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SUPPLEMENTARY SAFETY ANALYSIS REPORT PALISADES GADOLINIA DEMONSTRATION PROGRAM CYCLE 4

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PALISADES GADOLINIA DEMONSTRATION PROGRAM

CYCLE 4

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1.0 INTRODUCTION AND SUMMARY

The Batch H reload for Cycle 4 of the Palisades Reactor will consist of 68 assemblies with a batch average U235 enrichment of 3.27 w/o. Included in the reload will be thirty-two (32) fuel pins which contain 4.00 w/o Gd_2O_3 in UO_2 enriched to 2.69 w/o U-235. The gadolinia bearing pins will be distributed equally among four (4) fuel assemblies. The purpose of inserting the 4 w/o Gd_2O_3 bearing fuel rods in Batch H is to demonstrate the application of a concentration of gadolinia bearing fuel in a pressurized water reactor (PWR). The number of pins constitutes a sufficient quantity of gadolinia bearing fuel rods in the reload to control the power distribution and correspond to a measurable quantity of core reactivity. The four assemblies with the thirty-two gadolinia poisoned fuel rods at 4.00 w/o Gd_2O_3 are replacing thirty-two 3.43 w/o U-235 fuel pins. The continuing gadolinia demonstration program in Palisades will enhance the PWR data base obtained from the current Palisades and Prairie Island Unit 1 programs and provide the experience which will allow transition in the future from demonstration quantities of gadolinia to production quantities of gadolinia.

The incorporation of four assemblies with a high concentration of gadolinia into the cycle 4 core does not significantly change the operating parameters of the core. Safety analysis of the cycle 4 core and Batch H fuel with the Gd_2O_3 containing assemblies have been performed. Results of the analyses show that the gadolinia rods do not alter the safety limits or margins for the Palisades Batch H fuel design.

2.0 BACKGROUND

Gadolinia bearing fuel (UO_2 - Gd_2O_3) supplied by Exxon Nuclear Company (ENC) has undergone irradiation in BWR's for several years. In addition, Exxon Nuclear Company currently has small quantities of gadolinia bearing uranium fuel rods under irradiation in the Palisades and Prairie Island Unit 1 PWR Nuclear Plants.

A substantial number of Exxon Nuclear supplied BWR fuel assemblies containing gadolinia as a burnable poison have been irradiated to high burnups. The gadolinia is contained in several fuel rods in each assembly and is uniformly blended with the enriched UO_2.

Typical irradiated fuel assemblies have been examined during the reactor refueling outages. The examinations have included visual examinations, fuel rod diameter measurements, fuel rod length measurements, and gamma scan measurements. The fuel examinations performed to date, including fuel rods containing gadolinia, have revealed no abnormalities.

