WASHINGTON STATE UNIVERSITY
Nuclear Radiation Center

August 22, 2008

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Re: Docket # 50-27
Facility License # R-76

Enclosed please find the answers to the additional RAIs issued to the Washington State University Nuclear Radiation Center. As well as, the WSU NRC Technical Specifications.

I declare under penalty of perjury that the foregoing is true to the best of my knowledge.

Respectfully Submitted,

Donald Wall

Donald Wall,
Director

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A020
NRR

WSU Additional RAI
DRAFT4, 15 August 2008

1. Your additional input to your answer for request for additional information (RAI) 28 dated August 4, 2008, provided the results of thermal hydraulic analysis at 50 °C pool temperature and a reactor power level of 1.0 MW(t). However, TS 3.1 allows reactor power levels up to 1.3 MW(t). Please provide a new analysis performed at the license limits of 50 °C pool temperature and 1.3 MW(t) reactor power level. Discuss why the results of the analysis are acceptable.

Revised Response to RAI Question 28:

Washington State University currently has an administrative limit of 50°C for maximum pool water temperature – the reactor may not be operated with pool water temperatures greater than 50°C. The reactor pool water cooling system has been shown to be capable of indefinitely maintaining the pool water temperature below 50°C when operating at full licensed power, under all ambient weather conditions.

The analysis was repeated for a power level of 1 MW, to show that thermal hydraulic results are still acceptable at 50°C. Results are presented below for the hottest fuel element.

| Parameter | Inlet Temp 30°C (86°F) | Inlet Temp 50°C (122°F) |
|---|---|---|
| Exit Coolant Temperature, °C (°F) | 84.06 (183.3) | 98.3 (208.9) |
| Maximum Wall Temperature, °C (°F) | 142.6 (288.6) | 142 (288) |
| Peak Fuel Temperature, °C (°F) | 500 (932) | 499 (931) |
| Minimum DNB Ratio | 2.50 | 2.20 |
| Channel Mass Flow Rate, kg/sec | 0.0919 | 0.103 |
| Maximum Flow Velocity, cm/sec | 18.90 | 21.3 |
| Exit Clad Temperature, °C | 130.9 | 131 |

Since limited operation is permissible up to a power level of 1.3 MW, the analysis was repeated at that power level with an inlet temperature of 50°C to show that they are still acceptable. Results are presented below for the hottest fuel element.

| Parameter | Inlet Temp 30°C (86°F) | Inlet Temp 50°C (122°F) |
|---|---|---|
| Exit Coolant Temperature, °C (°F) | 91.98 (197.6) | 101.3 (214.4) |
| Maximum Wall Temperature, °C (°F) | 165 (330) | 165 (329) |
| Peak Fuel Temperature, °C (°F) | 541 (1005) | 540 (1004) |
| Minimum DNB Ratio | 1.92 | 1.69 |
| Channel Mass Flow Rate, kg/sec | 0.104 | 0.126 |
| Maximum Flow Velocity, cm/sec | 21.6 | 26.9 |
| Exit Clad Temperature, °C | 141 | 141 |

Both results show a reduction in the DNB ratio but very little change in fuel or cladding temperatures. An increase in natural circulation flow helps to offset the effect of the higher coolant inlet and exit temperatures.

The analyses for DNB are based on the Bernath correlation which has been used for TRIGA reactors for many years. The results shown in the tables above are reasonable to ensure the safety of the facility.

2. Your LOCA analysis shows that at a continuous reactor power of 1.3 MW(t), the power density in some fuel elements may exceed the acceptance criteria. Please provide additional analysis to show that the results of the LOCA are acceptable. If the boundary conditions of the additional analysis impact technical specifications (TSs) (e.g., power level), please propose amended TSs with justification.

*Response: The maximum licensed power level of the WSUR is 1000 kW(t). A Limiting Condition of Operation in Technical Specification 3.1 (Steady-State Operation) states that: "The reactor power level shall not exceed 1.3 MW under any condition of operation." The redundant high-power level trips at the reactor are set at 1.15 – 1.2 MW, providing a conservative margin to ensure that the power level of 1.3 MW is not exceeded. That is, the reactor is operated under normal conditions at its maximum licensed power of 1.0 MW.*

*The decay heat curve used in the LOCA analysis assumed that the reactor was operated continuously at 1.0 MW for an infinite length of time. Using this exceedingly conservative assumption, the limiting fuel element would reach the fuel temperature safety limit in air of 950°C based on hydrogen overpressure at a power level of 23.5 kW. The limiting fuel element has a power of 20.8 kW when the reactor is operated at 1.0 MW. Taking into account an uncertainty of 4% in the power level measurement, the maximum fuel element power during continuous operation at 1.0 MW would be 20.8 x 1.04 = 21.6 kW. This power is considerably less than the limiting power of 23.5 kW.*

*Washington State University would also like to request that the Technical Specifications 3.1 Steady-State Operation be written as a verbatim duplication of the language in Amendment 13, to wit:*

*3.1 Steady-State Operation*

*Applicability: This specification applies to the energy generated in the reactor during steady-state operation.*

*Objective: The objective is to ensure that the fuel temperature safety limit will not be exceeded during steady-state operation.*

*Specifications: The reactor power level shall not exceed 1.3 MW under any condition of operation. The normal steady-state operating power level of the reactor shall be 1.0 MW. However, for purposes of testing and calibration, the reactor may be operated at higher power levels not to exceed 1.3 MW during the testing period.*

*Basis: Thermal and hydraulic calculations performed by the vendor indicate that TRIGA fuel may be safely operated up to power levels of at least 2.0 MW with natural convection cooling.*

*WSU requests that TS 3.1 be written exactly as in Amendment 13 in order to clarify the fact that 1.0 MW is the power at which the reactor is operated, and that operation at power levels greater than 1.0 MW is an infrequent and unusual condition. The operational history of the WSU reactor was reviewed for the period of January 02, 2003 through August 20, 2008. The highest recorded power level for the period of 1/2/2003 through 8/20/2008 was 1.07 MW, on May 1, 2006, for instrument calibration purposes. The power was maintained at 1.07 MW for 8 minutes (also recorded as 0.13 hours). There were 7554.1 operational hours logged on the reactor during the same time period, i.e. 1/2/2003 through 8/20/2008. Reactor operation logs do not show any steady-state power level higher than 1.07 MW at any time since January 2, 2003. As a result, the LOCA analysis at 1.0 MW is an accurate representation based on actual operating history.*

3. Your additional input to your answer for RAI 40 dated August 4, 2008, contained limits on the location of the instrumented fuel element (IFE) in the core so that the limiting system safety setting protects the safety limit. However, the wording of TS 2.2 does not reflect the new restrictions on the location of the IFE given in the analysis. Please address.

The following supplemental information provides additional analysis for BOL, MOL, and EOL conditions that cause constraints on permissible locations for the IFE.

