Washington
State University

Nuclear Radiation Center, Pullman, Washington 99164-1300 / 509-335-8641

November 21, 1989

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

Gentlemen:

In accordance with the letter of October 26, 1989 from Mr. A. Adams to Mr. W.E. Wilson requesting additional information on Washington State University's request of September 6, 1989 to modify the technical specifications to facility license R-76, the attached Safety Analysis is herewith submitted.

Sincerely,

W. E. Wilson

W. E. Wilson
Associate Director

Enclosures: (4)
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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

October 26, 1989

Docket No. 50-27

Mr. W. E. Wilson
Associate Director
Nuclear Radiation Center
Washington State University
Pullman, Washington 99164-1300

Dear Mr. Wilson:

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION

We are continuing our review of the documentation submitted in support of your application for amendment of Operating License No. R-76 for the Washington State University Modified TRIGA Research Reactor that was submitted on September 6, 1989. During our review of your submittal, questions have arisen for which we require additional information and clarification. Please provide a response to the enclosed Request for Additional Information within 45 days of the date of this letter. Following receipt of the additional information, we will continue our evaluation of your amendment application. If you have any questions regarding this review, please contact me at (301) 492-1121.

The reporting and/or recordkeeping requirements contained in this letter affect fewer than ten respondents; therefore, OMB clearance is not required under P. L. 96-511.

Sincerely,

Alexander Adams

Alexander Adams, Jr., Project Manager
Non-Power Reactor, Decommissioning and
Environmental Project Directorate
Division of Reactor Projects - III,
IV, V and Special Projects
Office of Nuclear Reactor Regulation

Enclosure:
As stated

cc w/enclosure:
See next page

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ENCLOSURE

REQUEST FOR ADDITIONAL INFORMATION

WASHINGTON STATE UNIVERSITY

DOCKET NO. 50-27

1. Please provide a safety analysis to support your request for amendment. In your safety analysis make a determination if the amendment involves a significant hazards consideration. Provide information to justify changing pulse mode limits from reactivity insertion to peak fuel temperature. What uncertainties are involved in the calculation of the maximum reactivity insertion? What is the maximum allowable time span allowed between calculations?

NEW SAFETY ANALYSIS FOR PULSING OF THE WSU MODIFIED TRIGA REACTOR - November, 1989

Introduction

The present Technical Specifications for the WSU Triga reactor were approved on August 11, 1982, as part of the relicensing process. Section 3.3 of these Technical Specifications established a pulsing limit of $2.50 for the WSU reactor based on the information that was available at the time the proposed Technical Specifications were submitted during the relicensing process. Subsequent to the application for renewal of the reactor facility license, a FLIP fuel damage problem occurred at the Texas A&M TRIGA reactor. On September 27, 1976 (1), Texas A&M University discovered the fact that some of the FLIP fuel rods adjacent to the transient rod were severely damaged in the form of swollen cladding and bent and bowed fuel rods. The damage was limited to the four fuel rods surrounding the transient rod. The exact cause of the FLIP fuel damage was not apparent in 1976 since no existing safety limit had been exceeded. The cause of the damage has only more recently been determined after detailed metalurgical examination of sections taken from the damaged FLIP fuel. The WSU modified TRIGA reactor is similar to the Texas A& M reactor and is also fueled with a mixture of Standard and FLIP fuel. Accordingly, in order to preclude the possibility of a similar FLIP fuel damage problem occurring at WSU, WSU administratively limited all pulsing to $2.00 after the problem at Texas A&M became known.

