UR-77-72

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CONF-761103--23

SUBMITTED TO: American Nuclear Society 1976 International Conference November 15-19, 1976, Washington, DC

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UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

Fission and Explosive Energy Releases of PuO_2, PuO_2-UO_2, UO_2 and UO_3 Assemblies

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15 Pages

1 Table

10 Figures

ABSTRACT

The critical masses and fission and explosive energy releases of PuO_2, PuO_2 - UO_2, UO_2 and UO_3 assemblies have been calculated. The choice of parameters used in the model are conservative and were chosen after review of appropriate plants that have been and are proposed for construction in the future. The resulting data envelopes are intended to include any conceivable set of circumstances that could ultimately lead to a nuclear incident. All energy release analysis was performed for initial fission spikes only; recriticality mechanisms were not considered.

Fission and Explosive Energy Releases of PuO_2, PuO_2-UO_2, UO_2 and UC Assemblies. J. J. Koelling, G. E. Hansen, C. C. Byers, University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545.

For the purpose of determining off-site effects of criticality accidents it has been normal practice to postulate accidents in various configurations and media within a plant.[1,2,3] These potential accidents then assist in determining much of the plant and process design. For these accidents the off-site effects are dominated by the release of gaseous iodine and noble gases through the ventilation system, out the stack, and to the exclusion boundary via appropriate dilution and decay factors. For any specific proposed accident it is the fission energy estimate that ultimately determines the dose at the boundary since all other factors, i.e., fission product yields, decay rates, dilution effect, breathing rates, plateout, etc., involved in the dose estimate are relatively well understood.

The fission and explosive energy release from criticality incidents involving liquid and metal assemblies[4,5,6,7,8] has been well established from both accidents and experimental induced excursion data; however, to date very little work has been performed in the dry powder or near dry powder assemblies. With the possible advent of plutonium recycle, it has become increasingly apparent that the upper limits of energy release for PuO_2, UO_2 and PuO_2-UO_2 assemblies similar to that

found in nitrate to oxide conversion plants and mixed oxide fuel fabrication plants should be established. In addition, it was decided to investigate UO_3 commonly found in UF_6 plants.

This study focused on the following four types of assemblies:

a) PuO_2 assemblies: Light water reactor recycle plutonium in oxide form with approximately 80% fissile and 20% non-fissile plutonium isotopes. Water content was varied from 0 to 10% by weight.

b) PuO_2-UO_2 (MOX) assemblies: A mixture of recycle plutonium with natural uranium, both in oxide form. The mixture contained a maximum of 6% PuO_2. Water content was varied from 5 to 10% by weight.

c) UO_2 assemblies: Uranium oxide with a maximum uranium enrichment of 5%. Water content was varied from 2.5 to 10% by weight.

d) UO_3 assemblies: Uranium oxide with a maximum uranium enrichment of 5%. Water content was varied from 2.5 to 7.5% by weight.

The density (oxide density) of all assemblies was maintained at 5 gm/cm^3. Reactivity insertion rates were varied from \$1 to \$100/s. A nominal concrete composition was chosen for fully reflected critical masses. Spherical geometry was chosen for ease of modeling and for minimal critical masses. A Doppler coefficient $\frac{1}{\bar{T}} \frac{dk}{dT} = -0.02$ was chosen for all uranium cases. All energy release analysis was performed for initial fission

spikes only; recriticality mechanisms, e.g., recompaction under the influence of gravity, were not considered.

The fission and explosive energy releases were determined with the Pajarito Dynamics Code (PAD)[9] that has been used by LASL personnel in estimating low order disassemblies which might occur during a reactor or critical assembly accident. PAD is a one-dimensional coupled hydrodynamic-neutronic code with Lagrangian hydrodynamics and the discrete ordinates neutron transport code DTF-IV.[10] Neutron multiplication and period calculations were also performed with the aid of DTF-IV. Hansen-Roach cross sections were utilized in both the DTF-IV and PAD calculations.

For the PAD calculations, a two material option was used whereby the fission energy is deposited in the fuel and then transferred to the water (if present) via a predetermined energy transfer rate. If no water was present the energy remained in the fuel and ultimately changed the state of the media to a vapor phase.