**40. Section 14.2.2. Section 13.3 of the SAR evaluates the LSSS for two specific IFE locations. However, the TS allows the IFE to be located anywhere in the 30/20 fuel region. Please repeat the analysis for the worse case to show that the LSSS as proposed protects the safety limit.**

Revised Response (21 August 2008):

The worst IFE location would be E6SE which has an RPF of 1.224 and a maximum APF of 1.47 under BOL hot conditions. The rod power is lowest among the 30/20 LEU fuel because it is in the far SE corner. The APF is high because it is located adjacent to a control blade. Thermocouple sensing tips are located 6.5", 7.5", and 8.5" from the bottom of the fuel. TAC2D calculations of this location gave the following values for the highest and lowest temperatures of the three thermocouple sensing tips if the IFE were to be located there.

Highest and Lowest Temperatures of Thermocouple Sensing Tips of an IFE in Core Position E6SE as a Function of Reactor Power Under BOL Hot Conditions

| Reactor Power, MW | Highest Temperature Thermocouple Sensing Tip, °C | Lowest Temperature Thermocouple Sensing Tip, °C |
|---|---|---|
| 1.0 | 408 | 382 |
| 1.3 | 440 | 412 |
| 1.8 | 512 | 478 |
| 2.0 | - | 491 |
| 2.2 | - | 504 |

These calculations predict that the lowest temperature thermocouple at 8.5” from the bottom of the fuel would read 491°C at a reactor power of 2.0 MW and 504°C at a reactor power of 2.2 MW. Thus, a reactor power of 2.14 MW (interpolated) would be needed to reach an LSSS temperature of 500°C. At 2.2 MW, the maximum powered rod in position D4NE would have a peak fuel temperature of 836°C. Since the response to Question 28 of the June 2008 RAI submittal shows that departure from nucleate boiling (DNB) as predicted by the Bernath correlation is expected to occur at a power level of 2.2 MW, if the pool water inlet temperature were 50°C, position E6SE is not an acceptable location for the IFE because the IFE would not protect the safety limit of 1150°C if DNB were to occur in the hottest rod.

Actually, the safety limit would be protected by the redundant high power trips at 1.2 MW and an IFE in position E6SE would not be relevant. An approach to using the IFEs to protect the safety limit if both power trips were to fail is to select IFE locations where the reactor power level would be low enough to remain far below the power level (2.2 MW) at which DNB is predicted to occur in the hottest rod. A maximum reactor power level of 1.7 MW was selected as reasonable for this purpose.

The product of the reactor power level, the rod power peaking factor, and the axial power peaking factor at the level of the thermocouple being considered uniquely defines the thermocouple temperature reading. The TAC2D calculations described above indicated that a reactor power of 2.14 MW, a rod power peaking factor of 1.22, and an axial power peaking factor of 1.15 for the lowest temperature thermocouple produced a thermocouple reading of 500°C. Therefore, the product 2.14 MW × 1.22 × 1.15, which equals 3.00 MW, will correspond to a thermocouple reading of 500°C.

Analyses for BOL Hot Conditions

Table 40-1 shows the rod power peaking factors for LEU Mixed Core 35A under BOL hot conditions. All of the candidate core positions for the IFE are in the white region, which is located between the control blades where the LEU 30/20 fuel is planned to be inserted. Table 40-2 shows the maximum axial power peaking factor and the axial power peaking factors for the IFE thermocouples located at 6.5”, 7.5”, and 8.5” from the bottom of the fuel.

Table 40-3 shows the product of the rod power peaking factors in Table 40-1 and selected axial power peaking factors in Table 40-2 for the planned 30/20 fuel positions in LEU Mixed Core 35A. The upper value for each rod position is the product of the rod peaking factor and the axial peaking factor for the thermocouple located at 6.5” from the bottom of the fuel (hottest axial location). The lower value for each rod position is the product of the rod power peaking factor and the axial peaking factor for the thermocouple located at 8.5” from the bottom of the fuel (coldest axial location).

Table 40-4 shows the power level in each fuel rod when the hottest and the coldest thermocouples are predicted to reach 500˚C for LEU Mixed Core 35A under BOL hot conditions. These power levels are 3.0 MW/(Factors in Table 40-3).

For both the hottest and the coldest thermocouples, IFE located in the rod positions shown in green would protect the fuel temperature safety limit of 1150˚C for reactor power levels that are less than 1.7 MW. The positions shown in red are excluded as possible IFE locations because power levels greater than 1.7 MW would be required to reach 500°C in the coldest thermocouple. The positions shown in orange would also protect the fuel temperature safety limit, but could cause the reactor to trip at a temperature of 500°C on the hottest or the coldest thermocouple before the redundant power level trips at 1.2 MW. Thus, the positions shown in orange are excluded for practical operational reasons and not for safety reasons.

Analyses for EOL Hot Conditions

The next step is to repeat the above analysis for EOL hot conditions to determine if any additional core positions should be excluded as potential IFE positions due to changes in the power distributions during burnup. Table 40-5 shows the rod power peaking factors for LEU Mixed Core 35A under EOL hot conditions.

Since the control blades are fully-withdrawn at EOL, the axial power distribution has a chopped cosine shape. The axial power peaking factor at a height of 7.5 inches from the bottom the fuel where the central thermocouple is located is 1.26 (See Table 18, WSU Conversion Safety Analysis, August 2007). The corresponding axial power peaking factor for the thermocouples located at 6.5" and 8.5" from the bottom of the fuel is 1.244.

Table 40-6 shows the product of the rod power peaking factors in Table 40-5 and axial power peaking factors of 1.26 and 1.244 for the planned 30/20 fuel positions in LEU Mixed Core 35A under EOL hot conditions. The upper value for each rod position is the product of the rod peaking factor and the axial peaking factor for the thermocouple located at 7.5" from the bottom of the fuel (hottest axial location with the blades fully-withdrawn). The lower value for each rod position is the product of the rod power peaking factor and the axial peaking factor for the thermocouple located at 6.5" or at 8.5" from the bottom of the fuel (coldest axial locations).

Table 40-7 shows the power level in each fuel rod when the hottest and the coldest thermocouples are predicted to reach 500°C for LEU Mixed Core 35A under EOL hot conditions. These power levels are 3.0 MW/(Factors in Table 40-6). The results indicate that three additional rod positions C6SW, D2NW, and D2SW (in addition to those shown in red for BOL hot conditions in Table 40-4) should be excluded as possible IFE locations because power levels greater than 1.7 MW would be required to reach 500°C in the coldest thermocouple.

Based on the smoothly-descending burnup curve shown in Figure 30 of the WSU Conversion Safety Analysis submitted in August 2007, the product of the rod power peaking factors and axial power peaking factors at middle-of-life (MOL) hot conditions are expected to be in-between the results shown in Tables 40-3 and 40-6. Consequently, the positions shown in green in Table 40-7 are the allowed IFE locations for LEU Mixed Core 35A for its entire lifetime because they protect the fuel temperature safety limit of 1150°C for reactor power levels that are less than 1.7 MW. The positions shown in red are excluded as possible IFE locations because power levels greater than 1.7 MW would be required to reach 500°C in the coldest thermocouple under BOL, MOL, or EOL hot conditions. The positions shown in orange would also protect the fuel temperature safety limit, but could cause the reactor to trip at a temperature of 500°C on the hottest or the coldest thermocouple before the redundant power level trips at 1.2 MW are reached. Thus, the positions shown in orange are excluded for practical operational reasons and not for safety reasons.