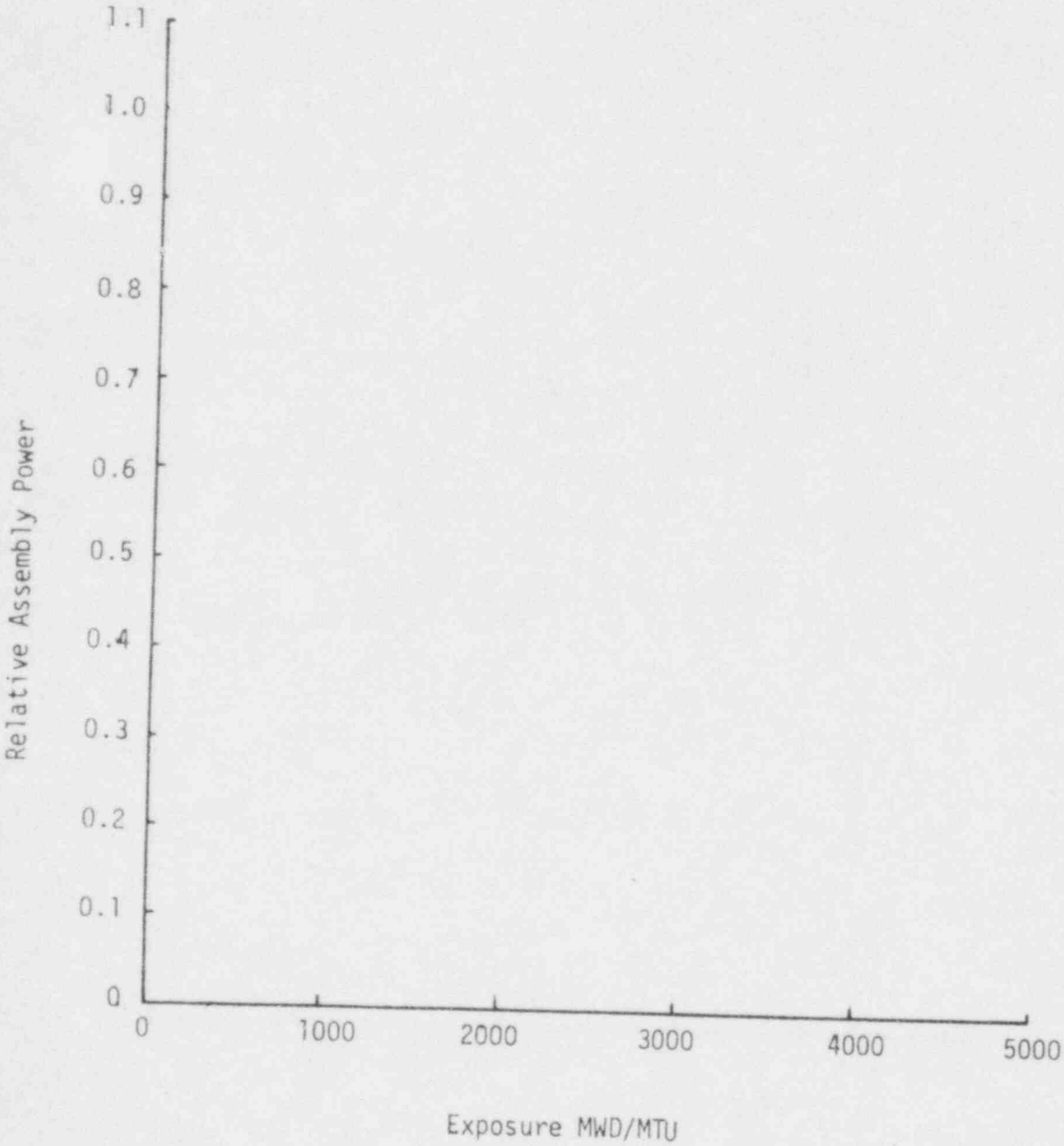
The gamma scan measurements have demonstrated the accuracy of the ENC calculational methods to predict the depletion of the gadolinia. A comparison of calculated and measured local power distributions for a BWR fuel assembly is shown on Figure 2.1. The calculated powers in the gadolinia rods compare well with the measured powers.

Currently in Palisades, there are a total of 32 rods distributed among eight assemblies with 1.00 w/o gadolinia in the UO_2 fuel pellets. These rods were loaded in the Palisades reactor at the start of the present operating cycle (Cycle 3). Comparisons of measured assembly power to predicted assembly power in the gadolinia poisoned assemblies shown in Figure 2.2 show power differences of less than variance from the ENC prediction. These assemblies will continue to be closely monitored and compared to ENC predictions throughout the cycle.

In the Prairie Island Unit 1 Nuclear Power plant, there are currently 64 gadolinia poisoned fuel rods being irradiated. These rods were loaded in 16 assemblies at the beginning of the current operating cycle (Cycle 5). Measured power distributions show power differences in the gadolinia bearing assemblies of only to variance from the ENC prediction. The close agreement of predicted and measured values of Prairie Island Unit 1 is similar to that for Palisades.

Figure 2.1 Ratio of Calculated to Measured Local Power Distribution Oyster Creek Lead Fuel Assembly - 3,800 MWD/MTU

Figure 2.2 Palisades Cycle 3
Gadolinia Poisoned Assemblies
Power Density Prediction vs
measured



3.0 NEUTRONIC ANALYSIS

The neutronics calculations for the gadolinia bearing rods to be loaded in Palisades are based on standard Exxon Nuclear Company methods.[1,2,3] Modeling techniques developed for the present gadolinia loading in Palisades are used. The UO_2 - Gd_2O_3 fuel cell cross sections are calculated with a multigroup transport theory code which includes the effect of the surrounding cells on the neutron energy spectrum. From this calculation, transport corrected diffusion theory cross sections are developed for a discrete pin cell. These cross sections may then be input directly in a discrete mesh core model or alternately into single assembly calculations from which flux weighted cross sections are calculated for use in a nodal code.