Cause of the FLIP Fuel Damage in the Texas A&M Reactor

Extensive cooperative research by the people at Texas A&M, Argonne National Lab West and General Atomics led to a resolution of the damage mechanism as described below: (2)

TRIGA fuel is fabricated with a nominal hydrogen to zirconium ratio of 1.6 for FLIP 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 (3). However, after extensive steady state operation at 1 Mw, the high temperature gradient created during steady state operation will cause the hydrogen to redistribute 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 $ZrH_{1.6}$. (2)

Figure 1 on the next page of this report shows the relationship between maximum fuel temperature during pulsing versus FLIP fuel damage that was observed in the Texas A&M TRIGA reactor. A detailed analysis of the failed FLIP fuel and extensive consideration of the properties of zirconium hydride fuel (4) by General Atomics established the fact (2)

FUEL DAMAGE VERSUS FUEL TEMPERATURE

IN TEXAS A & M TRIGA REACTOR, 1976

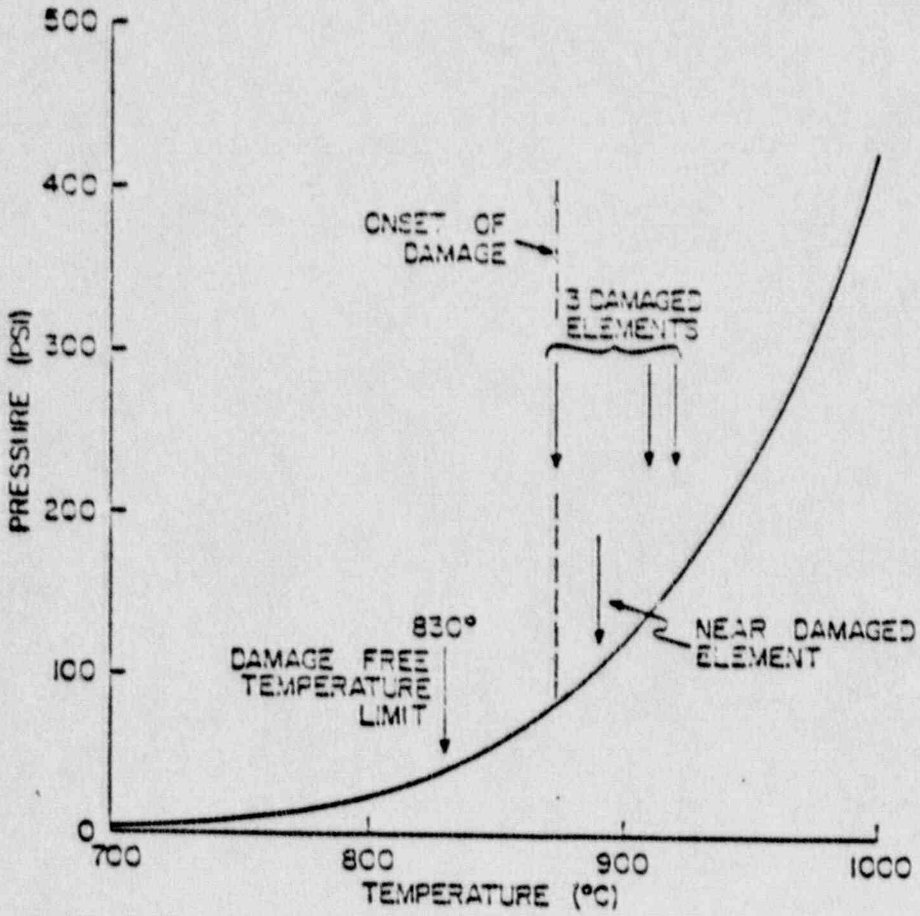


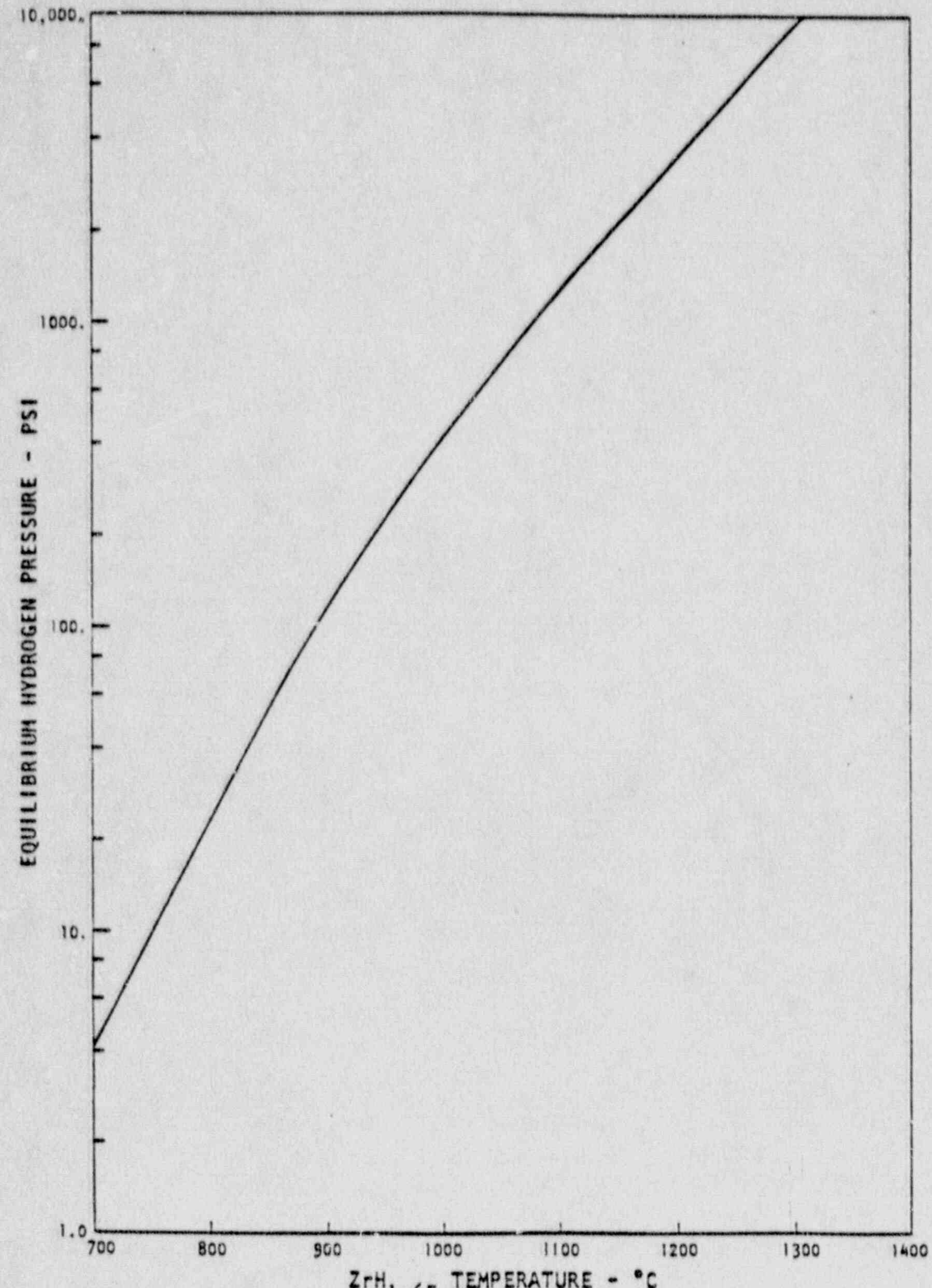
Figure 1

that the onset of FLIP damage occurred at a temperature of about 874°C during pulsing. That is, in a FLIP fueled core with extensive steady state operation, if the temperature of a FLIP fuel rod during subsequent pulsing exceeds 874°C, FLIP fuel rod damage is very likely to occur in that rod.

The failure mechanism is associated with the fact that above 874°C the hydrogen disassociation pressure in a FLIP fuel rod with extensive steady state operation and the associated hydrogen redistribution effect is sufficient to cause small microscopic holes to develop in the FLIP fuel. These microscopic holes grow larger and proliferate with each pulse that produces a FLIP fuel rod temperature above 874°C. The microscopic holes eventually caused the FLIP fuel rod material to fracture, swell and distort. The damaged FLIP fuel rod material, in turn, created distorted, bent and bowed FLIP fuel rods.

