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TRANSMUTATIONS IN FUSION TEST FACILITIES

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TRANSMUTATIONS IN FUSION TEST FACILITIES

F. M. Mann (Hanford Engineering Development Laboratory)

1.0 Objective

The objective of this work is to determine how typical materials transmute in various fusion test facilities.

2.0 Summary

Using an expanded nuclear data base, the transmutation of PCA, AMCR33 (a reduced activation austenitic steel), HT-9, Rafer2 (a reduced activation ferritic steel), V-15%Cr-5%Ti alloy, and SiAlON (a ceramic) were calculated for two positions in the Fast Flux Test Facility (FFTF), three positions in the High Flux Isotope Reactor (HFIR), and the first wall position of both the STARFIRE and MARS conceptual fusion reactors. The peripheral test (PTP) position, and to a lesser extent the radial beryllium (RB) position, of HFIR show significant transmutations which are often in the opposite direction to the transmutations in the fusion conceptual designs. The positions in FFTF, as well as the hafnium covered location in the HFIR RB position show relative minor transmutations.

3.0 Program

Title: Irradiation Effects Analysis
Principal Investigator: D. G. Doran
Affiliation: Westinghouse Hanford Company

4.0 Relevant Program Plan Task/Subtask

II.A.4 Gas Generation Rates
II.C.4 and II.C.10 Effects of Solid Transmutants

5.0 Accomplishments and Status

5.1 Introduction

Because no facility exists which has a spectrum similar to that expected in a fusion reactor, existing fission reactors are being used to test the behavior of materials. Although it is believed that the change in material behavior will be most sensitive to displacement damage, the transmutation of composition has long been considered important. The major effort is in the gaseous transmutation products, particularly helium. However, now the importance of solid transmutants is being raised. Also, it is becoming realized that the transmutations in thermal reactors can be very large and can completely distort the composition of a material.

To determine the compositional change in typical fusion materials, calculations were performed for the first wall positions of two conceptual fusion designs and for positions in high flux test reactors used by the fusion materials program. The materials were chosen to be candidate first wall materials, an insulator, and various elements to provide a broad treatment of possible material combinations. In the first wall candidates, reduced activation versions were also included.

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5.2 Description of the Calculations

To gain insight into the behavior in a fusion facility, the first wall positions of the STARFIRE and MARS conceptual designs were chosen. Because of its use of water as a coolant, STARFIRE has a strong 1/E low energy neutron flux shape. The MARS design, on the other hand, has relatively few low energy neutrons. Most of the high fluence irradiations for the fusion materials program will be in the FFTF or the HFIR. Therefore, two positions were chosen in the FFTF, one at core center [comparable to the midplane (or highest flux) position of the Material Open Test Assembly (MOTA)], and the other at the midplane position of the outer row (which is similar to the top of the MOTA). Calculations for three positions in HFIR were also performed, the first corresponding to the PTP, the second to a radial beryllium (RB) position, and the last to a hafnium shielded radial beryllium (RB-Hf) position. The fluxes for the last two positions (RB and RB-Hf) were kindly supplied by L. Greenwood (Argonne National Laboratory) from his dosimetry measurements, while fluxes for the other positions were taken from the standard REAC flux library.

The cross section and decay data needed for the calculations were taken from the newly expanded REAC libraries.⁽¹⁾ It should be noted that for many of the reactions, the needed cross sections were estimated.

The REAC computer code system⁽²⁾ was used to calculate the change in composition for a six-year exposure at each position. For the HFIR positions, time steps were taken to be 0.125 year; for the other positions time steps were taken to be 0.25 year. The materials included in the calculation are PCA, VCrTi, HT-9, AMCR33 (a reduced activation austenitic), RAFER2 (a reduced activation ferritic), CuBe, Sialon, Be, C, Al, Si, Cu, Mo, Nb, and W.

5.3 Results of the Calculations

Tables 1 through 15 give the results of the calculations for an exposure of five years. Figures 1 and 2 show the change of V in HT-9 and the change of Mn in Rafer2, respectively, as a function of exposure.