3.1 Gadolinia Bearing Fuel Cell Cross Section

The gadolinia bearing fuel cell was depleted and cross sections generated with the XPIN[4] code. XPIN calculates infinite lattice parameters by multigroup transport theory.

. This "super cell" is depleted and the cross sections in the central cell collapsed to two groups. In Figure 3.1 the infinite multiplication factor for a 2.69 w/o enriched pin cell containing 4 w/o gadolinia is compared as a function of exposure to a similar cell with no gadolinia.

Effective two group diffusion cross sections are developed using a rectangular representation of the super cell. The super cell is modeled with a discrete mesh (one mesh interval per pin pitch) diffusion theory calculation using PDQ.[5] The fast group cross sections are taken directly from the XPIN pin cell, while the thermal group absorption and fission cross sections are corrected until the diffusion theory reaction rates (fast and thermal) match those predicted with transport theory.

3.2 Gadolinia Bearing Fuel Assembly Calculation

Assembly calculations have been done to determine a desirable distribution of gadolinia bearing fuel rods within an assembly. A discrete mesh, diffusion theory PDQ representation was utilized. With this model, both the number and location of UO_2 - Gd_2O_3 pins can be studied in detail.

Based on the assembly calculations, and on core calculations to be discussed later, an assembly loading configuration has been determined. For the Palisades gadolinium demonstration program, eight standard fuel rods in the gadolinium bearing fuel assemblies were replaced with 2.69 w/o UO_2 rods containing 4 w/o gadolinia. On an assembly basis the worth of the gadolinia is predicted to be at beginning of life. At an assembly exposure of 4,000 MWD/MT, the poison worth has diminished to about at 8,000 MWD/MT, the poison worth has diminshed to about and has become indistinguishable by an assembly exposure of about 10,000 MWD/MT.

The effect of the UO_2-Gd_2O_3 pins on assembly local peaking was studied for the Reload H design. Included were fresh fuel assemblies containing B_4C - Al_2O_3 burnable poison and assemblies containing UO_2 - Gd_2O_3 pins.

3.3 Core Analysis

The Cycle 4 reference core design has been analyzed with the 3-D reactor simultor XTG[6]. With the planned loading, the gadolinia poison is predicted to be equivalent to about of soluble boron at beginning of cycle.

The Cycle 4 fuel loading pattern has been designed such that even if the gadolinia poison worth is significantly smaller or significantly larger than expected, a desirable core power distribution will be achieved. The effects of off-nominal gadolinia poison worths have been studied by varying the poison worth while maintaining a fixed loading pattern. Three cases were considered and the core depletion characteristics studied. The base case is the predicted core behavior, if the gadolinia worth and burnout is accurately calculated. The off-nominal extremes of poison worth were bracketed by setting the beginning of cycle (BOC) poison worth to one-half the nominal worth for one case and for the other extreme, the BOC gadolinia worth was assumed to be 50% more than predicted. These postulated core configurations were depleted and the resulting power distribution compared.

As expected, there are noticeable differences between the nominal and extremes in the BOL relative power distribution. However, as shown in Figure 3.2, the power shape associated with either extreme is acceptable. The power distributions for these three cases at equilibrium conditions (500 MWD/MTU) are given in Figure 3.2.

Figure 3.1 Pin Cell Infinite Multiplication Factor vs. Exposure

Figure 3.2 Cycle 4 Power Distribution Sensitivity to Gadolinia Worth at 500 MWD/MT ARO, HFP

4.0 THERMAL DESIGN--(Gd_2O_3 - UO_2 Rod Temperatures)

An analysis of the Palisades poison rods (4.00 w/o Gd_2O_3) was performed to determine allowable LHGR values which preclude pellet centerline melt as a function of pellet exposure. The impact upon plant operation was then determined by comparison of the limiting LHGR values anticipated for the poison rods during the life of the fuel. The results of the comparison indicate that sufficient margin exists between pellet centerline melt and maximum anticipated LHGR values for the poison rods up to pellet exposures of 40,000 MWD/MT.

