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PACIFIC NORTHWEST LABORATORY
MONTHLY REPORT
ON SPACE NUCLEAR SYSTEMS PROGRAM
FOR OCTOBER 1974

Battelle

Pacific Northwest Laboratories
Richland, Washington 99352

MASTER

Prepared for the U.S. Atomic Energy
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BNWL-1845-4

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operated by
BATTELLE
for the
U.S. ATOMIC ENERGY COMMISSION
Under Contract AT(45-1)-1830

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$5.45; Microfiche \$2.25

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by

H. T. Fullam

October 1974

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STRONTIUM HEAT SOURCE DEVELOPMENT PROGRAMS

At Hanford, strontium will be separated from the high-level waste, then converted to the fluoride, and doubly encapsulated in small, high-integrity containers for subsequent long-term storage. The fluoride conversion, encapsulation and storage will take place in the Waste Encapsulation and Storage Facilities (WESF). This encapsulated strontium fluoride represents an economical source of ^{90}Sr if the WESF capsule can be licensed for heat source applications under anticipated use conditions. The objectives of this program are to obtain the data needed to license $^{90}\text{SrF}_2$ heat sources and specifically the WESF $^{90}\text{SrF}_2$ capsules. The information needed for licensing can be divided into three general areas:

- 1. Long-term SrF_2 compatibility data.*
- 2. Chemical and physical property data on $^{90}\text{SrF}_2$.*
- 3. Capsule property data such as external corrosion resistance, crush strength, etc.*

The current program is designed to provide the required information.

SHORT-TERM COMPATIBILITY TESTS

A total of 20 $^{90}\text{SrF}_2$ compatibility test specimens have been examined and photomicrographs obtained. The negatives are now being printed and the results will be presented when the prints are available. A total of 51 $^{90}\text{SrF}_2$ compatibility test specimens have been shipped to ORNL for examination.

The 4400-hr tests with high-purity SrF_2 , containing controlled levels of added impurities, have been completed. The test couples have been sectioned and the test specimens are being evaluated. The results obtained to date are summarized in Table 1, together with data from equivalent

TABLE 1. Preliminary Estimates of Metal Attack Found in Couples Containing High-Purity SrF_2 with Controlled Levels of Impurities Added (Tests Carried Out at 1000°C)

Metal	Impurity Added	Depth of Metal Affected, mils**	
		1500 Hours	4400 Hours
TZM	NaF	<<1*	<<1
TZM	MnF ₂	<<1*	<1
TZM	PbF ₂	<1	<1
TZM	CuF ₂	2*	6
TZM	FeF ₃	2*	3
TZM	AlF ₃	<<1	<<1
TZM	(Ca-Ba-Mg)F ₂	<<1	<<1
TZM	SrO	<1	<1
TZM	Sr(NO ₃) ₂	<<1*	<<1
TZM	H ₂ O	<1	<<1
Tungsten	NaF	<<1	<1
Tungsten	MnF ₂	<1*	<1
Tungsten	PbF ₂	0*	<1
Tungsten	CuF ₂	2	<1
Tungsten	FeF ₃	<<1	<1
Tungsten	AlF ₃	0*	<1
Tungsten	(Ca-Ba-Mg)F ₂	<<1	<1
Tungsten	SrO	<1	<1
Tungsten	Sr(NO ₃) ₂	0*	<1
Tungsten	H ₂ O	<1*	0
Hastelloy-X	NaF	3	2
Hastelloy-X	MnF ₂	4	5
Hastelloy-X	PbF ₂	3*	4
Hastelloy-X	CuF ₂	30*	12
Hastelloy-X	FeF ₃	12	22
Hastelloy-X	AlF ₃	4	3
Hastelloy-X	(Ca-Ba-Mg)F ₂	3*	4
Hastelloy-X	SrO	15*	10
Hastelloy-X	Sr(NO ₃) ₂	5*	4
Hastelloy-X	H ₂ O	4*	5
Hastelloy-N	NaF	4	6
Hastelloy-N	MnF ₂	2	5
Hastelloy-N	PbF ₂	3	3
Hastelloy-N	CuF ₂	6	20
Hastelloy-N	FeF ₃	12	15
Hastelloy-N	AlF ₃	3	3
Hastelloy-N	(Ca-Ba-Mg)F ₂	3	4
Hastelloy-N	SrO	25	35
Hastelloy-N	Sr(NO ₃) ₂	2*	15
Hastelloy-N	H ₂ O	2*	5

* Indicated specimens overheated to 1200°C for about 4 hours

** Estimated from photomicrographs

1500-hr test couples. The remaining data will be reported in November together with a detailed interpretation of the results. The results presented in Table 1 show that the Hastelloy-X and Hastelloy-N reacted extensively with most of the fuel compositions tested. In almost every case the type of attack observed consisted of precipitate formation near the metal surface. Except for the couples containing SrO, there was little evidence of surface attack, pitting, intergranular attack, or subsurface void formation. Electron microprobe data will be needed to identify the precipitates. With the couples containing SrO there was very extensive intergranular attack of both the Hastelloy-X and Hastelloy-N.