In general, the most significant transmutations occur for the PTP position of HFIR, particularly for odd mass and for high mass nuclei. The RB positions of HFIR often show similar but smaller changes than the PTP positions. The hafnium-covered RB position (like the FFTF positions) shows practically no change in composition. The first wall positions show little change. The most notable changes in composition at a five-year exposure are: (1) the large burnout of Mn in HFIR (for PTP and RB) contrasted to the increase shown for STARFIRE and MARS for PCA, (2) the switch in composition from 80%V 15%Cr 5%Ti to 12%V 67%Cr 5%Ti again at the PTP position, (3) the 1300% increase in iron in VCrTi for PTP, (4) the 200% increase of Mn in HT-9 in the fusion designs, (5) the burnout of Mn (which replaces Ni in the reduced austenitic AMCR33) in PTP from an initial 15% to 1.5%, and (6) the transformation of N (initially 36%) to C (ending will be 18%) for Sialon in PTP. Various new elements are also created. How significant these additions are depends upon their metallurgical importance.

It should be noted some of the compositional changes are not linear functions of time. Vanadium in HT-9 (see Figure 1) shows this quite dramatically for the PTP position in HFIR. The amount of V first increases (as it does for all the positions studied), but then in the PTP position the vanadium burns out.

5.7 Conclusion

Whenever materials are exposed to a significant fluence in the PTP position in HFIR, the compositional change of the material should be investigated. However, other facilities (including fusion devices) also show some large changes for certain materials.

6.0 References

1. F. M. Mann, "Cross Sections for Reduced Activation Studies", DAFS Quarterly Progress Report, DOE/ER-0046/20, February 1985, p. 18.
2. F. M. Mann, "Transmutation of Alloys in MFE Facilities as Calculated by REAC (A Computer Code System for Activation and Transmutation)", HEDL-TME-81-37, Westinghouse Hanford Company.

FIGURE 1. The Amount of V in HT-9 as a Function of Time in STARFIRE, FFTF, and Three Positions in HFIR.

FIGURE 2. The Amount of Mn in RAFER2 as a function of time in STARFIRE, FFTF, and Three Positions in HFIR.

TABLE 1

TRANSMUTATIONS IN PCA AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Fe	0.651	0.36	0.13	0.55	2.16	0.39	0.41	0.75
Ni	0.152	-1.52	-0.02	-14.0	-5.3	-0.88	-5.6	-5.6
Cr	0.150	0.10	-0.06	-4.0	-2.85	-0.77	-0.43	-0.30
Mn	0.0190	-3.4	-4.6	-66.0	-48.0	-8.7	39.0	51.0
Mo	0.0116	-3.8	-1.03	-7.1	-2.83	-0.91	-2.72	-2.01
Si	0.0099	-0.02	-0.00	-0.14	-0.04	-0.01	-1.36	-1.37
Ti	0.0035	0.15	-0.00	-0.13	-0.14	0.01	14.8	15.2
C	0.0028	-0.03	-0.00	-0.02	-0.00	0.00	-1.33	-1.34

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	2.8	0.009	3.6	1.49	0.66	17.4	17.6
He	0.170	0.016	11.5	6.1	0.60	3.1	2.97
Be	0.001		0.001			0.011	0.011
Mg	0.001		0.001			0.049	0.049
Al						0.085	0.086
P	0.001		0.012	0.004	0.001		
Ca						0.002	0.002
Sc						0.004	0.004
V	0.201	0.086	1.45	3.8	1.37	2.57	2.31
Co	0.219	0.013	20.4	2.55	0.178	1.25	1.29
Cu		0.006	12.0	0.96	0.055	0.018	0.004
Zn			2.37	0.059	0.001		
Ga			0.019				
Ge			0.06				
Sr						0.001	0.001
P						0.004	0.004
Zr						0.020	0.019
Nb						0.050	0.057
Tc	0.262	0.078	0.44	0.199	0.073	0.016	0.108
Ru	0.136	0.030	0.285	0.093	0.021	0.046	0.021
Rh	0.001		0.014	0.002			
Pd			0.005				

TABLE 2

TRANSMUTATIONS IN VCRTi AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
V	0.797	-1.22	-0.50	-85.0	-46.0	-7.6	-2.20	-0.40
Cr	0.146	6.6	2.70	460.0	248.0	41.0	9.3	-0.51
Ti	0.0528	0.07	-0.00	-1.28	-0.17	-0.01	7.1	7.2
N	0.00189	2.66	-0.17	-50.0	-20.0	-3.2	-2.98	-2.81
O	0.00073	-0.13	-0.00	-0.15	-0.03	-0.03	-1.33	-1.32
C	0.00072	3.7	0.44	128.0	52.0	7.8	5.0	4.3
Fe	0.00050	-0.10	-0.02	1270.0	36.0	0.14	-1.71	-1.80
Mo	0.00030	-0.38	-1.03	-7.1	-2.82	0.91	-2.73	-2.01
Cu	0.00005	-5.8	-2.07	-66.0	-36.0	-6.4	-7.6	-4.9