Figures 1 through 4 show the critical masses of PuO_2, PuO_2-UO_2, UO_2 and UO_3 for various water concentrations. For PuO_2, the critical mass is finite with no water, whereas with MOX and both UO_2 and UO_3 the "minimum" water content was 5 and 2.5% by weight, respectively. The upper limit for investigation was established when the water content filled up the void space left by the oxide. For PuO_2, UO_2 and MOX this water content was approximately 10% by weight but for

UO_3 (at the same oxide density) this value was 7.5% by weight. Above these water levels, solution assembly data exist in the literature.

Figure 5 shows the energy release expected for PuO_2 assemblies for various water contents. At low ramp rates, water vaporizes and initiates disassembly. At high ramp rates fuel vaporization follows the water vaporization. For 0% water, air that fills the void spaces initiates disassembly and may or may not be followed by fuel vaporization depending on the ramp insertion. Gas viscosity and small particle size assure equal velocities in vapor and condensed states.

In the cases studied, the total energy release becomes greater than what is normally considered acceptable in accident analyses only for high reactivity insertion rates (>>\$1/s). These rates are much greater than those obtained by maximum estimated material transfer rates (<<\$1/s) achievable in conversion and fabrication facilities. In addition to the unlikelihood of achieving these insertion rates, the neutron emission rate from spontaneous fission and the $Pu(\alpha,n)O_2$ reaction[11] as shown in Figure 6 constitutes a formidable neutron source that is easily detected while an assembly is still far subcritical. For example, at k_{eff} = 0.9, or more than \$40 subcritical, the neutron source strength is approximately 10^7 n/s-kg or 10^9 n/s for a 100 kg assembly.

Figures 7 through 9 show the energy releases expected for MOX (PuO_2 + UO_2), UO_2 and UO_3 for various water contents.

Except for the inherent PuO_2 source strength (6% of the values stated for the PuO_2 assemblies) in MOX, all of these low enriched oxides indicate approximately the same level of energy release per kg oxide. The higher release levels of these low quality fuel assemblies are due mainly to the extremely large critical masses in comparison to the relatively small critical masses of PuO_2 assemblies. The large masses imply small neutron leakage probabilities and thus require larger dilations per unit reactivity reduction.

Table I lists maximum kinetic energy (an index of "explosive" energy) as a function of assembly composition and reactivity insertion rate.

Summary:

In all of the cases considered, water vapor pressure constitutes the basic disassembly mechanism even in the case of extremely small amounts (0.1% by weight for the PuO_2 study). The water content and subsequent vapor pressures resulting from the water will thus ultimately determine the fission yield during an excursion for a given reactivity insertion rate. For zero water content as in the case for PuO_2, the air in the void spaces supplies enough energy to start disassembly. If vaporization of the fuel is necessary to complete disassembly as in the case of very high ramp rates, very large energy releases can be realized. Of course the calculated energy releases are academic if the

necessary material to achieve a critical mass cannot be present or if a strong inherent neutron source such as seen in PuO_2 or PuO_2-UO_2 assemblies will preclude accumulation of critical masses by proper detection.

As indicated earlier, the choice of parameters used in this investigation are conservative and were determined only after review of appropriate plants. The resulting data envelopes are thus intended to include any conceivable set of circumstances that could ultimately lead to a nuclear incident.

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Table I. Maximum Kinetic Energy in Megajoules as a Function of Powder Composition and Ramp Reactivity Insertion.

Composition/ramp($/sec)	5	20	100	(Metric tons per dollar)
PuO_2	0.00	1.6	4.6	0.001
PuO_2+0.1 w/o H_2O	0.01	0.02	1.6	0.001
PuO_2+2.5 w/o H_2O	0.02	0.19	0.47	0.0008
PuO_2+10 w/o H_2O	0.00	0.07	0.45	0.0005
MOX+5.0 w/o H_2O	4	50	700	32
MOX+7.5 w/o H_2O	0.5	7	120	2.7
MOX+10 w/o H_2O	0.1	2	40	0.3
UO_2+2.5 w/o H_2O	15	120	650	9.1
UO_2+5.0 w/o H_2O	1	10	80	3.4
UO_2+10 w/o H_2O	0.1	1.5	15	0.03
UO_3+2.5 w/o H_2O	15	150	700	8.5
UO_3+5.0 w/o H_2O	1	10	80	3.0
UO_3+7.5 w/o H_2O	0.5	5	35	0.1