Table 40-1. Rod Peaking Factors for LEU Mixed Core 35A at BOL, HOT

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B | 0.23 | 0.27 | 0.35 | 0.42 | 0.46 | 0.52 | | | | | 0.49 | 0.42 | | |
| | 0.28 | 0.33 | 0.45 | 0.55 | 0.60 | 0.65 | | | | | 0.63 | 0.55 | | |
| C | 0.40 | 0.50 | 0.65 | 0.70 | **1.58** | **1.51** | **1.56** | **1.57** | **1.56** | **1.53** | **1.44** | **1.37** | 0.55 | 0.51 |
| | 0.47 | 0.62 | 0.70 | 0.73 | **1.72** | **1.68** | **1.76** | **1.86** | **2.22** | **1.73** | **1.49** | **1.42** | 0.62 | 0.58 |
| D | 0.50 | 0.60 | **1.55** | **1.67** | **1.73** | **1.88** | **1.98** | **2.47** | **TR** | **2.30** | **1.64** | **1.56** | 0.67 | 0.63 |
| | 0.50 | 0.59 | **1.54** | **1.66** | **1.73** | **1.87** | **1.97** | **2.07** | **2.41** | **1.89** | **1.62** | **1.54** | 0.67 | 0.62 |
| E | 0.46 | 0.61 | 0.68 | 0.71 | **1.70** | **1.65** | **1.74** | **1.76** | **1.72** | **1.61** | **1.43** | **1.37** | 0.59 | 0.55 |
| | 0.38 | 0.48 | 0.62 | 0.66 | **1.54** | **1.47** | **1.52** | **1.52** | **1.47** | **1.40** | **1.28** | **1.22** | 0.49 | 0.45 |
| F | 0.28 | 0.32 | 0.41 | 0.50 | 0.55 | 0.61 | | | | | 0.56 | 0.48 | 0.39 | 0.31 |
| | 0.22 | 0.25 | 0.31 | 0.37 | 0.45 | 0.52 | | | | | 0.45 | 0.38 | 0.30 | 0.24 |

Table 40-2. Axial Power Peaking Factors for the WSU LEU Mixed Core 35A, BOL, HOT

| | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | | Max | 1.475 | 1.470 | 1.454 | 1.433 | 1.374 | 1.336 | 1.342 | 1.341 |
| | | 6.5" | 1.461 | 1.457 | 1.443 | 1.424 | 1.368 | 1.333 | 1.342 | 1.341 |
| | | 7.5" | 1.371 | 1.369 | 1.361 | 1.352 | 1.312 | 1.295 | 1.322 | 1.327 |
| | | 8.5" | 1.153 | 1.151 | 1.155 | 1.162 | 1.175 | 1.211 | 1.259 | 1.270 |
| | | | 1.301 | 1.296 | 1.292 | 1.289 | 1.288 | 1.277 | 1.272 | 1.271 |
| | | | 1.301 | 1.296 | 1.292 | 1.289 | 1.288 | 1.277 | 1.271 | 1.269 |
| | | | 1.274 | 1.270 | 1.269 | 1.268 | 1.272 | 1.264 | 1.261 | 1.262 |
| | | | 1.209 | 1.208 | 1.209 | 1.213 | 1.222 | 1.218 | 1.219 | 1.221 |
| D | 1.284 | 1.286 | 1.284 | 1.283 | 1.282 | 1.286 | - | 1.283 | 1.274 | 1.273 |
| | 1.284 | 1.286 | 1.284 | 1.283 | 1.282 | 1.285 | - | 1.282 | 1.273 | 1.272 |
| | 1.268 | 1.269 | 1.267 | 1.267 | 1.267 | 1.273 | - | 1.272 | 1.264 | 1.264 |
| | 1.219 | 1.218 | 1.217 | 1.218 | 1.219 | 1.226 | - | 1.229 | 1.223 | 1.224 |
| | 1.284 | 1.286 | 1.284 | 1.283 | 1.282 | 1.281 | 1.285 | 1.279 | 1.278 | 1.278 |
| | 1.284 | 1.286 | 1.284 | 1.283 | 1.282 | 1.281 | 1.285 | 1.279 | 1.277 | 1.278 |
| | 1.268 | 1.269 | 1.267 | 1.267 | 1.267 | 1.267 | 1.272 | 1.267 | 1.265 | 1.266 |
| | 1.220 | 1.218 | 1.217 | 1.218 | 1.218 | 1.220 | 1.227 | 1.222 | 1.220 | 1.221 |
| E | | | 1.301 | 1.296 | 1.293 | 1.290 | 1.288 | 1.288 | 1.290 | 1.294 |
| | | | 1.300 | 1.296 | 1.293 | 1.290 | 1.288 | 1.288 | 1.290 | 1.294 |
| | | | 1.273 | 1.270 | 1.269 | 1.267 | 1.266 | 1.266 | 1.267 | 1.270 |
| | | | 1.209 | 1.207 | 1.208 | 1.208 | 1.209 | 1.209 | 1.208 | 1.208 |
| | | | 1.472 | 1.468 | 1.454 | 1.438 | 1.400 | 1.404 | 1.454 | 1.469 |
| | | | 1.459 | 1.455 | 1.442 | 1.426 | 1.385 | 1.389 | 1.442 | 1.455 |
| | | | 1.369 | 1.366 | 1.358 | 1.348 | 1.310 | 1.312 | 1.358 | 1.366 |
| | | | 1.153 | 1.150 | 1.151 | 1.153 | 1.152 | 1.151 | 1.152 | 1.150 |

Table 40-3. Product of Rod and Axial Power Peaking Factors for Thermocouples with the Lowest and the Highest Axial Peaking Factors for WSU LEU Mixed Core 35A, BOL, HOT

| | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | RPF x APF 6.5" | | | 2.31 | 2.20 | 2.25 | 2.24 | 2.13 | 2.04 | 1.93 | 1.84 |
| | RPF x APF 8.5" | | | 1.82 | 1.74 | 1.80 | 1.82 | 1.83 | 1.85 | 1.81 | 1.74 |
| | | | | 2.24 | 2.18 | 2.27 | 2.40 | 2.86 | 2.21 | 1.89 | 1.80 |
| | | | | 2.08 | 2.03 | 2.13 | 2.26 | 2.71 | 2.11 | 1.82 | 1.73 |
| D | | 1.99 | 2.15 | 2.22 | 2.41 | 2.54 | 3.17 | TR | 2.95 | 2.09 | 1.98 |
| | | 1.89 | 2.03 | 2.11 | 2.29 | 2.41 | 3.03 | | 2.83 | 2.01 | 1.91 |
| | | 1.98 | 2.13 | 2.22 | 2.40 | 2.53 | 2.65 | 3.10 | 2.42 | 2.07 | 1.97 |
| | | 1.88 | 2.02 | 2.11 | 2.28 | 2.40 | 2.53 | 2.96 | 2.31 | 1.98 | 1.88 |
| E | | | | 2.21 | 2.14 | 2.25 | 2.27 | 2.21 | 2.07 | 1.84 | 1.77 |
| | | | | 2.06 | 1.99 | 2.10 | 2.13 | 2.08 | 1.95 | 1.73 | 1.66 |
| | | | | 2.25 | 2.14 | 2.19 | 2.17 | 2.04 | 1.94 | 1.85 | 1.78 |
| | | | | 1.78 | 1.69 | 1.75 | 1.75 | 1.69 | 1.69 | 1.47 | 1.40 |