TABLE 2 (Cont'd)

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	M _r
H	0.174	0.004	1.07	0.40	0.083	5.3	5.3
He	0.037		0.035	0.009	0.007	1.32	1.33
Dt						0.003	0.003
Be						0.003	0.003
B	0.025		0.020	0.005	0.005	0.017	0.019
Ca	0.001		0.001			0.033	0.033
Sc	0.001					0.065	0.067
Mn	0.006	0.001	7.6	0.55	0.021	0.012	0.009
Co			0.023	0.001			
Ni	0.001	0.001	0.018	0.009	0.002	0.003	0.002
Zn	0.001		0.008	0.003			
Zr						0.001	
Nb						0.001	0.001
Tc	0.007	0.002	0.011	0.005	0.002	0.004	0.003
Ru	0.004	0.001	0.007	0.002	0.001	0.001	0.001

TABLE 3

TRANSMUTATIONS IN HT-9 AFTER 5 YEARS IN 7 FUSION FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Fe	0.840	-0.09	0.01	-3.5	-0.34	-0.04	-1.68	-1.77
Cr	0.122	0.27	-0.04	-1.68	-1.58	-0.64	0.14	0.17
C	0.0092	-0.03	-0.00	-0.02	-0.00	-0.00	-1.33	-1.34
Si	0.0078	0.03	0.00	-0.07	-0.03	0.00	-1.21	-1.21
Mo	0.0057	-3.8	-1.03	-7.1	-2.82	4.7	-2.72	-2.01
Mn	0.0055	5.2	-2.00	14.9	14.6	-0.90	211.0	228.0
Ni	0.0047	-1.52	-0.01	154.0	1.70	-0.71	-5.6	-5.6
V	0.0033	3.8	1.62	-50.0	49.0	26.0	62.0	58.0
W	0.0015	-17.5	-29.2	-90.0	-59.0	-35.0	-36.0	-10.0
P	0.0003	-0.35	-0.03	-3.9	-1.31	-0.21	-1.92	-1.92
S	0.0003	-0.67	0.03	5.1	1.93	0.13	-2.09	-2.23

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	0.85	0.002	0.75	0.189	0.171	12.3	12.4
He	0.078	0.001	0.42	0.206	0.032	2.33	2.34
Be	0.002		0.002			0.036	0.036
Mg	0.001		0.001			0.039	0.039
Al						0.067	0.068
Cl			0.001				
Ti	0.005		0.007	0.001	0.001	0.44	0.45
Co	0.035		24.6	2.27	0.056	0.065	0.045
Cu	0.001		0.493	0.030	0.002	0.001	
Zn			0.083	0.002			
Ga			0.001				
Sr						0.001	0.001
Y						0.002	0.002
Zr						0.010	0.010
Nb						0.025	0.028
Tc	0.129	0.038	0.214	0.098	0.036	0.080	0.053
Ru	0.067	0.015	0.140	0.046	0.010	0.023	0.010

TABLE 3 (Cont'd)

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Rh	0.001		0.007	0.001			
Pd			0.003				0.001
Ta	0.001	0.001				0.003	0.033
Re	0.176	0.233		0.233	0.111	0.210	0.108
Os	0.083	0.183	0.118	0.119	0.191	0.241	0.008
Ir		0.016	0.65	0.278	0.167	0.066	
Pt		0.002	0.079	0.112	0.045	0.015	
Au				0.006			
Hg			0.33	0.109			
Tl			0.37	0.003			
Pb			0.059				

TABLE 4

TRANSMUTATIONS IN AMCR33 AFTER 5 YEARS IN 7 FUSION TEST FACILITIES
AMCRSS IS A REDUCED ACTIVATION AUSTENITIC ALLOY

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Fe	0.723	1.18	1.12	15.7	13.5	2.59	0.48	-1.70
Mn	0.155	-5.8	-5.2	-91.0	-65.0	-12.1	-6.1	3.4
Cr	0.107	0.24	-0.06	-3.9	-2.83	-0.85	3.5	3.8
Si	0.0107	-0.02	-0.00	-0.01	-0.04	-0.01	-1.37	-1.37
C	0.0048	-0.03	-0.00	-0.02	-0.00	-0.00	-1.34	-1.35
Ni	0.0005	-1.49	0.05	1480.0	53.0	-0.29	-5.3	-5.6