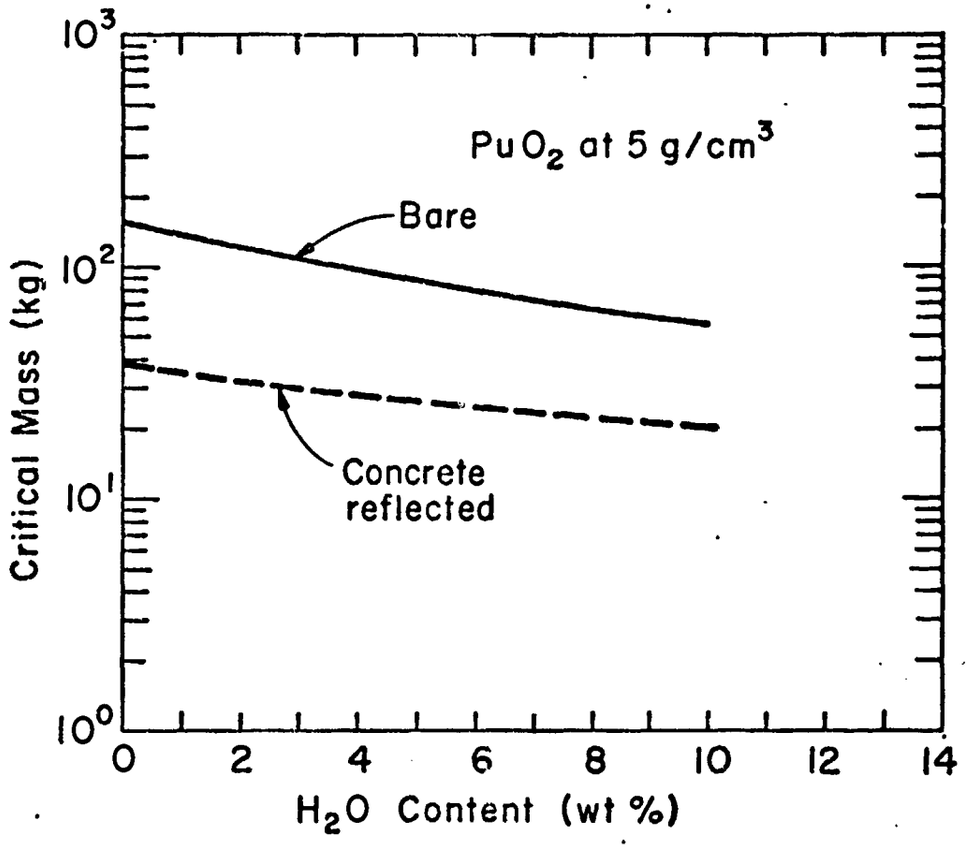

Figure 1. Critical Mass of PuO_2 Versus H_2O Content.

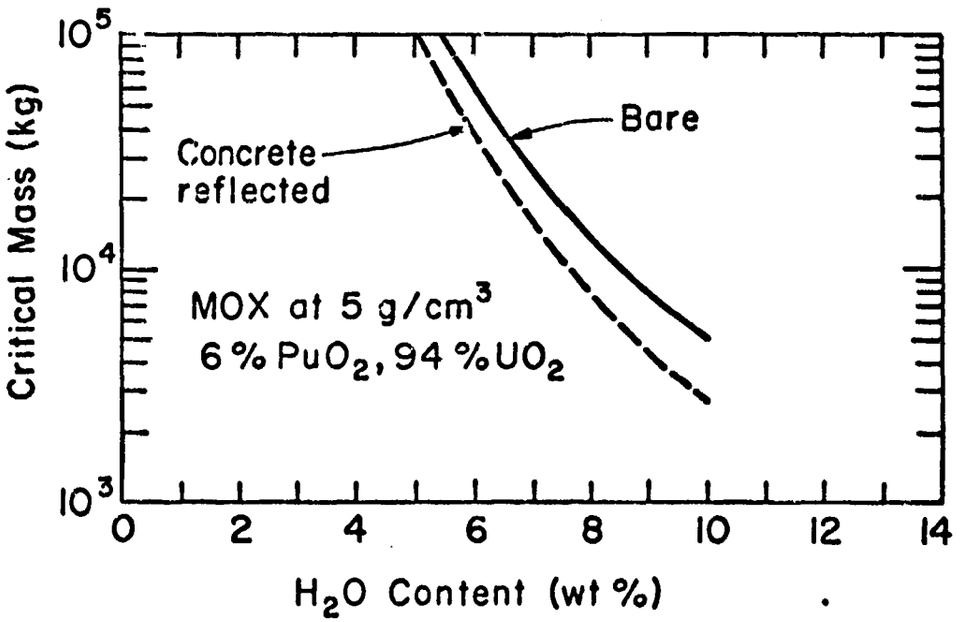

Figure 2. Critical Mass of MO_x Versus H_2O Content.