As reported previously, a number of the test couples in the 1500-hr tests were inadvertently overheated to about 1200°C for a short period of time (~4 hr) the day the tests were to be stopped; the couples which were overheated are indicated by an asterisk in Table 1. A comparison of the results from the 1500 and 4400-hr tests indicate that, except for a few cases, the overheating did not seriously increase the metal attack observed.

It is currently anticipated that evaluation of the short-term test couples will be completed in December. This will permit selection of the three containment materials for long-term compatibility testing by January.

STRONTIUM FLUORIDE DISSOLUTION RATE STUDIES

Work continues on measuring the dissolution rates of nonradioactive SrF_2 , SrTiO_3 and Sr_2TiO_4 in aqueous media. Samples of the three compounds, which have been prepared in different ways, are being tested in demineralized water (2-megohm resistivity), seawater, plant tap water and synthetic seawater. The materials being tested are described in Table 2. The material labeled SR-7 represents a simulated WESF SrF_2 without the minor impurities present.

The results obtained to date with the various SrF_2 samples are summarized in Table 3. As discussed in earlier reports, the data is presented in two forms: 1) as micrograms of strontium dissolved per hour per gram of strontium present, and 2) as micrograms of strontium dissolved per hour

TABLE 2. Compounds Evaluated in Dissolution Tests

Identification Number	Description of Material	Surface Area (cm ² /g of compound)
SR-1A	SrF ₂ powder containing 0.5% impurities; fired at 1100°C for 20 hours; crushed to -1/4 in. +1/8 in. lumps.	370
SR-1B	SrF ₂ powder containing 0.5% impurities; fired at 900°C for 20 hours; crushed to -1/4 in. +1/8 in. lumps.	580
SR-2	Commercial SrF ₂ powder (99.5%); fired at 1100°C for 48 hours; crushed to -1/4 in. +1/8 in. lumps.	250
SR-3A	High-purity SrF ₂ powder (>99.9%); fired at 1100°C for 20 hours; crushed to -1/4 in. +1/8 in. lumps.	510
SR-3B	High-purity SrF ₂ powder (>99.9%); fused at 1500°C; crushed to -1/4 in. + 1/8 in. lumps.	620
SR-3C	High-purity SrF ₂ powder (>99.9%); pressed into pellets at 70% TD; fired at 1100°C for 4 hours; crushed to -1/4 in. +1/8 in. lumps.	910
SR-3D	High-purity SrF ₂ powder (>99.9%); pressed to pellets at 70% TD; fired at 1100°C for 20 hours; crushed to -1/4 in. +1/8 in. lumps.	390
SR-3E	High-purity SrF ₂ powder (>99.9%) +10 wt% NaF; fired at 1100°C for 20 hours; crushed to -1/4 in. +1/8 in. lumps.	520
SR-4A	WESF-grade SrF ₂ powder; fired at 1100°C for 20 hours; crushed to -1/4 in. +1/8 in. lumps.	660
SR-4B	WESF-grade SrF ₂ powder; fired at 1100°C for 1 hour; crushed to -1/4 in. +1/8 in. lumps.	
SR-4C	WESF-grade SrF ₂ powder; fired at 1100°C for 24 hours; crushed to -1/4 in. +1/8 in. lumps.	
SR-4D	WESF-grade SrF ₂ powder; fired at 1100°C for 96 hours; crushed to -1/4 in. +1/8 in. lumps.	
SR-5A	SrTiO ₃ powder; fired at 1450°C for 4 hours; crushed to -1/4 in. +1/8 in. lumps.	15,000
SR-5B	SrTiO ₃ powder; fired at 1450°C for 8 hours; crushed to -1/4 in. +1/8 in. lumps.	
SR-6A	Sr ₂ TiO ₄ powder; fired at 1450°C for 4 hours; crushed to -1/4 in. +1/8 in. lumps.	12,000
SR-6B	Sr ₂ TiO ₄ powder; fired at 1450°C for 8 hours; crushed to -1/4 in. +1/8 in. lumps.	
SR-7	SrF ₂ containing 2% Na, 0.63% Ba, 0.22% Ca and 0.14% Mg; fired at 1100°C for 16 hours; crushed to -1/4 in. +1/8 in. lumps.	