Table 40-4. Reactor Power Levels at Which the Hottest (top value) and Coldest (bottom value) Thermocouples Reach 500°C in Each 30/20 Fuel Rod in LEU Mixed Core 35A, BOL, HOT. The Current IFE Are Located in Positions C4NW and D6NW.

| | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | RPF x APF 6.5" | | | 1.30 | 1.36 | 1.33 | 1.34 | 1.41 | 1.47 | 1.55 | 1.63 |
| | RPF x APF 8.5" | | | 1.65 | 1.72 | 1.67 | 1.65 | 1.64 | 1.62 | 1.66 | 1.72 |
| | | | | 1.34 | 1.38 | 1.32 | 1.25 | 1.05 | 1.36 | 1.59 | 1.67 |
| | | | | 1.44 | 1.48 | 1.41 | 1.33 | 1.11 | 1.42 | 1.65 | 1.73 |
| D | | 1.51 | 1.40 | 1.35 | 1.24 | 1.18 | 0.95 | TR | 1.02 | 1.44 | 1.52 |
| | | 1.59 | 1.48 | 1.42 | 1.31 | 1.24 | 0.99 | | 1.06 | 1.49 | 1.57 |
| | | 1.52 | 1.41 | 1.35 | 1.25 | 1.19 | 1.13 | 0.97 | 1.24 | 1.45 | 1.52 |
| | | 1.60 | 1.49 | 1.42 | 1.32 | 1.25 | 1.19 | 1.01 | 1.30 | 1.52 | 1.60 |
| E | | | | 1.36 | 1.40 | 1.33 | 1.36 | 1.36 | 1.45 | 1.63 | 1.69 |
| | | | | 1.46 | 1.51 | 1.43 | 1.41 | 1.44 | 1.54 | 1.73 | 1.81 |
| | | | | 1.33 | 1.40 | 1.37 | 1.38 | 1.47 | 1.55 | 1.62 | 1.69 |
| | | | | 1.69 | 1.78 | 1.71 | 1.71 | 1.78 | 1.78 | 2.04 | 2.14 |

Table 40-5. Product of Rod and Axial Power Peaking Factors for Thermocouples with the Lowest and the Highest Axial Peaking Factors for WSU LEU Mixed Core 35A, EOL, HOT

**RPFs for the Core 35A Mixed LEU at EOL, Hot Conditions**

| 1 | | | | 2 | | 3 | | 4 | | 5 | | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.23 | 0.27 | 0.35 | 0.43 | 0.48 | 0.56 | | | | | 0.51 | 0.43 | | |
| 0.29 | 0.34 | 0.50 | 0.62 | 0.66 | 0.73 | | | | | 0.64 | 0.55 | | |
| 0.38 | 0.48 | 0.62 | 0.69 | 1.75 | 1.72 | 1.78 | 1.78 | 1.71 | 1.61 | 1.46 | 1.35 | 0.52 | 0.48 |
| 0.42 | 0.54 | 0.61 | 0.66 | 1.65 | 1.65 | 1.74 | 1.83 | 2.11 | 1.66 | 1.41 | 1.31 | 0.54 | 0.51 |
| 0.43 | 0.51 | 1.39 | 1.54 | 1.64 | 1.80 | 1.91 | 2.33 | TR | 2.15 | 1.55 | 1.43 | 0.58 | 0.54 |
| 0.43 | 0.51 | 1.38 | 1.54 | 1.64 | 1.79 | 1.90 | 2.00 | 2.28 | 1.82 | 1.55 | 1.44 | 0.59 | 0.54 |
| 0.41 | 0.53 | 0.59 | 0.64 | 1.64 | 1.64 | 1.73 | 1.75 | 1.71 | 1.60 | 1.42 | 1.33 | 0.55 | 0.51 |
| 0.36 | 0.46 | 0.60 | 0.67 | 1.72 | 1.69 | 1.77 | 1.78 | 1.71 | 1.62 | 1.49 | 1.41 | 0.54 | 0.50 |
| 0.28 | 0.34 | 0.46 | 0.57 | 0.63 | 0.71 | | | | | 0.67 | 0.58 | 0.48 | 0.39 |
| 0.22 | 0.26 | 0.32 | 0.39 | 0.47 | 0.57 | | | | | 0.52 | 0.42 | 0.34 | 0.28 |

Table 40-6. Product of Rod and Axial Power Peaking Factors for Thermocouples with the Lowest and the Highest Axial Peaking Factors for WSU LEU Mixed Core 35A, EOL, HOT

| | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|
| C | RPF x APF 7.5" | | 2.21 | 2.17 | 2.24 | 2.24 | 2.15 | 2.03 | 1.84 | 1.70 |
| | RPF x APF 8.5" | | 2.18 | 2.14 | 2.21 | 2.21 | 2.13 | 2.00 | 1.82 | 1.68 |
| | | | 2.08 | 2.08 | 2.19 | 2.31 | 2.66 | 2.09 | 1.78 | 1.65 |
| | | | 2.05 | 2.05 | 2.16 | 2.28 | 2.62 | 2.07 | 1.75 | 1.63 |
| D | 1.75 | 1.94 | 2.07 | 2.27 | 2.41 | 2.94 | - | 2.71 | 1.95 | 1.80 |
| | 1.73 | 1.92 | 2.04 | 2.24 | 2.38 | 2.90 | - | 2.67 | 1.93 | 1.78 |
| | 1.74 | 1.94 | 2.07 | 2.26 | 2.39 | 2.52 | 2.87 | 2.29 | 1.95 | 1.81 |
| | 1.72 | 1.92 | 2.04 | 2.23 | 2.36 | 2.49 | 2.84 | 2.26 | 1.93 | 1.79 |
| E | | | 2.07 | 2.07 | 2.18 | 2.21 | 2.15 | 2.02 | 1.79 | 1.68 |
| | | | 2.04 | 2.04 | 2.15 | 2.18 | 2.13 | 1.99 | 1.77 | 1.65 |
| | | | 2.17 | 2.13 | 2.23 | 2.24 | 2.15 | 2.04 | 1.88 | 1.78 |
| | | | 2.14 | 2.10 | 2.20 | 2.21 | 2.13 | 2.02 | 1.85 | 1.75 |

Table 40-7. Reactor Power Levels at Which the Hottest (top value) and Coldest (bottom value) Thermocouples Reach 500˚C in Each 30/20 Fuel Rod in LEU Mixed Core 35A, EOL, HOT. The Current IFE Are Located in Positions C4NW and D6NW.