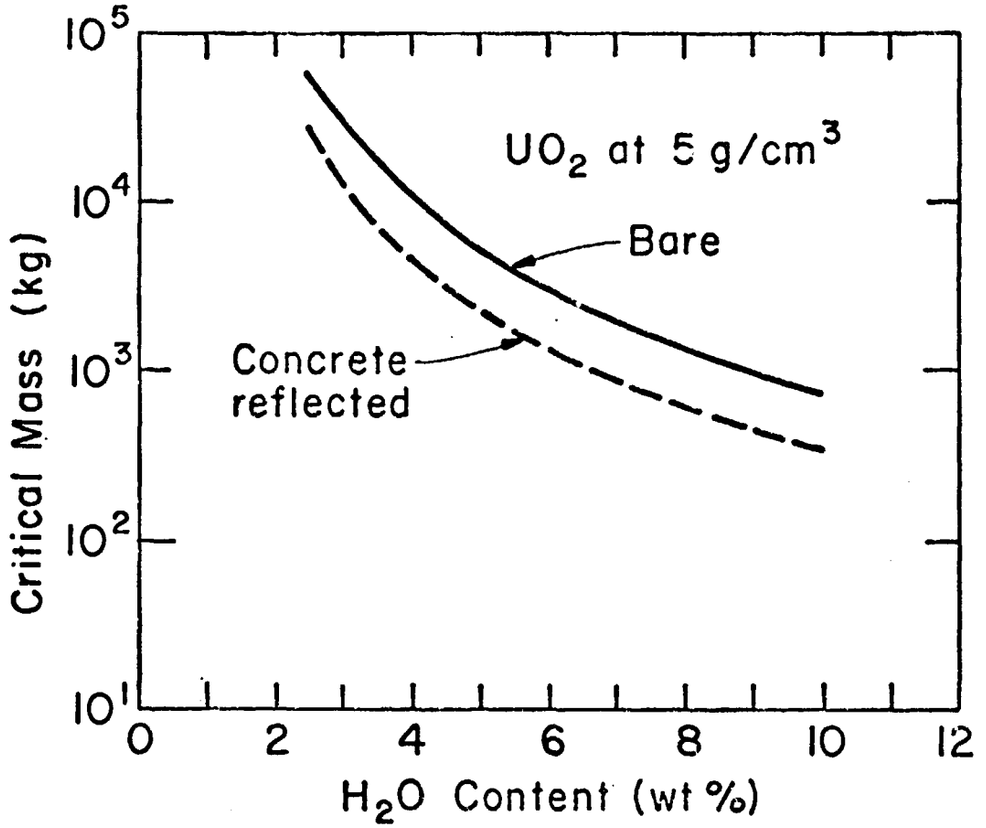

Figure 3. Critical Mass of UO_2 Versus H_2O Content.

