for an amendment to the facility operating license for Watts Bar.

3.4 Changes in Reload Safety Analysis

In Section 3.4 of its report, DOE discusses the change in the standard suite of NRC-approved Westinghouse core analysis codes (PHOENIX/ANC) to account for the presence of the TPBAR in the core. In a letter dated May 17, 1988, the NRC staff approved the Westinghouse Topical Report WCAP-11596, "Qualification of the PHOENIX-P/ANC Nuclear Design System for Pressurized Water Reactor Cores," for use. Only the PHOENIX-P code, which is one of the NRC-approved Westinghouse core analysis codes, will be altered slightly to accommodate the presence of the TPBARs in the core. The proposed changes to the PHOENIX-P code model the depletion of ^{6}Li in the TPBARs, the decay of ^{3}H, and the production/depletion of ^{3}He. Westinghouse will document the new version, PHOENIX-L, in a report to PNNL and TVA, subject to the reporting criteria imposed by 10 CFR 50.46(a)(3). Westinghouse will maintain computer software verification and validation files on PHOENIX-L. The staff has asked Westinghouse to describe (in a letter to the staff) the specific changes to the PHOENIX-P code and the results of the benchmarking. The staff will review the letter from Westinghouse, discussing the changes to the PHOENIX-P code, as part of its review of TVA's application for an amendment to the facility operating license for Watts Bar.

The DOE report makes several comparisons between PHOENIX-L and WIMS-E in order to assess the reactivity as a function of fuel depletion. A number of studies compare the infinite medium multiplication factor (k_∞) as a function of burnup for various combinations of components. The staff notes that the studies show very good agreement between the codes. However, although the comparisons do not constitute a validation of the PHOENIX-L version, they do support the conclusion that use of PHOENIX-L does not introduce any significant degradation in predictions. The DOE report also indicates that the PHOENIX-L version will be benchmarked against the MCNP code in the Westinghouse verification and validation process.

3.5 Summary

In Section 3.5 of its report, DOE concludes that the TPBARs mimic the neutronic behavior of BPRAs and WABAs and that the plant-specific reload safety analysis will demonstrate that all established fuel design limits will be met. On the basis of this information, the staff concludes that the scoping analysis offers evidence that the TPBARs and the WABAs are functionally similar, but does not present a basis for assuring that all core design limits are satisfied.

As part of its application for an amendment to the facility operating license for Watts Bar, TVA should include the following:

(1) the Cycle-2 reload analysis;

(2) a comparison of the reactivity characteristics of the TPBAR and the BPRA, since they are dimensionally similar;

(3) an analysis of the effect of a 400-mil gap in the absorber pellet stack to demonstrate that a local power peak of 4.5 percent in the surrounding fuel pins will be the maximum achieved;

(4) a case that assesses the maximum negative worth of the TPBAR LTA;

(5) benchmarking of the PHOENIX-L code.

Since the reload core analysis is not complete, the staff cannot determine whether unreviewed safety questions exist in the TPBAR nuclear design.

4 THERMAL AND HYDRAULIC DESIGN

Chapter 4 of the Department of Energy (DOE) report addresses the impact of the tritium-producing burnable absorber rod (TPBAR) lead test assembly (LTA) on the Watts Bar reactor core thermal-hydraulic design.

4.1 TPBAR Thermal-Hydraulic Design

Section 4.1 of the DOE report presents the thermal-hydraulic design criteria for TPBARs. Three of the four criteria are the same for burnable poison rod assemblies (BPRAs) and wet annular burnable assemblies (WABAs). The design criteria are as follows:

(1) The maximum TPBAR coolant outlet temperature from the guide thimble must not exceed the coolant bulk boiling temperature during Condition I (normal operation and operational transients) events.

(2) The maximum TPBAR cladding temperature must not exceed the temperature associated with the onset of subcooled nucleate boiling during Condition I and II (faults of moderate frequency) events.

(3) The core bypass flow through the guide thimbles must be limited to ensure that sufficient coolant flow is provided to the fuel rod channels to meet fuel and thermal-hydraulic design criteria.

(4) The TPBARs must not be placed (inserted) in a limiting core location.

The fourth provision is standard for any LTA. As discussed in Chapter 2 of the DOE report, the TPBARs are designed to withstand the same core temperatures as other reactor core components. As the dimensions of a TPBAR are similar to those of a BPRA, bypass flow in the guide tube is nominally the same. Guide tubes in the fuel assembly not used for TPBARs are plugged with standard Westinghouse thimble plugs. The total flow through guide tubes containing a TPBAR LTA is expected to be similar to flow for a standard BPRA. The argument for hydrodynamic stability is also based on the similarity of design parameters. Since the dimensions, heating, and mechanical characteristics of the TPBAR in a guide tube channel are the same as for the BPRA, the hydrodynamic stability is likely to be the same for Condition I and II events.

The DOE report states that the thermal-hydraulic analysis of the TPBAR design was performed by hand calculations and MATHCAD software. These calculations were not presented in the report; however, Tables 4-2 and 4-3 of the report summarize some of the Watts Bar parameters that were used in the thermal-hydraulic analysis. The staff notes that these parameters appear to

be Cycle 1 parameters. As noted in Table 4-2 of the report, Cycle 2 parameters increase slightly but have not yet been entirely established. On the basis of this preliminary analysis, the DOE report states that the thermal-hydraulic criteria are met with the TPBAR located in an assembly with a total power peaking of up to 1.42 and with the TPBAR adjacent to a fuel rod with an F_{dh} (enthalpy-rise hot channel factor) of 1.65 or less. Since the analysis, i.e., the hand calculations, was not presented in the DOE report, the staff cannot conclude at this time that the thermal-hydraulic criteria are met with TPBARs located in assemblies discussed above. The staff will review the Cycle-2 thermal-hydraulic analysis as part of its review of the Tennessee Valley Authority's (TVA's) application for an amendment to the facility operating license for Watts Bar.

4.2 Impact on Reactor Core Thermal-Hydraulic Design

In Section 4.2 of the its report, DOE states that the thermal and hydraulic design parameters for Watts Bar were used as evaluation points to determine if any impacts of the TPBAR LTA on the reactor core thermal-hydraulic design would exist. DOE presents these parameters in Table 4-4. The staff notes that no parameter of the core design is changed by the TPBAR LTAs, except that the TPBARs have a slightly higher power than the BPRAs. Section 4.3 of the DOE report concludes that the thermal and hydraulic design bases of the TPBARs ensure that the TPBAR cladding will not be breached during Condition I and II events. DOE bases this statement on the assumption that the TPBAR LTAs will not be placed in a limiting position in the core. The staff cannot conclude, on the basis of the information provided in the DOE report, that the TPBAR LTAs will not affect the Watts Bar thermal-hydraulic design, with the TPBAR located in an assembly with a total power peaking of up to 1.42 and with the TPBAR adjacent to a fuel rod with an F_{dh} of 1.65 or less. Since the DOE thermal-hydraulic analysis is preliminary, it is the host facility's responsibility to determine whether the thermal-hydraulic behavior of the TPBAR LTAs located in non-limiting positions in the core represents an unreviewed safety question, as defined in 10 CFR 50.59(a)(2). As stated above, the staff will review the Cycle-2 thermal-hydraulic analysis as part of its review of TVA's application for an amendment to the facility operating license for Watts Bar.