| | | 2 | | 3 | | 4 | | 5 | | 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | RPF x APF 7.5"<br>RPF x APF 8.5" | | | 1.36<br>1.38 | 1.38<br>1.40 | 1.34<br>1.35 | 1.34<br>1.35 | 1.39<br>1.41 | 1.48<br>1.50 | 1.63<br>1.65 | 1.76<br>1.79 |
| | | | | 1.44<br>1.46 | 1.44<br>1.46 | 1.37<br>1.39 | 1.30<br>1.32 | 1.13<br>1.14 | 1.43<br>1.45 | 1.69<br>1.71 | 1.82<br>1.84 |
| D | | 1.71<br>1.73 | 1.55<br>1.57 | 1.45<br>1.47 | 1.32<br>1.34 | 1.25<br>1.26 | 1.02<br>1.04 | TR | 1.11<br>1.12 | 1.54<br>1.56 | 1.67<br>1.69 |
| | | 1.73<br>1.75 | 1.55<br>1.57 | 1.45<br>1.47 | 1.33<br>1.35 | 1.25<br>1.27 | 1.19<br>1.21 | 1.04<br>1.06 | 1.31<br>1.33 | 1.54<br>1.56 | 1.65<br>1.67 |
| E | | | | 1.45<br>1.47 | 1.45<br>1.47 | 1.38<br>1.39 | 1.36<br>1.38 | 1.39<br>1.41 | 1.49<br>1.51 | 1.68<br>1.70 | 1.79<br>1.81 |
| | | | | 1.38<br>1.40 | 1.41<br>1.43 | 1.35<br>1.36 | 1.34<br>1.35 | 1.39<br>1.41 | 1.47<br>1.49 | 1.60<br>1.62 | 1.69<br>1.71 |

*Response: The following paragraphs of TS 2.2 should be revised to read:*

*<u>Specifications</u>: The limiting safety system settings shall be 500˚C as measured in an instrumented fuel rod ~~located~~ in selected locations in the central region of the core. ~~For a mixed core, the instrumented rod shall be located in the region of the core containing the 30/20-type fuel rods.~~ For a mixed core, the instrumented rod shall be located in one of the following positions in the region of the core containing the 30/20-type fuel rods: D2NE, D2SE, C3 (except for C3NE), D3, E3 (except for E3SE), C4, E4NE, E4NW, C5 (except for C5SW), D5SE, E5NE, E5NW, C6NW, or D6.*

*<u>Bases</u>: The limiting safety system setting is the measured instrumented fuel rod temperature that, if exceeded, shall initiate a scram to prevent the fuel temperature safety limit from being exceeded. ~~Section 5.4 of the FLIP conversion safety analysis report for the Washington State University (WSU) TRIGA reactor indicated that a 500C safety system setting would limit the maximum possible steady-state temperature in the 30/20 fuel region to less than 800˚C.~~ The response to Question number 40 of the additional RAI for the FLIP-to-30/20 conversion safety analysis report for the Washington State University (WSU) TRIGA reactor showed that for both the hottest and the coldest thermocouples, an IFE located in core positions D2NE, D2SE, C3 (except for C3NE), D3, E3 (except for E3SE), C4, E4NE, E4NW, C5 (except for C5SW), D5SE, E5NE, E5NW, C6NW, or D6 would protect the fuel temperature safety limit of 1150˚C for reactor power levels that are less than 1.7 MW and limit the maximum steady-state temperature in the 30/20 fuel region to less than 800˚C. This setting provides at least a 350˚C margin of safety for 30/20 fuel and at least a 200˚C margin of safety for Standard fuel.*

4. Your proposed TSs contain changes to the TSs that appear not to be impacted by conversion of the reactor to LEU such as TS 5.1(2) (the technical content of your conversion application did not contain a discussion of any changes to the current 8.5/20 LEU fuel) and Figure 6.1 (the organizational change does not appear to be related to conversion). Please justify or withdraw these proposed changes.

*Response: TS 5.1(2) describes the Specifications for Standard TRIGA fuel. This specification and its basis will not change because the same Standard fuel elements will be used in the LEU mixed core. However, TS 5.1(1) needs to describe the specifications and basis for 30/20 fuel instead of FLIP fuel and should read:*

*(1) <u>TRIGA 30/20 Fuel</u> – The individual unirradiated 30/20 fuel elements shall have the following characteristics:*

- *uranium content: maximum of 30 wt% enriched to a maximum of 19.95% with nominal enrichment of 19.75% U-235.*
- *hydrogen-to-zirconium ratio (in the $ZrH_x$):nominal 1.6 H atoms to 1.0 Zr atoms with a maximum H to Zr ratio of 1.65*
- *natural erbium content (homogeneously distributed): nominal 0.90 wt%.*
- *cladding: 304 stainless steel, nominal 0.020 inch thick.*

*(2) Standard TRIGA Fuel – No changes are needed.*

*Basis:*

*<u>30/20 Fuel</u>: The fuel specification permits a maximum uranium enrichment of 19.95%. This is about 1% greater than the design value for 19.75% enrichment. Such an increase in loading would result in an increase in power density of less than 1%. An increase in local power density of 1% reduces the safety margin by less than 2%.*

*The fuel specification for a single fuel element permits a minimum erbium content of about 5.6% less than the design value of 0.90 wt%. (However, the quantity of erbium in the full core must not deviate from the design value by more than -3.3%). This variation for a single fuel element would result in an increase in fuel element power density of about 1-2%. Such a small increase in local power density would reduce the safety margin by less than 2%.*

*The maximum hydrogen-to-zirconium ratio of 1.65 could result in a maximum stress under accident conditions in the fuel element clad about a factor of two greater than for a hydrogen-to-zirconium ration of 1.6. This increase in the clad stress during an accident would not exceed the rupture strength of the clad.*

*<u>Standard Fuel</u>: No changes are required in the existing TS basis.*

5. The NRC staff identified in your replacement TS pages changes that were made but were not designated by a bar in the margin of the TSs. Please resubmit replacement TS pages (you need only submit those pages that have changes, not the entire TSs) showing all changes that are proposed.

*Response: Replacement TS pages are included with this document.*

6. TS 3.5(2) contains a limit on the peak-to-measured-fuel temperature ratio (PTR) of 1.5. Please show that this TS remains valid given your updated thermal hydraulic and LSSS analysis or update your TSs with justification as needed.