Fuel Temperature Limit for Pulsing of a FLIP Fueled TRIGA Reactor

Extensive studies conducted in the aftermath of the FLIP fuel damage problem that occurred at Texas A&M as discussed in the previous section of this report revealed the fact that FLIP fuel damage occurs when the FLIP fuel temperature exceeds 874°C during pulsing. The FLIP fuel damage was discovered at Texas A&M before a cladding failure occurred with an associated release of fission products. However, if the FLIP fuel damage had not been discovered, a cladding failure would



Equilibrium hydrogen pressure over $ZrH_{1.65}$ versus temperature

Figure 2

probably have occurred eventually which is a much more severe problem than just bent and bowed fuel rods.

Figure 2 on the following page shows the equilibrium hydrogen pressure over $ZrH_{1.65}$ versus temperature. These pressures are not actually achieved during pulsing because the pressure is more a function of the average temperature of the fuel than the peak temeprature during a pulse. However, the curve may be used to compare relative values for comparison purposes. At a fuel temperature of 874°C, this curve predicts an equilibrium hydrogen pressure of about 70 psi. If we select a safety margin factor of two, then the allowable equilibrium hydrogen pressure would be set at 35 psi. Referring to the graph in Figure 2, we see that this corresponds to a fuel temperature of 830°C. Accordingly, if the maximum allowable FLIP fuel temperature during a pulse is limited to 830°C, this temperature limit should preclude the development of damage in the FLIP fuel rods of the type that occurred at Texas A&M. This limit is consistent with observed results shown in Figure 1.

Pulsing Performance of the WSU Modified TRIGA Reactor

The pulsing performance of the WSU modified TRIGA reactor with the present mixed fuel core No. 32A is shown in Figures 3 and 4 and Table I. Core 32A is composed of 75% FLIP fuel in the center of the core and 25% Standard fuel around the edges of the core. This core has a fuel temperature to power density relationship (3) of:

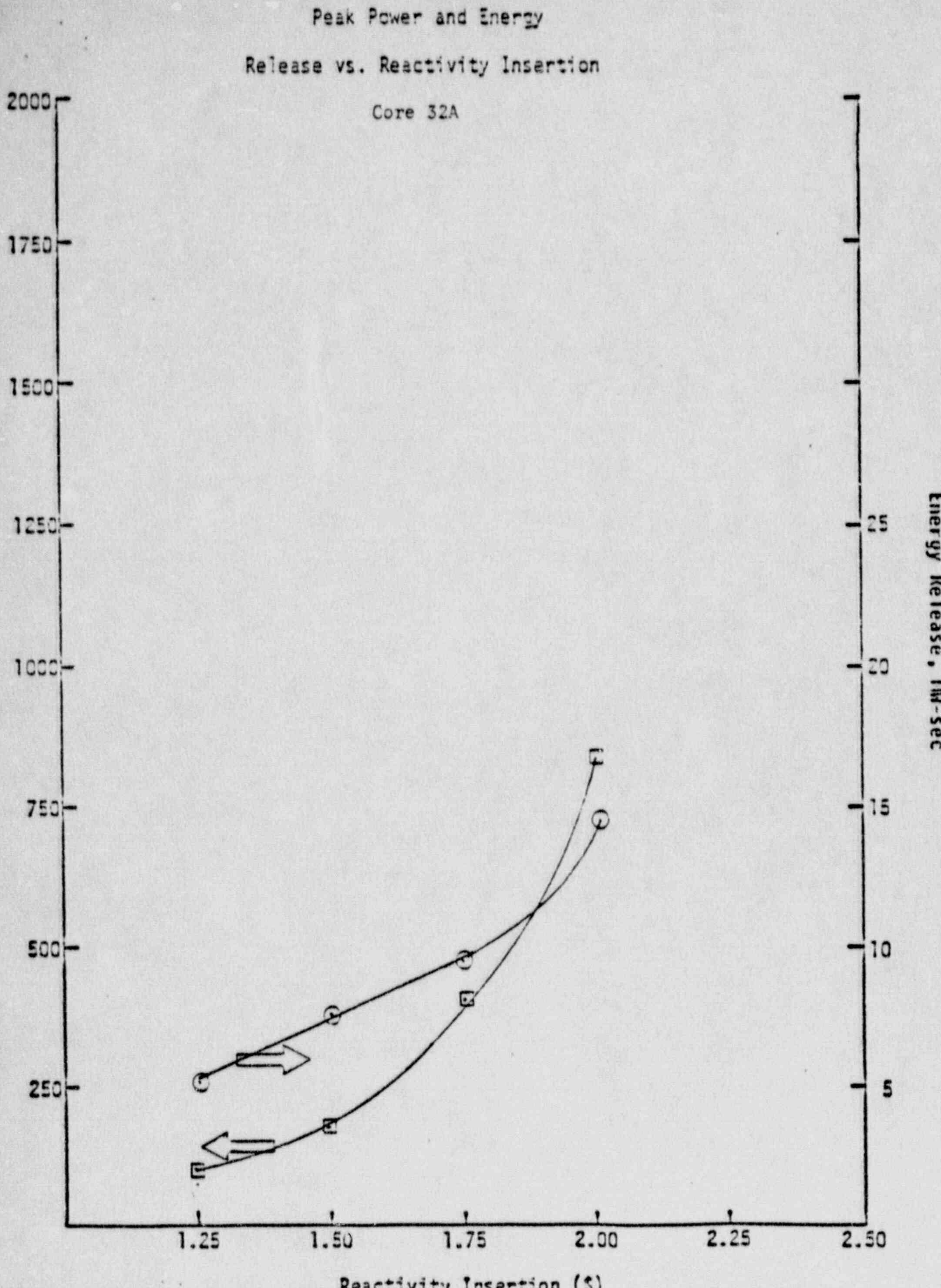

Peak Power and Energy
Release vs. Reactivity Insertion
Core 32A
Peak Power, MW
Energy Release, MW-sec
Reactivity Insertion ($)
2000
1750
1500
1250
1000
750
500
250
25
20
15
10
5
1.25
1.50
1.75
2.00
2.25
2.50