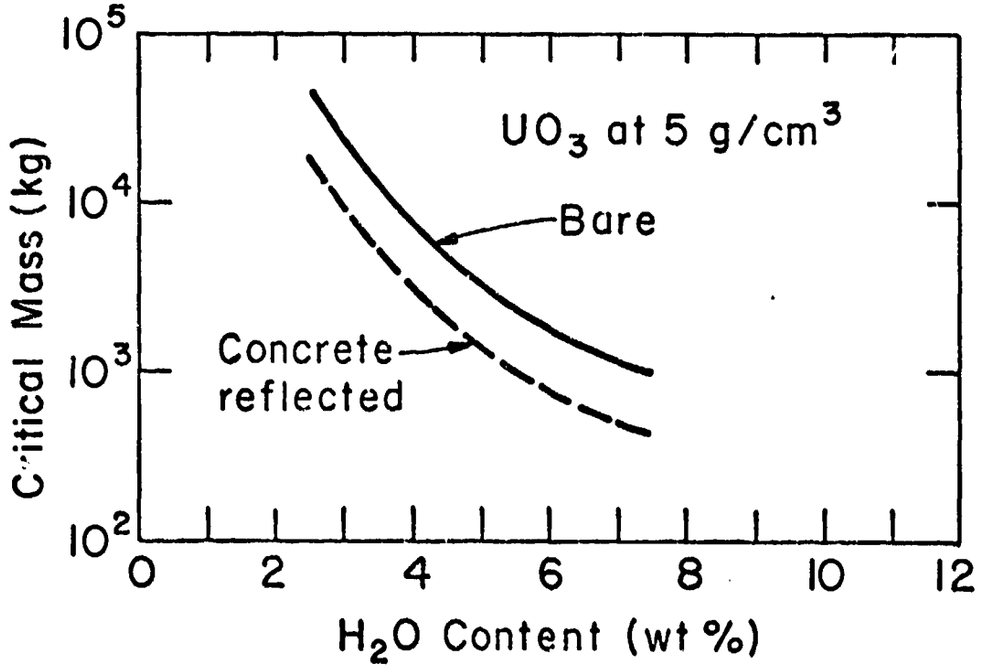

Figure 4. Critical Mass of UO_3 Versus H_2O Content.