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	0.69	0.001	0.60	0.135	0.138	10.9	11.0
He	0.065		0.105	0.035	0.014	2.12	2.14
Be	0.001		0.001			0.018	0.019
Mg	0.001		0.001			0.053	0.053
Al						0.093	0.093
P	0.001		0.013	0.004	0.001		
Ti	0.004		0.006	0.001	0.001	0.38	0.38
V	0.145	0.061	1.01	2.73	0.98	1.88	1.70
Co	0.024	0.010	23.3	2.01	0.043	0.026	0.008
Cu			0.150	0.003			
Zn			0.017				

TABLE 5

TRANSMUTATIONS IN RAHER2 AFTER 5 YEARS IN 7 FUSION TEST FACILITIES
RAHER2 IS A REDUCED ACTIVATION FERRITIC ALLOY

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Fe	0.863	0.01	0.10	-2.05	0.77	0.17	-1.53	-1.79
Cr	0.0961	-3.0	-0.00	-1.46	-1.48	-0.60	1.16	1.18
Mn	0.0203	0.40	-4.4	-66.0	-45.0	-7.7	50.0	61.0
W	0.01305	-17.5	-29.2	-90.0	-59.0	-35.0	-36.0	-10.0
C	0.00457	-0.03	-0.00	-0.02	-0.00	-0.00	-1.33	-1.35

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	0.78	0.001	0.66	0.147	0.155	12.0	12.1
He	0.070		0.069	0.016	0.013	2.08	2.09
Be	0.001		0.001			0.018	0.018
Ti	0.004		0.005	0.001	0.001	0.35	0.36
Co	0.028	0.012	25.4	2.31	0.051	0.026	0.005
Ni			8.4	0.342	0.003	0.002	
Cu			0.127				
Zn			0.010				
Hf						0.003	0.005
Ta	0.005	0.007			0.006	0.022	0.287
Re	1.53	1.59		2.02	0.97	1.82	0.94
Os	0.72	0.180	1.027	1.03	1.67	2.10	0.068
Ir		0.139	5.6	2.41	1.45	0.58	
Pt		0.017	0.68	0.97	0.39	0.134	
Au				0.055	0.003		
Hg			2.87	0.95	0.001		
Tl			3.2	0.030			
Pb			0.52				

TABLE 6

TRANSMUTATIONS IN CuBe AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Cu	0.874	-4.4	-1.38	-43.0	-23.6	-4.2	-5.9	-4.1
Be	0.126	-2.26	-0.01	-2.66	-0.48	-0.46	-3.8	-3.9

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	2.96	0.007	302.(?)	1.34	0.49	10.4	10.2
He	3.40	0.008		0.49	0.77	8.5	8.5
Li	0.46	0.003			0.011	0.197	0.47
Fe						0.019	0.021
Co	0.077		0.216	0.010	0.015	1.97	2.05
Ni	25.7	8.9	219.0	151.0	28.3	44.0	32.0
Zn	9.06	3.2	148.0	56.0	8.6	5.4	1.70
Ga			5.3	0.197			
Ge			2.92	0.033			

TABLE 7

TRANSMUTATIONS IN SIALON AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents								
Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
N	0.357	-2.66	-0.17	-50.0	-20.0	-32.0	-2.96	-2.78
O	0.214	-0.13	-0.00	-0.16	-0.03	-0.03	-1.33	-1.32
Al	0.214	-0.28	-0.04	-8.4	-2.81	-0.39	-0.46	-0.39
Si	0.214	0.24	0.04	8.2	2.76	0.38	-1.24	-1.31

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	5.2	0.60	180.0	71.0	10.7	14.1	13.1
He	5.0	0.015	1.86	0.95	1.01	9.5	9.8
Li	0.001		0.001			0.56	0.53
Be						0.024	0.026
B	4.7	0.015	3.8	0.89	0.94	3.3	3.6
C	5.1	0.60	175.0	71.0	10.7	9.5	8.6
Ne						0.004	0.005
Na						0.024	0.024
Mg	0.055		0.049	0.010	0.010	3.6	3.6
P	0.016	0.003	0.268	0.089	0.013	0.006	0.003
S			0.009	0.001			

TABLE 8

TRANSMUTATIONS IN Be AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents								
Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Be	1.000	-2.26	-0.01	-2.66	-0.48	-0.46	-3.8	-3.9

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	not calculated separately						
He	not calculated separately						
Li	3.7	0.024			0.087	1.56	3.7

TABLE 9

TRANSMUTATION IN C AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents								
Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
C	1.000	-0.03	-0.00	-0.02	-0.00	-0.00	-1.33	-1.35