TABLE 3. Equilibrium Dissolution Rate^(a) of SrF_2 in Aqueous Media at 24°C

SrF ₂ Tested	Dissolution Rate							
	μg Sr Dissolved/hr - g Sr				μg Sr Dissolved/hr - cm ²			
	Demineral Water	Tap Water	Synthetic Seawater	Natural Seawater	Demineral Water	Tap Water	Synthetic Seawater	Natural Seawater
SR-1A	620 ± 40	680 ± 80	140 ± 47	110 ± 16	1.2 ± 0.07	1.3 ± 0.15		0.21 ± 0.03
SR-1B	980 ± 120	1160 ± 240	210 ± 43	350 ± 240	1.2 ± 0.15	1.4 ± 0.28		0.42 ± 0.02
SR-2	235 ± 17	330 ± 200	220 ± 27	150 ± 47	0.64 ± 0.05	0.92 ± 0.56	0.61 ± 0.08	0.48 ± 0.13
			200 ± 42				0.56 ± 0.12	
SR-3A	880 ± 190			290 ± 64	1.20 ± 0.26			
SR-3B	170 ± 30	220 ± 30	90 ± 22	83 ± 4	0.19 ± 0.03	0.24 ± 0.03	0.10 ± 0.02	0.094 ± 0.005
SR-3C	350 ± 40	240 ± 26	130 ± 40	120 ± 17	0.27 ± 0.03	0.18 ± 0.02	0.080 ± 0.03	0.092 ± 0.01
				100 ± 15				0.080 ± 0.01
SR-3D	120 ± 21			52 ± 30				0.092 ± 0.05
				89 ± 24				0.092 ± 0.09
SR-3E	1200 ± 140	430 ± 100			1.5 ± 0.19			
SR-4A	140 ± 24	170 ± 29	76 ± 27	50 ± 14	0.15 ± 0.03	0.18 ± 0.03	0.080 ± 0.03	0.053 ± 0.01
				67 ± 26				
SR-4B	67 ± 34			30 ± 13				
SR-4C								
SR-4D	120 ± 53			60 ± 14				
SR-7	910 ± 280			150 ± 40				

(a) Obtained using a dynamic (flow) system

per cm^2 of compound surface. The values given represent the equilibrium dissolution rates. With the SrTiO_3 the dissolution rates continually decreased with time and failed to reach an equilibrium level even after several days' exposure. With the Sr_2TiO_4 the dissolution rates also decreased with time except for sample SR-6B in demineralized water. In this test the lumps of Sr_2TiO_4 disintegrated during the latter stage of the run and the dissolution rate increased significantly. Results obtained with titanate samples SR-5A and SR-6A were reported previously, and results obtained with SR-5B and SR-6B will be reported as soon as the surface area data is available.

Comparing the data in Table 3, it is obvious that the dissolution rate of SrF_2 is affected by several factors including the impurities present, surface area and thermal history. For each solution studied (i.e., demineralized water, natural seawater), the variation in dissolution rate between the different grades of SrF_2 is about one order of magnitude. The dissolution rates for all grades of SrF_2 are substantially lower in seawater than in tap or demineralized water. This is to be expected because of the high initial concentration of strontium in the seawater. The dissolution rates of the titanates are also lower in seawater than in the other solutions.

Dissolution rate studies with the nonradioactive compounds will be completed in November. Tests with $^{90}\text{SrF}_2$ will begin in December.

THERMODYNAMIC ANALYSIS OF $^{90}\text{SrF}_2$ COMPATIBILITY

Work has started on a thermodynamic analysis of the compatibility of $^{90}\text{SrF}_2$ with the nine containment materials being evaluated in the short-term compatibility tests (see Table 4 for the nine materials and their compositions). The first system analyzed, SrF_2 -tungsten, was selected because it is the least complex of the nine systems to be evaluated. Even with the SrF_2 -W system, however, a great many potential reactions must be considered because of the decay products and impurities present in the $^{90}\text{SrF}_2$ fuel.