The allowable LHGR values to preclude pellet centerline melt were determined using models identified in the ENC gadolinia fuels topical report[7] which includes the effect of Gd_2O_3 on the thermal properties of the fuel pellets. This report indicates the melting temperature for a 4.00 w/o poison rod to be at beginning-of-life. The melting temperature was assumed to degrade at the same rate as a fuel pellet containing no Gd_2O_3

LHGR values corresponding to T_{melt} at several exposures appear in Table 4.1. Also shown in Table 4.1 are the maximum calculated transient LHGR values indicating a minimum margin of occurring at end of life.

In order to determine the impact of the poison rods upon reactor operation, the results of the plant transient analysis[10] for the Palisades reactor were examined to determine the peak kw/ft anticipated for the rod withdrawal transient and compared against the limit values. The values of the peak kw/ft for the rod withdrawal transient were conservatively evaluated and the values appear in Table 4.1.

As the results in Table 4.1 indicate, sufficient margin exists between T_{melt} and the maximum anticipated kw/ft to preclude centerline melt for the poison pellets.

Table 4.1 Comparison of LHGR Values for 4 w/o Gd_2 - UO_2 Fuel Rods

Pellet Exposure (MWD/MTM)	(kw/ft)*Transient
10,000	17.9
20,000	17.9
30,000	17.9
40,000	17.9

*Single rod withdrawal transient, EOC conditions, 126% power overshoot $F_R = 1.45$, $F_a = 1.75$, $F_\ell = 1.0$, $F_E = 1.03$.

5.0 ECCS ANALYSIS

This section establishes that the 4.0 wt % gadolinia (Gd_2O_3) bearing fuel rods (referred to as Gd_2O_3 rods) to be included in the Palisades H gadolinia assemblies are not limiting rods in a LOCA, and hence, do not impact the ECCS allowable total peaking limits applicable to the Palisades H design. The use of a lower enrichment for the Gd_2O_3 rods in the Palisades H gadolinia assemblies precludes these rods from being the limiting rods in a LOCA. The lower enrichment (2.69% for the Gd_2O_3 rods versus 3.43% in assemblies without gadolinia) reduces both the power and burnup of the Gd_2O_3 rods relative to the UO_2 rods in the assembly. The lower power and burnup lead to corresponding reductions in fuel temperature and fission gas release.

Figure 5.1 shows the ratio of Gd_2O_3 rod power to peak UO_2 rod power versus the exposure of the peak UO_2 rod. The UO_2 rod considered is the ECCS limiting (peak power) UO_2 rod in the assembly. Figure 5.1 shows that the Gd_2O_3 burnable isotopes are largely depleted when the peak UO_2 rod reaches a burnup of 15,000 MWD/MTM (8000 MWD/MTM burnup on the Gd_2O_3 rod). Beyond this point, the relative power of the Gd_2O_3 rod increases slowly from about 80% of the UO_2 rod power at a UO_2 rod burnup of 15000 MWD/MTM to just over 90% of the UO_2 rod power at end-of-life.

Figure 5.2 provides the corresponding ratio of Gd_2O_3 rod burnup to peak UO_2 rod burnup versus the exposure of the peak UO_2 rod. The burnup of the Gd_2O_3 rod is considerably less than that of the peak UO_2 rod throughout life and even at end-of-life the Gd_2O_3 rod burnup is only 80% that of the UO_2 rod.

A comparison of steady-state peak pellet volume average temperatures (i.e., stored energy) between the Gd_2O_3 rod and the peak power UO_2 rod as a function of the UO_2 rod peak pellet burnup is shown in Figure 5.3.

The results correspond to the ECCS total peaking limit, F_q, of 2.76 for the limiting UO_2 rod in the Palisades H design (14.98 kw/ft total power, 14.61 kw/ft heat release in the fuel). At low exposures, the Gd_2O_3 rod has much lower stored energy than the UO_2 rod because of its reduced power (Figure 5.1).

is due to the reduced thermal conductivity for Gd_2O_3 bearing pellets identified in Reference 7.

The Gd_2O_3 rod will have a lower peak clad temperature (PCT) in the LOCA than the limiting UO_2 rod.

