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FISSION GAS INVENTORIES AND ESTIMATED RELEASES
FROM PRTR HPD FUEL

INTRODUCTION

The PRTR is entering a phase of operation in which there is an increased danger of high level fission product release from failed fuel. The higher fuel operating temperatures result in a much larger percentage fission gas release from the fuel crystal; also it is believed that the central voids and inter-crystal cracks greatly improve the transport of fission gases from the far end of a fuel rod to a defect location.

SUMMARY

The fission product inventories in $\text{UO}_2 - 2 \text{ w/o PuO}_2$ fuel were calculated using the RIBD code and PRTR parameters. A summary of these fission product activities is included, based upon a fuel power of 1000 kw. Inventories for other powers may be calculated by direct proportion.

The 1800 C fission gas release formula is discussed and evaluated for various fuel specific powers. There is a large unexplained discrepancy between the quantities of stable noble gases and the radioactive gases released from PRTR HPD fuel during the post irradiation examination. The 1800 C formula describes the release of the stable gases, which are believed to be the more accurate measure of gas release. The use of the 1800 C method, if not correct, derives conservative estimates of the gas release.

FISSION PRODUCT INVENTORIES

The quantities of fission products in a 1000 kw $\text{UO}_2 - 2 \text{ w/o PuO}_2$ fuel element after irradiation times of 14 days, 30 days, 100 days, and 1000 days and after various decay times were calculated with the RIBD computer program.⁽¹⁾ The output data gave the quantity in curies* and in gram-atoms of four hundred thirteen stable and radioactive isotopes.

Tables I through V give a summary of these calculations. A complete listing of all the isotopes in the calculation would require far too much space for this report, therefore the fission product breakdown of only the more important fission products are given.

(1) Personal communication, R. O. Gumprecht and W. R. Markillie.

* Curies as used in this report means 3.7×10^{10} disintegrations per second of the unstable isotope. The total curies presented in the table include non-gamma emitters as well as gamma emitters.

Table I gives the I-131 activities, Table II gives the total iodine activities, Table III gives the total noble gas (Kr + Xe) activities, Table IV gives the total volatile solid (Se, Ru, Te, Cs) activities, and Table V gives the total fission product activities.

Variables entered as input to the program besides the fission product properties, the irradiation time, and the decay time were the following:

Power	=	1 MW
ϕ	=	3×10^{13} nv
σ_a^{25}	=	642 barns
δ	=	Non-U-235 fissions/U-235 fissions = 5.2

To obtain fission product quantities corresponding to fuel powers other than 1 MW, the values in the tables should be multiplied by the fuel power in MW.

TABLE I

I-131 QUANTITIES IN A 1000 KW UO_2 - 2 w/o PuO_2 FUEL ELEMENT (CURIES)

Irradiation Time	Decay Time								
	0	1 day	2 days	3 days	7 days	14 days	28 days	56 days	84 days
14 days	21,160	19,810	18,340	16,930	12,090	6625	1985	178	16
30 days	28,310	26,370	24,370	22,450	16,000	8768	2627	236	21
100 days	30,730	28,590	26,410	24,330	17,330	9495	2845	255	23
1000 days	31,540	29,340	27,100	24,960	17,790	9745	2920	262	23.5

TABLE II

TOTAL IODINE QUANTITIES IN A 1000 KW UO_2 - 2 w/o PuO_2 FUEL ELEMENT (CURIES)

Irradiation Time	Decay Time								
	0	30 sec	60 sec	15 min	30 min	60 min	4 hr	8 hr	16 hr
14 days	333,300	260,200	245,300	223,300	218,400	205,800	147,200	120,100	94,400
30 days	342,600	269,400	254,600	232,600	227,700	215,100	156,300	129,000	103,000
100 days	345,100	271,900	257,100	235,200	230,200	217,600	158,800	131,500	105,400
1000 days	346,200	272,900	258,200	236,900	232,000	219,400	160,200	132,700	106,400

TABLE II (CONTINUED)

Irradiation Time	Decay Time							
	1 day	2 days	3 days	7 days	14 days	28 days	56 days	84 days
14 days	79,010	55,240	43,040	21,530	8,707	2090	178	16
30 days	67,290	62,650	49,690	25,930	10,960	2738	236	21
100 days	89,590	64,770	51,640	27,290	11,690	2956	256	23
1000 days	90,540	65,690	52,520	27,890	11,980	3033	262	23.5

TOTAL NOBLE GAS QUANTITIES IN A 1000 KW UO₂ - 2 w/o PuO₂ FUEL ELEMENT (CURIES)

-4-

Irradiation Time	2 days	3 days	7 days	14 days	28 days	56 days	84 days	1 year	2 years
14 days	45,550	38,380	22,800	9,137	1,492	54	8.5	4.4	4.1
30 days	53,010	44,940	26,700	10,720	1,769	71.7	15.4	9.4	8.8
100 days	54,000	45,800	27,220	10,950	1,832	98.6	38.6	30.9	28.9
1000 days	55,350	46,960	28,000	11,420	2,140	359	295	273	256

TABLE IV
TOTAL VOLATILE SOLIDS (Cs + Te + Se + Ru) QUANTITIES IN A 1000 KW UO_2 - 2 w/o PuO_2 FUEL ELEMENT (CURIES)