Figure 3

WSU TRIGA CORE 32A

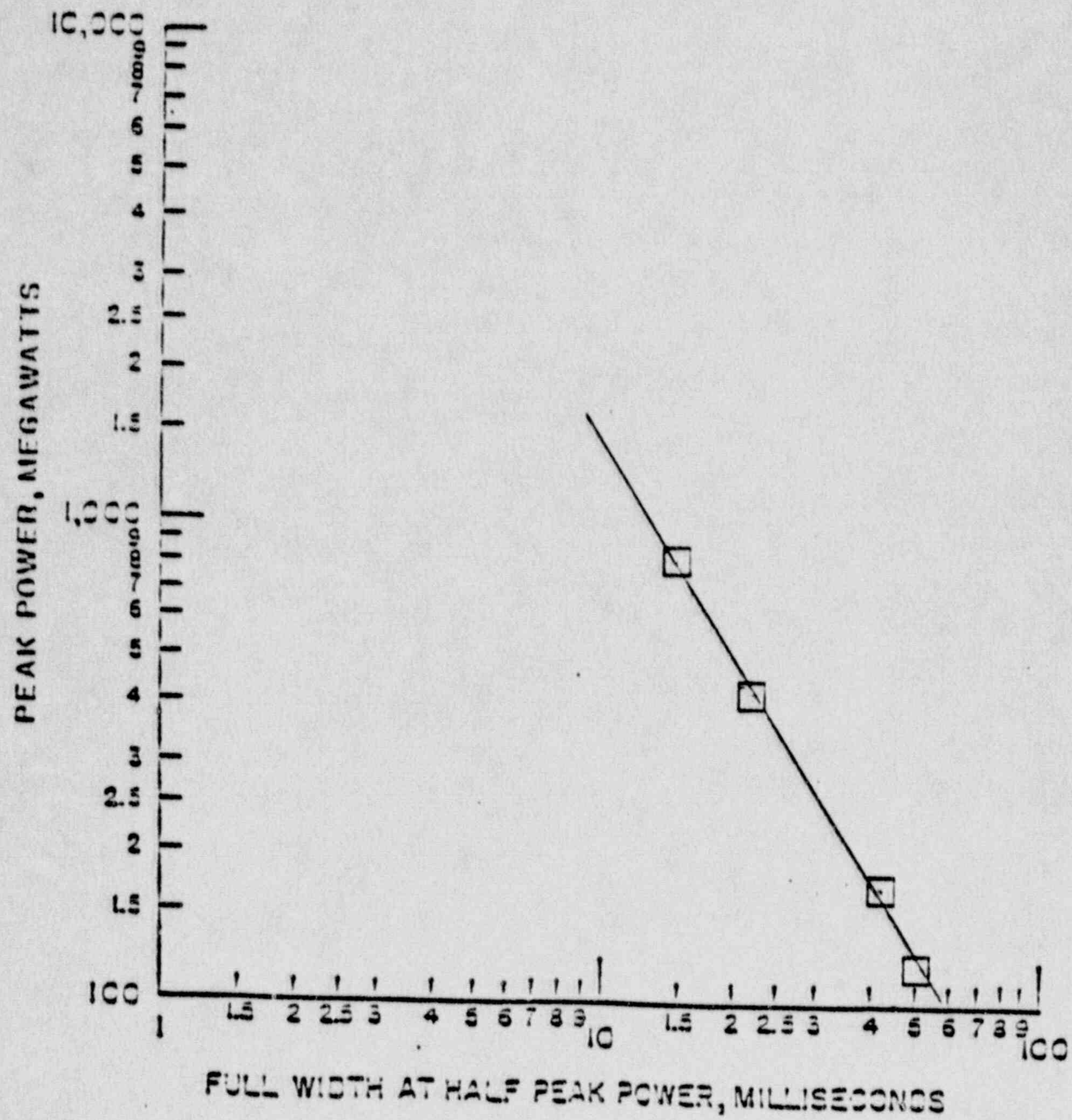


Figure 4

TABLE 1

CORE 32A PULSING CHARACTERISTICS

XL = 24 usec   Tc = -0.0145 $/°C
N = 102 TRIGA rods   To = 35°C

Reactivity ($)	P_{max} (Megawatts)	$\overline{Tp}$ (°C)	E (Megawatt-Sec)	$\overline{E}/cm^3$ (Watt-Sec/cc)
1.25	51	69	5.9	159
1.50	205	103	9.0	243
1.75	467	136	12.2	330
2.00	839	168	15.6	420
2.25	1324	200	19.0	513
2.5C	1926	232	22.5	609
2.75	2648	263	26.2	708

$ = reactivity inserted in dollars

$\overline{Tp}$ = average peak core temperature in °C

E = energy released in megawatt-sec

$\overline{E}/cm^3$ = average energy per cm^3 of fuel in watt-sec/cm^3

$$\frac{\text{Watts-sec}}{\text{cm}^3} = 2.08 \times 10^{-3} (\Delta T)^2 - 2.09 \Delta T - 53.6$$

where ΔT is the average core temperature rise in degrees centigrade. Using the limiting fuel temperature of 830°C established in the previous section of this report which corresponds to a ΔT of 795°C above ambient, we calculate a maximum allowable power density during a pulse of 2923 watts-sec/cm^3. This value represents the worst case condition and thus we must make a correction for heterogeneous effects in the real core. The total peaking factor for the WSU TRIGA reactor calculates out to be 5.91 using the data developed at General Atomics (6). That is, the ratio between the average temperature in the core to the highest temperature point in the core due to heterogeneous effects is 5.91. Thus, the average power density in the core should not exceed 2923/5.91 = 495 watts-sec/cm^3 in order to limit the temperature in the hottest spot to 830°C.