Figure 5.4 compares the internal gas quantity (gram moles) within the free volume of the Gd_2O_3 and peak UO_2 rods. At low exposure, the slightly higher gas quantity of the UO_2 rod is associated with sorbed gas release which, in turn, is associated with the comparatively high fuel average temperature of the UO_2 rod at beginning-of-life and low exposure. The increasing gas quantity for both the UO_2 and Gd_2O_3 rods at high exposure results from the burnup dependent enhanced fission gas release model specified by the NRC. Figure 5.4 shows that for UO_2 rod peak pellet burnups in excess of 20,000 MWD/MTM, the fission gas release enhancement effect on the pin internal gas quantity at any time is much less for the Gd_2O_3 rod than for the limiting UO_2 rod. This is because the burnup of the Gd_2O_2 rod is only 65-80% that of the peak UO_2 rod (Figure 5.2).

The lower Gd_2O_3 rod fission gas release is a further factor which makes the Gd_2O_3 rod less limiting than the peak power UO_2 rod. At high exposures ($\geq$ 30,000 MWD/MTM peak pellet burnup) the calculated PCT in the LOCA increases due to increased cladding strain and associated increases in metal water reaction. The increased strain stems from increased fuel rod internal pressure due to enhanced fission gas release.

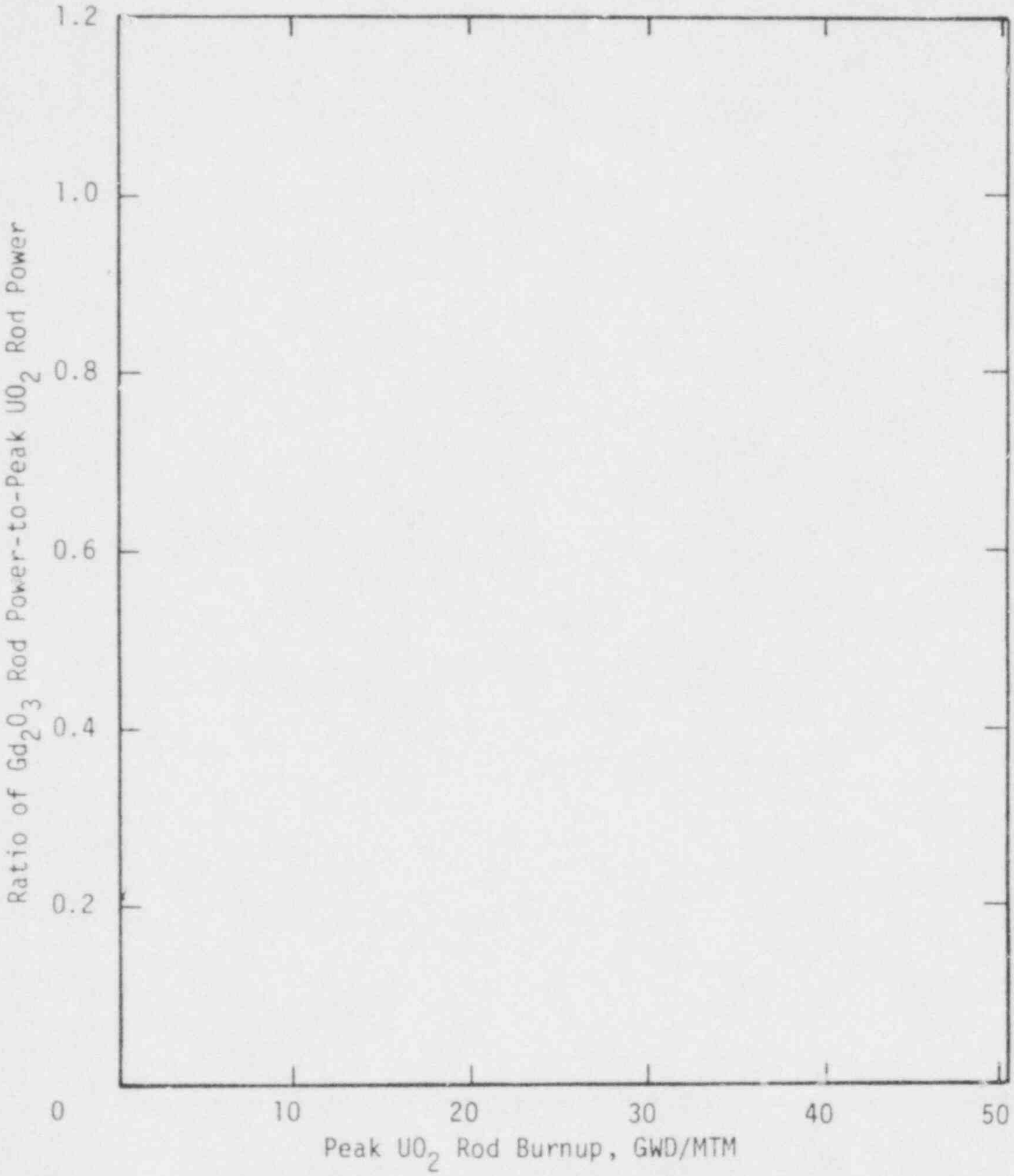