Irradiation Times	Decay Times									
	0	30 sec	60 sec	15 min	30 min	60 min	4 hr	8 hr	16 hr	1 day
14 days	593,800	440,300	410,000	263,200	217,500	164,000	80,890	67,950	57,790	52,660
30 days	608,700	455,400	425,300	278,300	232,500	179,000	95,770	89,300	72,280	66,939
100 days	637,600	485,400	455,400	308,200	262,400	208,700	125,200	111,900	101,300	95,730
1000 days	680,500	533,700	504,700	356,300	309,900	255,600	230,800	210,200	198,100	192,000

Irradiation Times	84 days				1 year		2 years	
	2 days	3 days	7 days	14 days	28 days	56 days	1 year	2 years
14 days	43,680	37,290	22,500	13,440	8,944	5,595	3,667	265
30 days	57,410	50,510	34,230	23,520	16,840	10,690	7,073	561
100 days	85,690	78,330	60,310	46,900	35,820	23,581	16,240	1,792
1000 days	128,700	120,900	101,600	86,310	72,290	55,690	45,260	11,700

TABLE V

TOTAL FISSION PRODUCT QUANTITIES IN A 1000 KW UO_2 - 2 w/o PuO_2 FUEL ELEMENT

(Thousands of Curies)

Irradiation Times	Decay Times									
	0	30 sec	60 sec	15 min	30 min	60 min	4 hr	8 hr	16 hr	1 day
14 days	3975	3068	2862	1853	1578	1317	937	783	627	535
30 days	4098	3192	2987	1977	1702	1441	1060	906	747	653
100 days	4269	3366	3161	2151	1876	1615	1234	1079	919	824
1000 days	4467	3580	3373	2357	2080	1818	1440	1287	1128	1031

Irradiation Times	Decay Times					
	2 days	3 days	7 days	14 days	28 days	56 days
14 days	389	316	189	112	62.2	31.8
30 days	502	423	279	182	110	60.3
100 days	669	586	430	315	217	136
1000 days	872	785	619	494	381	277

			84 days	1 year	2 years
			20.7	2.71	1.11
			40.5	5.63	2.34
			96.8	16.7	7.31
			222	76.0	40.0

FISSION GAS RELEASES FROM FUEL

The release of fission gases from the fuel crystal to the fuel void spaces may be estimated by the 1800 C formula⁽²⁾ in which a 100% release is assumed for all fuel above a temperature of 1800 C and no release is assumed for fuel below 1800 C. This formula is just a rule of thumb formula and has its limitations. Actually, the gas release from fuel above 1800 C is not complete and there is some gas release from crystals below a temperature of 1800 C. But for the temperature range of the PRTR HPD fuel, factors compensate well enough that the method may be applied with reasonable confidence.

Table VI gives the estimated percent gas release from the fuel for various PRTR HPD fuel powers based upon the 1800 C formula:

TABLE VI
PERCENT FISSION GAS RELEASE FROM FUEL CRYSTAL

<u>HPD Fuel Power</u>	<u>Outer Rod Specific Power*</u>	<u>Percent Release</u>
1350 kw	17.4 kw/ft	31%
1450	18.7	36
1500	19.3	38
1600	20.6	43
1700	21.9	47
1800	23.2	52
2100	27.1	62
2150	27.7	65

There are experimental data from PRTR HPD fuel elements which both support and oppose the 1800 C formula results given in Table VI. The Table VI values are supported by measurements of the quantity of stable noble gases collected from outer rods of non-plenum type HPD fuel elements #6000 and #6502, in which measured percentage releases of 32.8, 47 and 49 compared with calculated values of 33, 43 and 43 respectively.

Opposing data comes from radiation dose rate measurements of the samples. The dose rate of the gas from the fuel element #6504 outer rod corresponded to about 50 curies** when about 2000 curies was expected. Likewise the dose rate of the gas removed from fuel element #6000 was considerably below that expected.

* Axial average based upon a pin factor of 1.2.

** Dose rates from the entire quantity of gas in a thin wall glass bottle with only air for additional shielding were 4.8 rad/hr including 2.8 r/hr at a distance of 10 ft, 120 rad/hr at 3 ft, and 500 rad/hr at 1 ft. (Courtesy of Bob Elder, Radiometallurgy) Measurements were taken $\approx$ 2 PM August 31, 1965; reactor shutdown was $\approx$ 4 PM, August 25, 1965. Curies were estimated from $D = 6 EC/R^2$ formula where D is dose in r/hr, E is average γ energy of 1, C is curies, R is ft. distance.

(2) Personal communication, Glenn R. Horn, BNW. Also, G. R. Horn, J. L. Bates, and D. R. deHalas, Irradiation Breeding of UO₂, Paper presented at the June ANS Meeting in Gattinburg.

This large discrepancy has not been explained. Possible causes include error in dose rate measurement, inaccuracy of dose rate vs curie computation, holdup of gases in fuel causing time delay in which the radioactive gases decay, uncertainties in fission product yields used in calculations. Because of the inaccuracies in dose rate measurement and because of the advantages of conservatism, it seems prudent to use the 1800 C formula until sufficient data has been obtained to confirm a lower release of the radioactive gases.

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