*Response: The following paragraphs of TS 3.5 should be revised to read:*

*3.5 <u>Core Configuration Limitation</u>*

*(1) <u>Specifications</u>: The 30/20-fueled region in a mixed core shall contain at least ~~22~~ 51 30/20 fuel rods in a contiguous block of fuel in the central region of the reactor core. Water holes in the 30/20 region shall be limited to nonadjacent single-rod holes.*

*(2) ~~The PTR as defined in Section 1.4 and as calculated by the method used in the 30/20 conversion safety analysis report shall not exceed 1.5 for an operational core~~. Each new mixed core configuration shall be evaluated to determine the allowed locations for the IFE (Reference: Response to RAI Question Number 40).*

*<u>Bases</u>: The limitation on the allowable core configuration of the 30/20 fuel limits power peaking effects. The limitation on power peaking effects ensures that the fuel temperature limit will not be exceeded in a mixed core.*

*~~A 500°C safety system setting and a 1.5 PTR limit the maximum possible steady-state fuel temperature in the 30/20 region to less than 800°C.~~ A 500°C safety system setting and the allowed locations for the IFE limit the peak fuel temperature to less than 800°C (Reference: Response to RAI Question Number 40).*

*Additionally, The Specifications and Bases for TS 2.2, Limiting Safety System Settings, and the Specifications for TS 5.2, Reactor Core, should be modified as follows:*

*2.2 Limiting Safety System Settings*

*Specifications: The limiting safety system settings shall be 500°C as measured in an instrumented fuel rod located in the central region of the core. For a mixed core, the instrumented rod shall be located in one of the following ~~the region of the~~ core positions containing the 30/20-type fuel rods: D2NE, D2SE, C3 (except for C3NE), D3, E3 (except for E3SE), C4, E4NE, E4NW, C5 (except for C5SW), D5SE, E5NE, E5NW, C6NW, or D6.*

*Bases: The limiting safety system setting is the measured fuel rod temperature that, if exceeded shall initiate a scram to prevent the fuel temperature safety limit from being exceeded. ~~Section 5.4 of the FLIP conversion safety analysis report of the Washington State University (WSU) TRIGA reactor~~ The analysis for RAI Question Number 40 indicated that a 500°C safety system setting would limit the maximum possible steady-state fuel temperature in the 30/20 fuel region to less than 800°C. This setting provides at least a 350°C margin of safety for 30/20 fuel and at least a 200°C margin of safety for Standard fuel.*

*5.2 Reactor Core*

*Specifications:*

*(2) The TRIGA core assembly may be composed of Standard fuel, 30/20 fuel, or a combination thereof (mixed cores) provided that the 30/20 fuel region contains at least ~~22~~ 51 30/20 fuel rods located in a contiguous block in the central region of the core.*

*Basis: Standard TRIGA cores have been used for years and their characteristics are well-documented. Cores of 30/20 fuel have been tested by General Atomics Co. Calculations~~, as well as measured performance~~ of a mixed ~~cores~~ core (Standard and ~~FLIP~~ 30/20) in the WSU reactor~~, the Texas A&M reactor, and the University of Wisconsin reactor,~~ have shown that such a ~~cores~~ core may be safety operated.*

APPENDIX A

FACILITY LICENSE NO. R-76

TECHNICAL SPECIFICATIONS

AND BASES

FOR THE

WASHINGTON STATE UNIVERSITY

MODIFIED TRIGA REACTOR

DOCKET NO. 50-27

Updated Version of August 26, 2004

Proposed Amendment No. 19

(6) release of fission products into the environment

Shutdown Margin: Shutdown margin shall mean the minimum shutdown reactivity necessary to provide confidence that (1) the reactor can be made subcritical by means of the control and safety systems, starting from any permissible operating conditions, and (2) the reactor will remain subcritical without further operator action.

Steady-State Mode: Steady-state mode operation shall mean any operation of the reactor with the mode selector switch in the steady-state position.

1.2 Reactor Experiments and Irradiations

Experiment: Experiment shall mean: (1) any apparatus, device or material which is not a normal part of the core or experimental facilities, but which is inserted into these facilities or is in line with a beam of radiation originating from the reactor, or (2) any operation designed to measure reactor parameters or characteristics.

Experimental Facilities: Experimental facilities shall mean beam ports, including extension tubes with shields, thermal columns with shields, vertical tubes, in-core irradiation baskets or tubes, pneumatic transfer systems, and any other in-pool irradiation facilities.

Irradiation: Irradiation shall mean the insertion of any device or material that is not a normal part of the core or experimental facilities into an irradiation facility so that the device or material is exposed to a significant amount of the radiation available in that irradiation facility.

Irradiation Facilities: Any in-pool experimental facility that is not a normal part of the core and that is used to irradiate devices and materials.

Secured Experiment: A secured experiment shall mean any experiment that is held firmly in place by a mechanical device or by gravity, that is not readily removable from the reactor, and that requires one of the following actions to permit removal:

(1) removal of mechanical fasteners
(2) use of underwater handling tools
(3) moving of shield blocks or beam port components

1.3 Reactor Component

30/20 LEU Fuel: 30/20 LEU fuel is TRIGA fuel that contains a nominal 30 weight percent of uranium with a nominal $^{235}U$ enrichment of 19.75% and erbium, a burnable poison.

Fuel Bundle: A fuel bundle is a cluster of three or four fuel rods fastened together in a square array by a top handle and bottom grid plate adapter.

Fuel Rod: A fuel rod is a single TRIGA-type fuel rod of either Standard or 30/20 LEU fuel.

Instrumented Fuel Rod: An instrumented fuel rod is a special fuel rod in which thermocouples have been embedded for the purpose of measuring the fuel temperatures during reactor operation.

Mixed Core: A mixed core is a core arrangement containing Standard and 30/20 LEU-type fuels with at least 51 30/20 LEU fuel rods located in the central positions in the core.

Operational Core: An operational core is any arrangement of TRIGA fuel that is capable of operating at the maximum licensed power level and that satisfies all the requirements of the Technical Specifications.

Regulating Control Element: Regulating control element shall mean a low worth control element that may be positioned either manually or automatically by means of an electric motor-operated positioning system and that need not have a scram capability.

Standard Control Element: Standard control element shall mean any control element that has a scram capability, that is utilized to vary the reactivity of the core, and that is positioned by means of an electric motor-operated positioning system.

Standard Core: A standard core is any arrangement of all-Standard fuel.

Standard Fuel: Standard fuel is TRIGA fuel that contains a nominal 8.5 weight percent of uranium with a $^{235}U$ enrichment of less than 20%.

Transient Control Element: Transient control element shall mean any control element that has the capability of being rapidly withdrawn from the reactor core by means of a pneumatic drive, that is capable of being positioned by means of an electric motor-operated positioning system, and that has scram capabilities.

1.4 Reactor Instrumentation

Channel Calibration: A channel calibration consists of comparing a measured value from the measuring channel with a corresponding known value of the parameter so that the measuring channel output can be adjusted to respond with acceptable accuracy to known values of the measured variables.

Channel Check: A channel check is a qualitative verification of acceptable performance by observation of channel behavior. This verification may include comparison with independent channels measuring the same variable or other measurements of the variables.

Channel Test: A channel test is the introduction of a signal into the channel to verify that it is operable.

Experiment Safety Systems: Experiment safety systems are those systems, including their associated input circuits, that are designed to initiate a scram for the primary purpose of protecting an experiment or to provide information that requires manual protective action to be initiated.

Limiting Safety Systems Setting: Limiting safety systems settings are the settings for automatic protective devices related to those variables having significant safety functions.

Measured Value: The measured value is the magnitude of that variable as it appears on the output of a measuring channel.

## 2.0 SAFETY LIMITS AND LIMITING SAFETY SYSTEM SETTINGS

### 2.1 Safety Limit - Fuel Element Temperature

Applicability: This specification applies to the temperature of the reactor fuel.

Objective: The objective is to define the maximum fuel temperature that can be permitted with confidence that a fuel cladding failure will not occur.