Figure 5.1 Gadolinia Rod Relative Power versus Peak UO_2 Rod Exposure

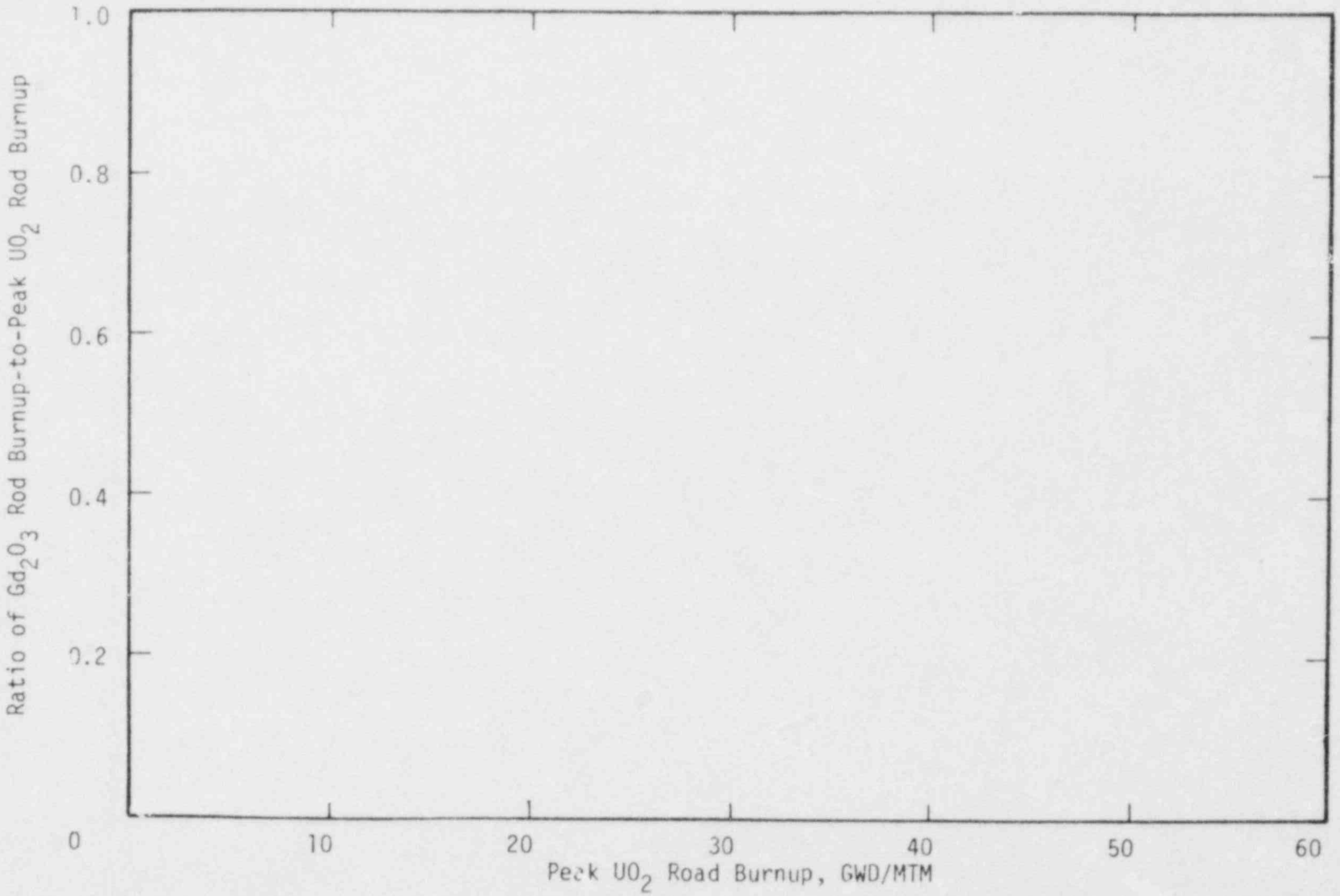


Figure 5.2 Gadolinia Rod Relative Burnup versus Peak UO_2 Rod Exposure

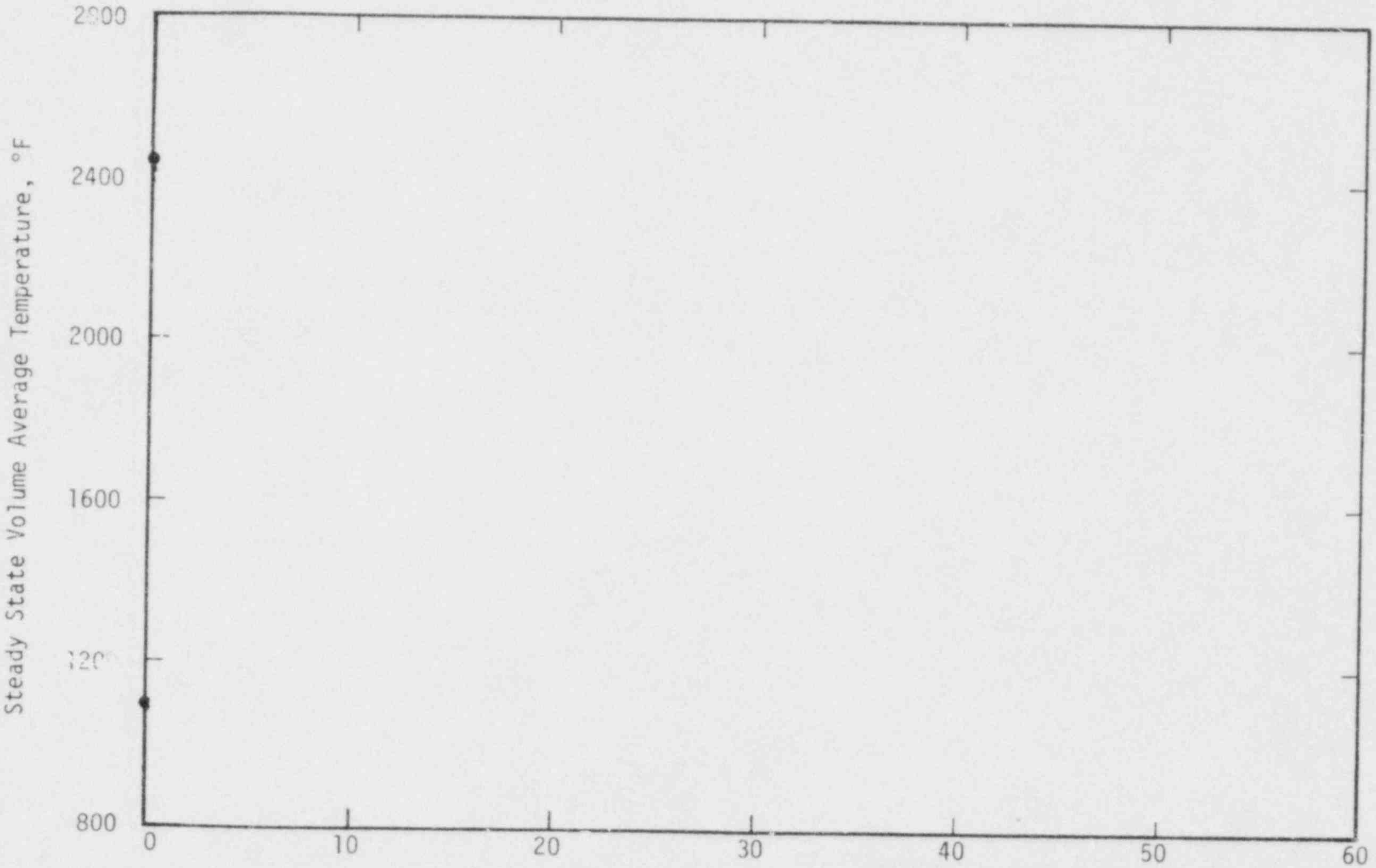


Figure 5.3 Comparison of Fuel Temperatures versus Exposure

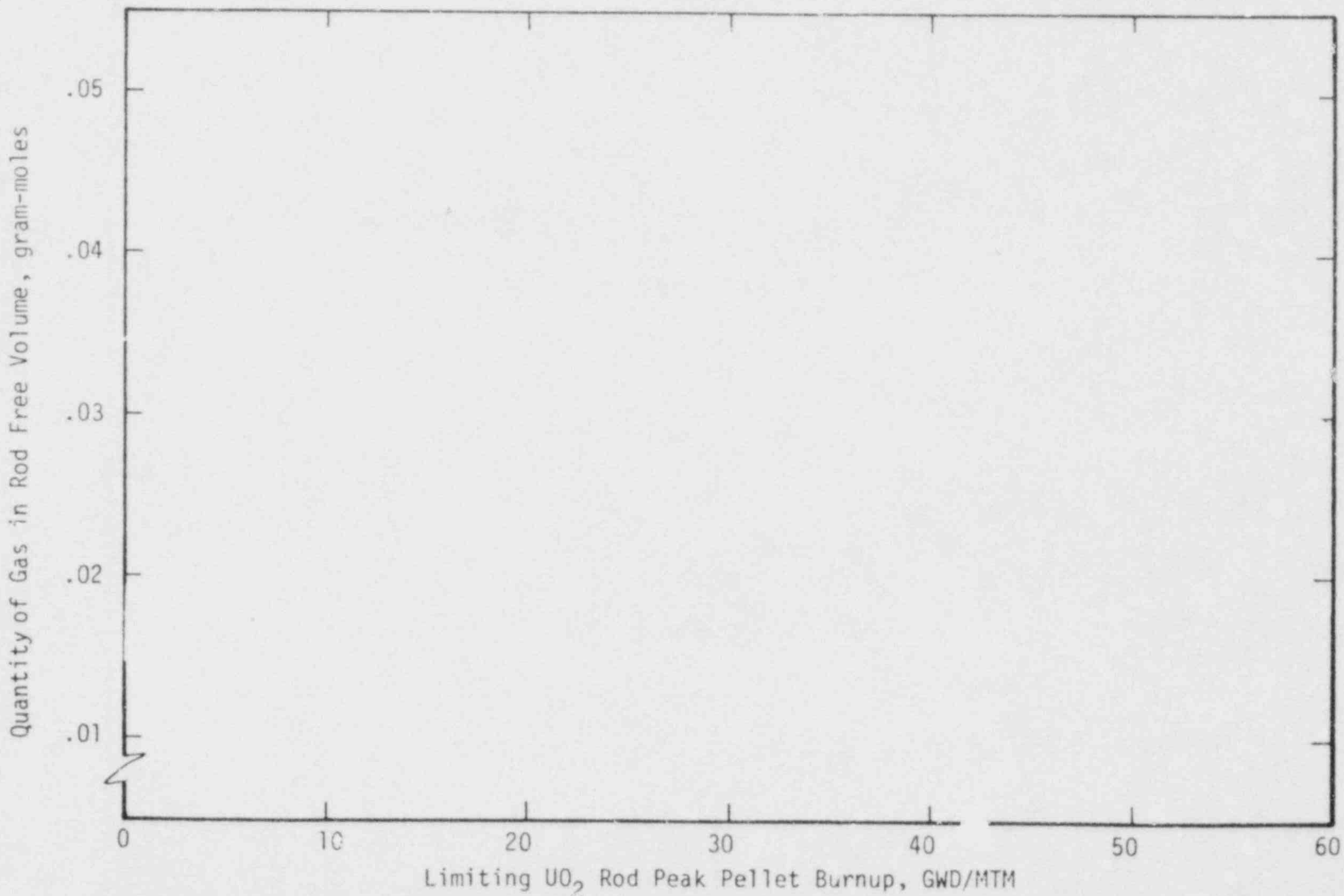


Figure 5.4 Comparison of Fuel Rod Internal Gas Quantities versus Exposure

APPENDIX A REFERENCES

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