TABLE 9 (Cont'd)

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	not calculated separately						
He	not calculated separately						
Be	0.212		0.197	0.039	0.037	3.85	3.89

TABLE 10

TRANSMUTATIONS IN Al AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Al	1.000	-0.29	-0.00	-8.4	-2.81	-0.39	-1.32	-1.26

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	0.68	0.001	7.4	0.139	0.130	8.2	8.2
He	0.139		0.120	0.024	0.024	5.7	5.7
Ne						0.012	0.012
Na	0.001					0.099	0.100
Mg	0.171		0.137	0.029	0.028	11.8	11.9
Si	2.77	0.042	84.0	28.1	3.9	1.26	0.56

TABLE 11

TRANSMUTATIONS IN Si AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Si	1.000	-0.02	-0.01	-0.14	-0.04	-0.01	-1.36	-1.37

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	not calculated separately						
He	not calculated separately						
Na						0.011	0.012
Mg	0.095		0.092	0.017	0.016	5.0	5.0
Al	0.034		0.016	0.005	0.004	8.6	8.7
P	0.072	0.013	1.25	0.41	0.061	0.029	0.016
S			0.044	0.005			

TABLE 12
TRANSMUTATIONS IN Cu AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents								
Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Cu	1.000	-4.0	-1.38	-43.0	-23.7	-4.2	-5.8	-4.1
New Elements (parts per thousand)								
Element	FFTF		HFIR			First Wall		
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS	
H	not separately calculated							
He	not separately calculated							
Fe						0.022	0.024	
Co	0.088		0.247	0.011	0.017	2.25	2.35	
Ni	29.4	10.2	251.0	173.0	32.0	50.0	37.0	
Zn	10.3	3.6	169.0	64.0	9.8	6.2	2.04	
Ga			6.1	0.225				
Ge			3.3	0.038				

TABLE 13
TRANSMUTATIONS IN Nb AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents								
Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Nb	1.000	-10.6	-4.0	-66.0	-30.0	-3.5	-9.2	-5.3

New Elements (parts per thousand)								
Element	FFTF		HFIR			First Wall		
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS	
H	0.109		0.236	0.022	0.005	5.5	5.5	
He	0.034			0.005	0.005	1.15	1.22	
Sr						0.001	0.013	
Y	0.005		0.002	0.001	0.001	0.261	0.293	
Zr	0.236		0.126	0.037	0.040	26.5	28.8	
Mo	106.0	40.0	660.0	298.0	35.0	65.0	24.4	
Tc	0.001		1.48	0.020				
Ru			0.151	0.001				
Rh			0.001					

TABLE 14
TRANSMUTATIONS IN Mo AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents								
Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
Mo	1.000	-3.5	-0.93	-6.3	-2.54	-0.81	-2.44	-1.81

TABLE 14 (Cont'd)

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	not calculated separately						
He	not calculated separately						
Sr						0.109	0.113
Y	0.001					0.31	0.32
Zr	0.029		0.020	0.004	0.005	1.71	1.62
Nb	0.039		0.038	0.010	0.009	4.3	5.0
Tc	22.5	6.72	38.0	17.2	6.3	14.0	9.3
Ru	11.7	2.56	24.6	8.0	1.81	4.0	1.78
Rh	0.109	0.003	1.22	0.162	0.003	0.009	0.001
Pd	0.009		0.046	0.019			

TABLE 15

TRANSMUTATIONS IN W AFTER 5 YEARS IN 7 FUSION TEST FACILITIES

Fractional Change (%) in Initial Constituents

Element	Initial Amount	FFTF		HFIR			First Wall	
		2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
W	1.000	-17.2	-29.0	-90.0	-57.0	-34.0	-36.0	-10.0

New Elements (parts per thousand)

Element	FFTF		HFIR			First Wall	
	2101	2909	PTP	RB4	RB4(HF)	STARFIRE	MARS
H	0.003		0.001			0.218	0.254
He	0.002					0.213	0.226
Hf	0.002					0.211	0.39
Ta	0.41	0.54	0.001	0.008	0.47	1.69	22.0
Re	117.0	155.0	360.0	155.0	74.0	140.0	72.0
Os	55.0	122.0	66.0	80.0	128.0	161.0	5.2
Ir	0.080	10.8		185.0	111.0	44.0	
Pt	0.005	1.29	44.0	74.0	30.0	10.3	
Au				4.2	0.263	0.012	
Hg			185.0	72.0	0.086	0.007	
Tl			207.0	2.31			
Pb			34.0	0.058			