Specifications:

(1) The maximum temperature in a Standard TRIGA fuel rod shall not exceed 1000°C under any condition of operation.

(2) The maximum temperature in a 30/20 LEU-type TRIGA fuel rod shall not exceed 1150°C under any condition of operation.

Bases: The important parameter for a TRIGA reactor is the fuel rod temperature. This parameter is well-suited as a single specification, especially since it can be measured. A loss in the integrity of the fuel rod cladding could arise from a buildup of excessive pressure between the fuel moderator and the cladding if the fuel temperature exceeds the safety limit. The pressure is caused by the presence of air, fission product gases, and hydrogen from the disassociation of the hydrogen and zirconium in the fuel moderator. The magnitude of this pressure is determined by the fuel-moderator temperature and the ratio of hydrogen to zirconium in the alloy. The safety limit for the 30/20 LEU fuel is based on data that indicate that the stress in the cladding because of the hydrogen pressure from the disassociation of zirconium hydride will remain below the ultimate stress, provided the temperature of the fuel does not exceed 1150°C and the fuel cladding is water cooled.* The safety limit for the Standard TRIGA fuel is based on data, including the large mass of experimental evidence obtained during high performance reactor tests on this fuel. These data indicate that the stress in the cladding because of hydrogen pressure from the disassociation of zirconium hydride will remain below the ultimate stress, provided that the temperature of the fuel does not exceed 1000°C and the fuel cladding is water cooled.*

### 2.2 Limiting Safety System Settings

Applicability: This specification applies to the settings that prevent the safety limit from being reached.

Objective: The objective is to prevent the safety limits from being reached.

Specifications: The limiting safety system settings shall be 500°C as measured in an instrumented fuel rod in selected locations in the central region of the core. For a mixed core, the instrumented rod shall be located in one of the following positions in the region of the core containing the 30/20 LEU-type fuel rods: D2NE, D2SE, C3 (except for C3NE), D3, E3 (except for E3SE), C4, E4NE, E4NW, C5 (except for C5SW), D5SE, E5NE, E5NW, C6NW, or D6.

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*GA-9064, Safety Analysis Report for the Torrey Pines TRIGA Mark III Reactor, submitted under Docket No. 50-227.

Bases: The limiting safety system setting is the measured instrumented fuel rod temperature that, if exceeded, shall initiate a scram to prevent the fuel temperature safety limit from being exceeded. The response to Question number 40 of the additional RAI for the FLIP-to-30/20 LEU conversion safety analysis report for the Washington State University (WSU) TRIGA reactor showed that for both the hottest and the coldest thermocouples, an IFE located in core positions D2NE, D2SE, C3 (except for C3NE), D3, E3 (except for E3SE), C4, E4NE, E4NW, C5 (except for C5SW), D5SE, E5NE, E5NW, C6NW, or D6 would protect the fuel temperature safety limit of 1150°C for reactor power levels that are less than 1.7 MW and limit the maximum steady-state temperature in the 30/20 fuel region to less than 800°C. This setting provides at least a 350°C margin of safety for 30/20 fuel and at least a 200°C margin of safety for Standard fuel.

In the pulse mode of operation, the same limiting safety system setting will apply. However, the temperature channel will not limit the peak power generated during the pulse because of the relatively long response time of the temperature channel as compared with the width of a pulse. On the other hand, the temperature scram would limit the total amount of energy generated in a pulse by cutting off the "tail" of the energy transient in the event that the fuel temperature limit is exceeded. Thus, the fuel temperature scram provides an additional degree of safety in the pulse mode of operation to protect the fuel in the event of such conditions as sticking of the transient control element in the withdrawn position after a pulse.

## 3.0 LIMITING CONDITIONS OF OPERATION

### 3.1 Steady-State Operation

Applicability: This specification applies to the energy generated in the reactor during steady-state operation.

Objective: The objective is to ensure that the fuel temperature safety limit will not be exceeded during steady-state operation.

Specifications: The reactor power level shall not exceed 1.3 MW under any condition of operation. The normal steady-state operating power level of the reactor shall be 1.0 MW. However, for purposes of testing and calibration, the reactor may be operated at higher power levels not to exceed 1.3 MW during the testing period.

Basis: Thermal and hydraulic calculations performed by the vendor indicate that TRIGA fuel may be safely operated up to power levels of at least 2.0 MW with natural convection cooling.

### 3.2 Reactivity Limitations

Applicability: These specifications apply to the reactivity condition of the reactor and the reactivity worth of control elements and experiments. They apply for all modes of operation.

Objective: The objective is to ensure that the reactor can be shut down at all times and to ensure that the fuel temperature safety limit will not be exceeded.

Specifications: The reactor shall not be operated unless the shutdown margin provided by control elements shall be 0.25$ or greater with:

(1) the highest worth nonsecured experiment in its most reactive state

(2) the highest worth control element and the regulating element (if not scrammable) fully withdrawn

(3) the reactor in the cold critical condition without xenon

Basis: The value of the shutdown margin ensures that the reactor can be shut down from any operating condition even if the highest worth rod should remain in the fully withdrawn position. If the regulating rod is not scrammable, its worth is not used in determining the shutdown reactivity.

### 3.3 Pulse Mode Operation

Applicability: This specification applies to the peak fuel temperature in the reactor as a result of a pulse insertion of reactivity.

Objective: The objective is to ensure that fuel element damage does not occur in any fuel rod during pulsing.

Specifications: The maximum reactivity inserted during pulse mode operation shall be such that the peak fuel temperature in any fuel rod in the core does not exceed 830°C. The maximum safe allowable reactivity insertion shall be calculated annually for an existing core and prior to pulsing a new or modified core arrangement.

Basis: TRIGA fuel is fabricated with a nominal hydrogen to zirconium ratio of 1.6 for 30/20 LEU fuel and 1.65 for Standard. This yields delta phase zirconium hydride which has a high creep strength and undergoes no phase changes at temperatures over 1000°C. However, after extensive steady-state operation at 1 MW, the hydrogen will redistribute due to migration from the central high temperature regions of the fuel to the cooler outer regions. When the fuel is pulsed, the instantaneous temperature distribution is such that the highest values occur at the surface of the element and the lowest values occur at the center. The higher temperatures in the outer regions occur in fuel with a hydrogen to zirconium ratio that has now substantially increased above the nominal value. This produces hydrogen gas pressures considerably in excess of that expected for $ZrH_{1.6}$. If the pulse insertion is such that the temperature of the fuel exceeds 874°C, then the pressure will be sufficient to cause expansion of microscopic holes in the fuel that grow larger with each pulse. The expansion of the fuel stresses and distorts the fuel rod material which, in turn, can cause overall swelling and distortion of the cladding and entire fuel rod. The pulsing limit of 830°C is obtained by examining the equilibrium hydrogen pressure of zirconium hydride as a function of temperature. The decrease in temperature from 874°C to 830°C reduces hydrogen pressure by a factor of two, which provides an acceptable safety factor. This phenomenon does not alter the steady-state safety limit since the total hydrogen in a fuel element does not change. Thus, the pressure exerted on the clad will not be significantly affected by the distribution of hydrogen within the element.