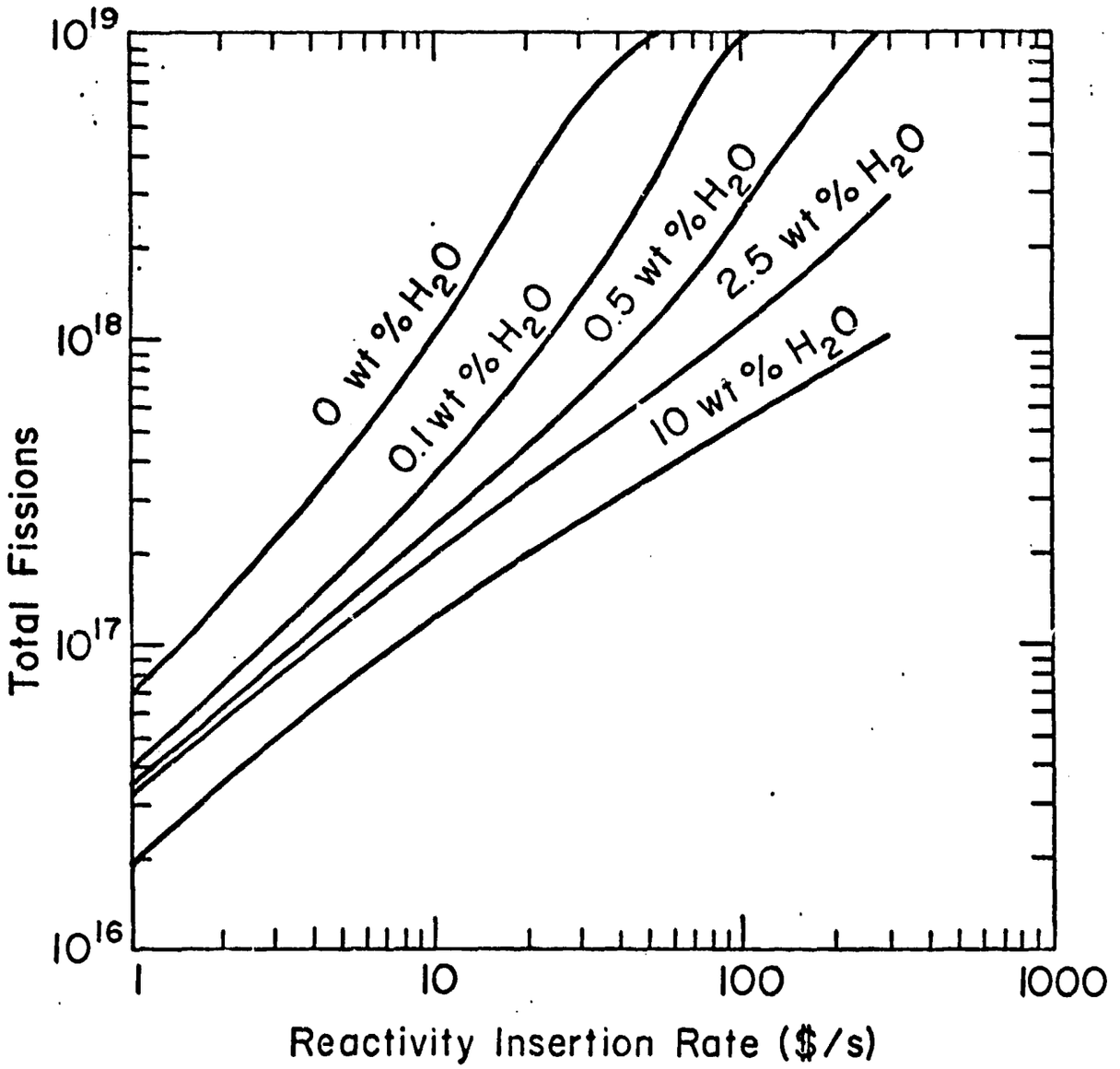

Figure 5. Fission Energy Release of PuO_2 Versus Reactivity Insertion Rate.

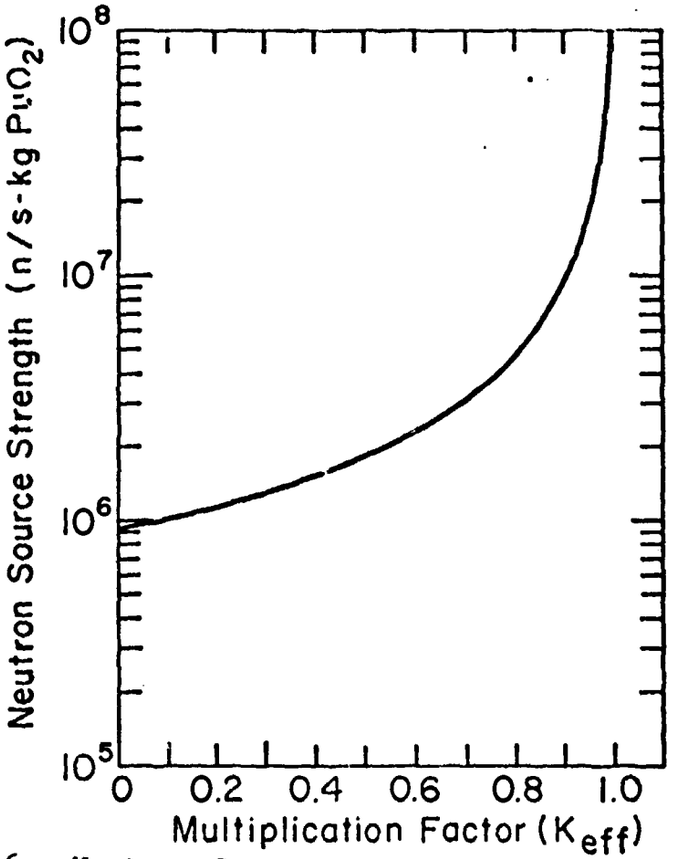

Figure 6. Neutron Source Strength of PuO_2 Versus k_{eff}.

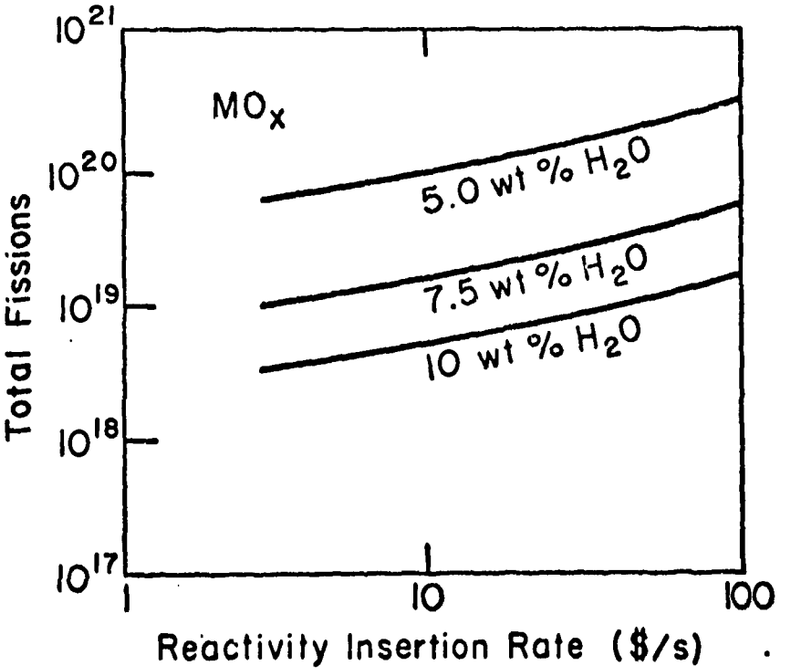

Figure 7. Fission Energy Release of MO_x Versus Reactivity Insertion Rate.