Referring to Table I which depicts the performance of core 32A using the Fuchs-Nordheim variable heat capacity model (6); we see that the safe pulsing limit for this core is between $2.00 and $2.25. Interpolation of data in Table I yields a safe pulsing limit of $2.20. Figure 5 shows the performance of the Texas A&M reactor during pulsing and the pulsing limit of $2.28 that was established for the core represented by Figure 1. The cores in the Texas A&M and WSU reactors are quite similar and thus one would expect the pulsing limits to be similar even though the calculations were done by somewhat different methods.

TEXAS A&M MIXED CORE III A

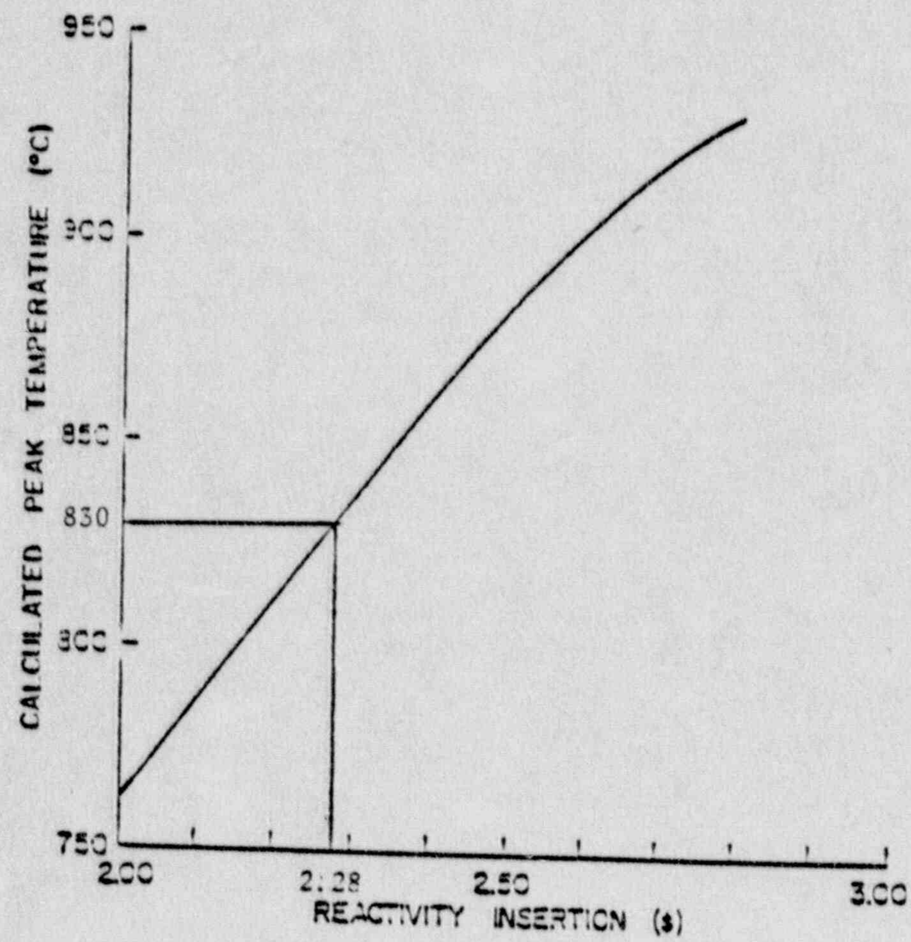


Figure 5

Hazards Evaluation of Present WSU Reactor Pulsing Limit

Retaining the present technical specification limit for the WSU TRIGA reactor with a pulsing limit of $2.50 is inconsistent with reactor safety methodology since the analysis upon which that limit was set now turns out to be less than conservative. The most likely result from pulsing the WSU TRIGA reactor at the $2.50 level would be a FLIP fuel problem like the one that occurred at Texas A&M and the possibility of a fuel cladding rupture with the release of fission products into the reactor pool room. The Design Basis Accident in the SAR for the WSU TRIGA reactor is the failure of one fuel rod and the release of the contained fission products into the pool room. The SAR analysis demonstrates that this postulated accident would not constitute a significant safety hazard to the general public. Thus, the present non-conservative pulsing limit of $2.50 does not involve a significant safety hazard.