## 3.4 Maximum Excess Reactivity

Applicability: This specification applies to the maximum excess reactivity, above cold critical, which may be loaded into the reactor core at any time.

Objective: The objective is to ensure that the core analyzed in the safety analysis report approximates the operational core within reasonable limits.

Specifications: The maximum reactivity in excess of cold, xenon-free critical shall not exceed 5.6% $\Delta k/k$.

Basis: Although maintaining a minimum shutdown margin at all times ensures that the reactor can be shut down, that specification does not address the total reactivity available within the core. This specification, although over-constraining the reactor system, helps ensure that the licensee's operational power densities, fuel temperatures, and temperature peaks are maintained within the evaluated safety limits. The specified excess reactivity allows for power coefficients of reactivity, xenon poisoning, most experiments, and operational flexibility.

## 3.5 Core Configuration Limitation

Applicability: This specification applies to mixed cores of 30/20 LEU and Standard types of fuel.

Objective: The objective is to ensure that the fuel temperature safety limit will not be exceeded as a result of power peaking effects in a mixed core.

Specifications:

(1) The 30/20-fueled region in a mixed core shall contain at least 51 30/20 fuel rods in a contiguous block of fuel in the central region of the reactor core. Water holes in the 30/20 region shall be limited to nonadjacent single-rod holes.

(2) Each new mixed core configuration shall be evaluated to determine the allowed locations for the IFE (Reference: Response to RAI Question Number 40).

Bases: The limitation on the allowable core configuration of the 30/20 fuel limits power peaking effects. The limitation on power peaking effects ensures that the fuel temperature limit will not be exceeded in a mixed core.

A 500°C safety system setting and the allowed locations for the IFE limit the peak fuel temperature to less than 800°C (Reference: Response to RAI Question Number 40).

3.6 Control and Safety System

3.6.1 Scram Time

Applicability: This specification applies to the time required for the scrammable control rods to be fully inserted from the instant that a safety channel variable reaches the safety system setting.

Objective: The objective is to achieve prompt shutdown of the reactor to prevent fuel damage.

Specifications: The scram time from the instant that a safety system setting is exceeded to the instant that the slowest scrammable control rod reaches its fully inserted position shall not exceed 2 seconds. For purposes of this section, the above specification shall be considered to be satisfied when the sum of the response time of the slowest responding safety channel, plus the fall time of the slowest scrammable control rod, is less than or equal to 2 seconds.

Basis: This specification ensures that the reactor will be promptly shut down when a scram signal is initiated. Experience and analysis have indicated that for the range of transients anticipated for a TRIGA reactor, the specified scram time is adequate to ensure the safety of the reactor.

3.6.2. Reactor Control System

Applicability: This specification applies to the information that must be available to the reactor operator during reactor operation.

Objective: The objective is to require that sufficient information is available to the operator to ensure safe operation of the reactor.

Specifications: The reactor shall not be operated in the specified mode of operation unless the measuring channels listed in Table 3.1 are operable.

## 5.0 DESIGN FEATURES

### 5.1 Reactor Fuel

Applicability: This specification applies to the fuel elements used in the reactor core.

Objective: The objective is to ensure that the fuel elements are of such a design and fabricated in such a manner as to permit their use with a high degree of reliability with respect to their physical and nuclear characteristics.

Specifications:

(1) 30/20 LEU Fuel – The individual unirradiated 30/20 fuel elements shall have the following characteristics:

- uranium content: maximum of 30 wt% enriched to a maximum of 19.95% with nominal enrichment of 19.75% U-235.
- hydrogen-to-zirconium ratio (in the $ZrH_x$):nominal 1.6 H atoms to 1.0 Zr atoms with a maximum H to Zr ratio of 1.65
- natural erbium content (homogeneously distributed): nominal 0.90 wt%.
- cladding: 304 stainless steel, nominal 0.020 in. thick

(2) Standard TRIGA Fuel - The individual unirradiated Standard TRIGA fuel elements shall have the following characteristics:

- uranium content: maximum of 9.0 wt% enriched to less than 20% $^{235}U$
- hydrogen-to-zirconium atom ratio (in the $ZrH_x$): between 1.5 and 1.8
- cladding: 304 stainless steel, nominal 0.020 in. thick

Basis: The fuel specification permits a maximum uranium enrichment of 19.95% in the 30/20 LEU fuel. This is about 1% greater than the design value for 19.75% enrichment. Such an increase in loading would result in an increase in power density of less than 1%. An increase in local power density of 1% reduces the safety margin by less than 2%.

The fuel specification for a single fuel element permits a minimum erbium content of about 5.6% less than the design value of 0.90 wt%. (However, the quantity of erbium in the full core must not deviate from the design value by more than -3.3%). This variation for a single fuel element would result in an increase in fuel element power density of about 1-2%. Such a small increase in local power density would reduce the safety margin by less than 2%.

The maximum hydrogen-to-zirconium ratio of 1.65 could result in a maximum stress under accident conditions in the fuel element clad about a factor of two greater than for a hydrogen-to-zirconium ration of 1.6. This increase in the clad stress during an accident would not exceed the rupture strength of the clad.

ratio of 1.60. However, this increase in the clad stress during an accident would not exceed the rupture strength of the clad.

5.2 Reactor Core

Applicability: This specification applies to the configuration of fuel and in-core experiments.

Objective: The objective is to ensure that provisions are made to restrict the arrangement of fuel elements and experiments so as to provide assurance that excessive power densities will not be produced.

Specifications:

(1) The core shall be an arrangement of TRIGA uranium-zirconium-hydride fuel-moderator bundles positioned in the reactor grid plate.

(2) The TRIGA core assembly may be composed of Standard fuel, 30/20 LEU fuel, or a combination thereof (mixed cores) provided that the 30/20 LEU fuel region contains at least 51 30/20 LEU fuel rods located in a contiguous block in the central region of the core.

(3) The reactor fueled with a mixture of fuel types shall not be operated with a core lattice position vacant in the 30/20 LEU fuel region. Water holes in the 30/20 LEU region shall be limited to single-rod holes. Vacant lattice positions in the core fuel region shall be occupied with fixtures that will prevent the installation of a fuel bundle.

(4) The reflector, excluding experiments and experimental facilities, shall be water or a combination of graphite, aluminum and water.

Basis: Standard TRIGA cores have been used for years and their characteristics are well-documented. Cores of 30/20 fuel have been tested by General Atomics Co. Calculations of a mixed core (Standard and 30/20) in the WS reactor has shown that such a core may be safety operated.

In mixed cores, it is necessary to arrange 30/20 LEU elements in a contiguous, central region of the core to control flux peaking and power generation peak values in individual elements.

Vacant core lattice positions in the Standard fuel region will contain experiments or an experimental facility to prevent accidental fuel additions to the reactor core. Vacant core positions are not permitted in the 30/20 LEU fuel region as specified by Section 3.5.

The core will be assembled in the reactor grid plate which is located in a pool of light water. Water in combination with graphite reflectors can be used for neutron economy and the enhancement of experimental facility radiation requirements.

5.3 Control Elements

Applicability: This specification applies to the control elements used in the reactor core.