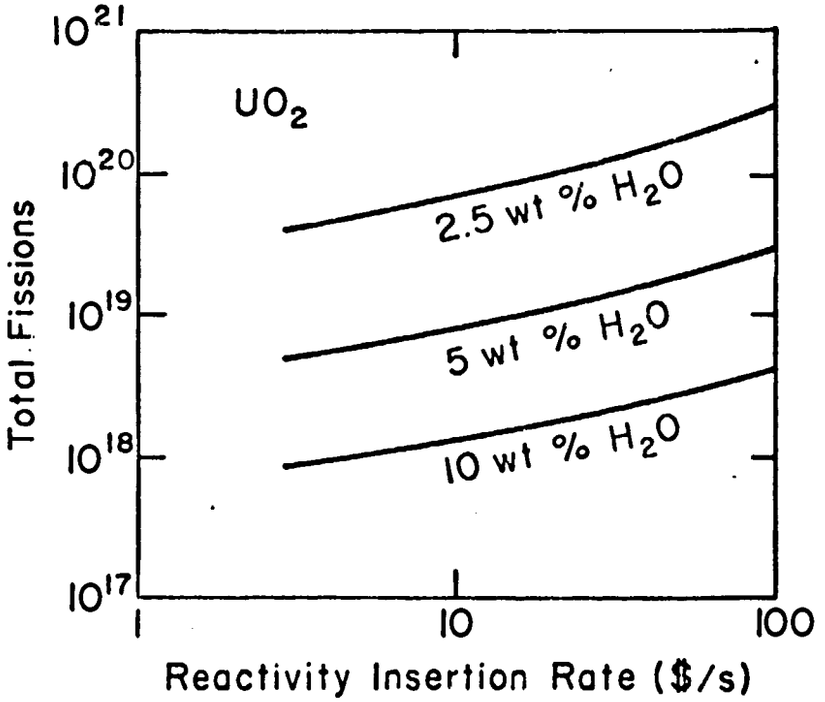

Figure 8. Fission Energy Release of UO_2 Versus Reactivity Insertion Rate.

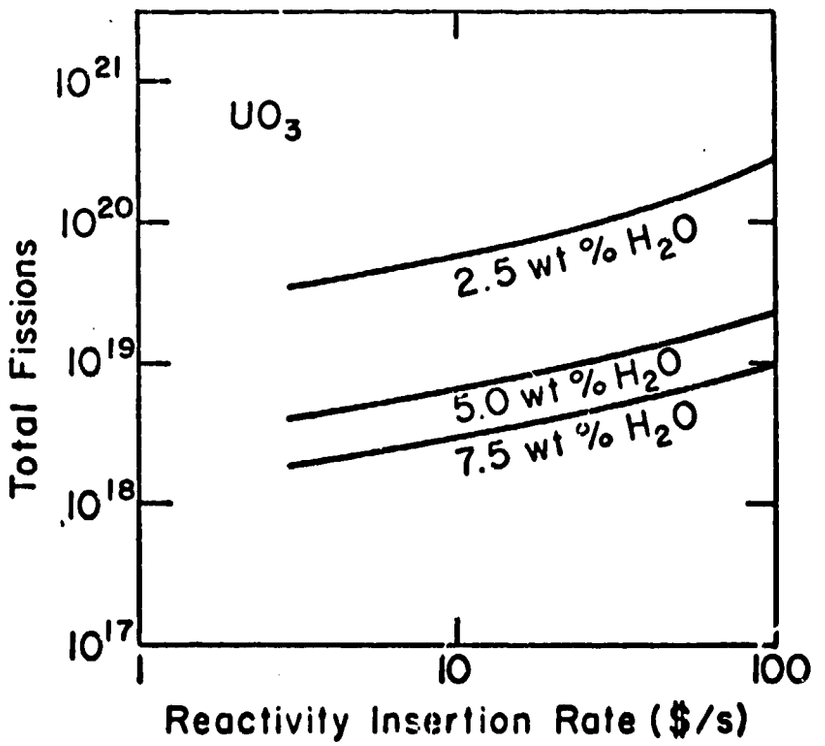

Figure 9. Fission Energy Release of UO_3 Versus Reactivity Insertion Rate.