The requested change in the technical specification for the WSU TRIGA reactor from the present $2.50 pulsing limit to one related to the maximum allowable fuel temperature during a pulse does not involve a significant safety hazard consideration on the basis of the considerations listed above. The change involves shifting to a more conservative limit based on the results of the analysis of the cause of the FLIP fuel damage problem that occurred at Texas A&M. The requested change is also consistent with the technical specification established for the Texas A & M reactor as a result of the FLIP fuel damage problem that occurred at that facility.

Uncertainties in the Pulsing Limit Based on Fuel Temperature

The primary uncertainties associated with the calculation of the maximum allowable pulse insertion based on fuel temperature by the method outlined in this report fall into two areas. These areas are 1) the accuracy of the Fuchs-Nordheim pulsing model, and 2) calculation of the average core temperature and the core temperature peaking factor. The Fuchs-Nordheim variable heat capacity mode is known to be conservative (7) and thus the actual average power density will be slightly less than predicted by this model. The conservative nature of this model primarily stems from the fact that the model assumes a constant negative temperature coefficient whereas the real temperature coefficient of a FLIP fueled reactor increases with increasing temperature. At WSU, core temperature calculations are based on the fuel rod power density as calculated using the two dimensional EXTERMINATOR-2 diffusion code. (8) This code has been used at WSU and Texas A&M for a number of years and has been found to be quite accurate. The peaking factors used to make the average to peak temperature calculation are a small modification of those reported in report GA-9350 (5) that are as accurate as one can calculate. The small modification used at WSU increases the total peaking factor and thus makes the analysis more conservative. In general, all the uncertainties are such that lead to the setting of a conservative limit.

Recommended Frequency of Pulsing Limit Evaluation

The two primary parameters that cause a change in a core's performance that necessitate a recalculation of the temperature related pulsing limit are: 1) core changes and 2) fuel burnup. Accordingly, a new calculation must be made each time the core is rearranged including just moving fuel rods around in the core. Also, the temperature limit should be calculated annually to take into account the effects of burnup and of the buildup of fission products in the core. Due to the fact that the highest burnup is in the center of the core, the power density in the hottest rod decreases with burnup thereby making a previously calculated temperature related pulsing limit more conservative. Accordingly, annual calculations on an unchanged core is conservative.

REFERENCES

1. Status Report on Damaged FLIP Fuel During Operation of the NSCR at Texas A & M University, Letter to the USAEC of November 1, 1976, from John D. Ronald, Director, Texas A & M University, Nuclear Science Center.

2. Supplement I to the 1979 Safety Analysis Report for the Texas A & M Nuclear Science Center Reactor, 30 March, 1982.

3. Safeguards Summary Report for the TRIGA-FLIP Reactor at the Puerto Rico Nuclear Center, PRNC-123, Revision C, November 11, 1969.

4. The U-ZrH_x Alloy: Its Properties and Use in TRIGA Fuel, G.A. Report E-117-833 of February 1980 by M. T. Simnad.

5. Experimental Results from Tests of 18 TRIGA-FLIP Fuel Elements in the Torrey Pines Marte F Reactor, G.A. report GA-9350 by G. B. West and J. R. Shoptaugh.

6. The Fuchs-Nordheim Model with Variable Heat Capacity, NS & E, Vol 16, No. 4, August 1963, R. Scaleter.

7. Safety Analysis Report for the Illinois Advanced TRIGA, University of Illinois, August 1967.

8. EXTERMINATOR-2: A Fortran-IV Code for Solium, Multigroup Neutron Diffusion Equations in Two Dimensions, ORNL-4078, April 1967, J. B. Fowler et al.