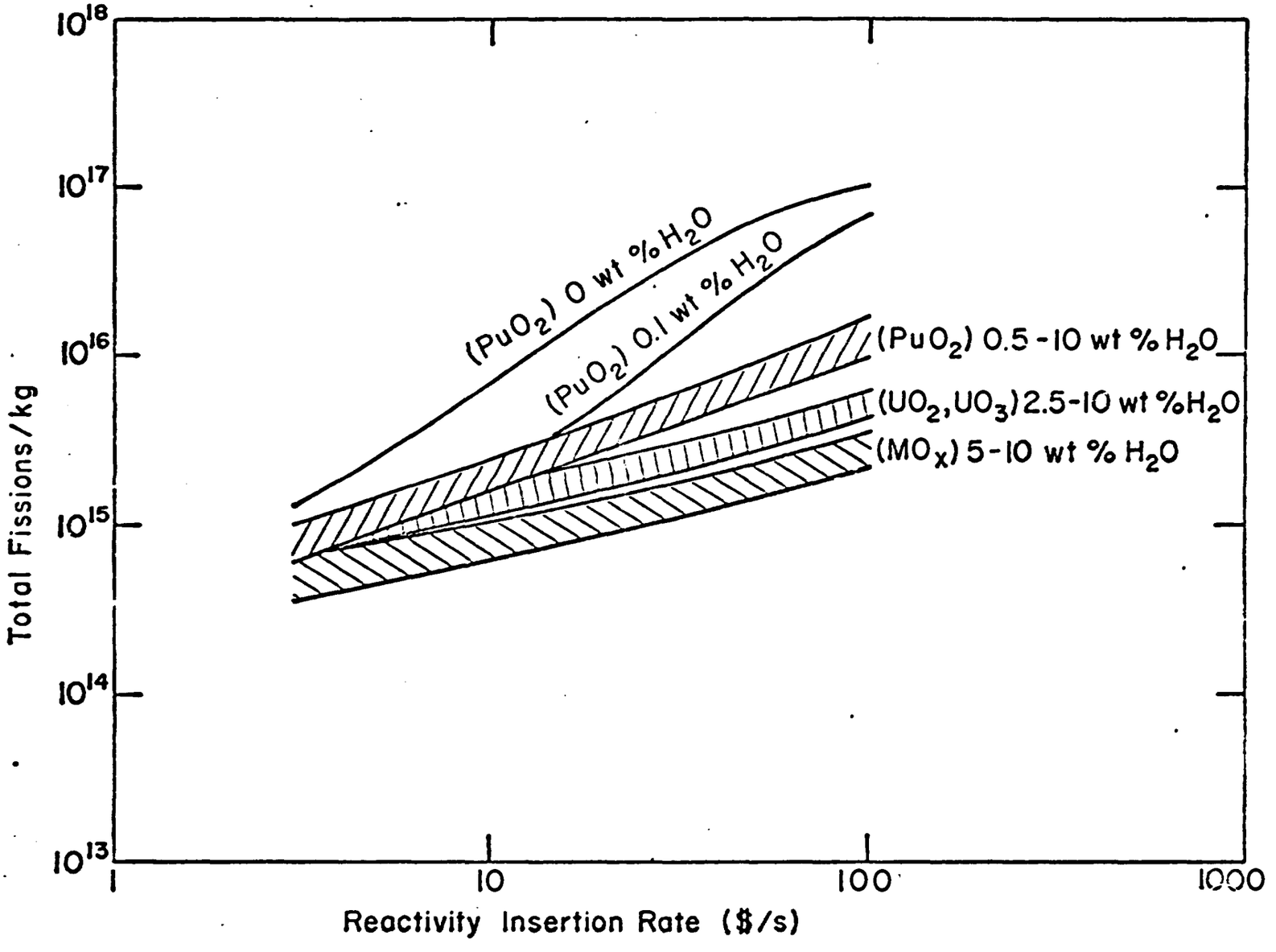

Figure 10. Fission Energy Release of Oxides Versus Reactivity Insertion Rate.