TABLE 4. Composition of Metals Evaluated in Short-Term Compatibility Tests

Element	Nominal Alloy Composition, Weight %								Tungsten
	Hastelloy C-276	Hastelloy X	Hastelloy N	Haynes 25	Haynes 188	Inconel 600	Inconel 625	TZM	
Ni	Bal	47.0	Bal	10.0	22.0	76.0	Bal.		
Co	2.5*	1.5	0.2*	Bal	Bal.		1.0*		
Fe	5.5	18.5	5.0*	3.0*	3.0*	8.0	5.0*		
Cr	15.5	22.0	7.0	20.0	22.0	15.5	21.5		
Cu			0.35*			0.5 *			
Ti							0.4*	0.5	
Zr								0.1	
Al							0.4*		
Mo	16.0	9.0	16.5				9.0	Bal.	
Mn	1.0*	0.6	0.8*	1.5	1.25*	1.0*	0.5*		
Si	0.005*	1.0*	1.0*	1.0*	0.35	0.5*	0.5*		
W	3.8	0.6	0.5*	15.0	14.5				99.8
V	0.35*								
Cb									
Cb + Ta							3.6		
C	0.02*	0.1	0.06	0.1	0.1	0.15*	0.1		
B		0.001	0.01*						
S	0.03*	0.01	0.02*	0.03*		0.015*	0.015*		
P	0.03*	0.02	0.015*	0.03*			0.015*		
La					0.09				
Al + Ti			0.5*						

* Maximum

Radioactive SrF_2 , prepared by the WESF flowsheet, has been analyzed by various methods to determine the impurities present, and the ^{90}Sr solution from which the $^{90}\text{SrF}_2$ is prepared has been analyzed. Nonradioactive SrF_2 , prepared from simulated strontium nitrate feed solution by the WESF flowsheet, has also been thoroughly analyzed for impurities. Based on all the analytical data available, the $^{90}\text{SrF}_2$ prepared by WESF should contain the impurities listed in Table 5; the probable chemical form and concentration range of each impurity is also given in Table 5. For the thermodynamic analyses, it is assumed that the polyvalent elements can be present in any of their normal valence states (i.e., FeF_2 , FeF_3).

TABLE 5. Probable Impurities in WESF $^{90}\text{SrF}_2$

<u>Impurity</u>	<u>Probable Form</u>	<u>Concentration Range (wt%)</u>
Na	NaF	1 - 4
Ca	CaF_2	0.1 - 1.0
Ba	BaF_2	0.1 - 1.0
Mg	MgF_2	0.05 - 0.5
Mn	MnF_2	< 0.1
Fe	FeF_3	< 0.2
Pb	PbF_2	< 0.2
Cu	CuF_2	< 0.01
Al	AlF_3	< 0.5
Cr	CrF_3	< 0.2
Cd	CdF_2	< 0.1
Ni	NiF_2	< 0.1
K	KF	< 0.1
O_2	H_2O	< 0.05
H_2	H_2O	< 0.01
NO_3	$\text{Sr}(\text{NO}_3)_2$	< 0.05
Si	SiO_2	< 0.02
R*	RF_3	< 2.0

* Rare Earth

Analysis of nonradioactive SrF_2 , prepared by the WESF flowsheet from simulated nitrate feed, shows the oxygen content of the fluoride, after firing at 1100°C , is quite low (<500 ppm) as is the hydrogen content. The oxygen-hydrogen ratio of the SrF_2 is such that most, if not all, of the oxygen appears to be present in the fluoride as water rather than metal oxides. For the thermodynamic analysis, however, it has been assumed that some oxygen in the fluoride is present as metal oxides, and potential reactions between the metal oxides and the containment materials will be considered.

Since some water is present in the fluoride, potential hydrolysis reactions must be considered. In an operating $^{90}\text{SrF}_2$ source, these reactions could produce hydrogen fluoride which could, in turn, react with the containment material with the resulting hydrogen lost from the source by diffusion through the containment vessel wall.

The chemical composition of $^{90}\text{SrF}_2$ decay products has not been adequately determined.

Zirconium difluoride has been reported to exist, but is said to be unstable at elevated temperatures, disproportionating to ZrF_4 and zirconium metal.⁽¹⁾

With our current state of knowledge, it is impossible to say what the chemical form of the zirconium decay product will be. In an operating $^{90}\text{SrF}_2$ source, any $^{90}\text{ZrF}_2$ formed should disproportionate to $^{90}\text{ZrF}_4$ and ^{90}Zr metal, but this has not been demonstrated experimentally. It is possible that a complex fluoride structure involving ^{90}Sr and ^{90}Zr could be formed. For the thermodynamic analyses, potential reactions of ZrF_4 , ZrF_2 and Zr metal are being considered.

Conducting an adequate thermodynamic analysis of systems involving fluorides is hampered by a lack of reliable thermodynamic data on metal

fluorides. The thermodynamic properties of only a few fluorides have been determined experimentally; the data on other fluorides have been estimated by various techniques.

In carrying out the thermodynamic calculations, certain simplifying assumptions are used.

1. The impurities and decay products in the $^{90}\text{SrF}_2$ are present as individual compounds and not as solid solutions or complex compounds with $^{90}\text{SrF}_2$ or each other.
2. The reaction products do not form complex compounds or solid solutions with the $^{90}\text{SrF}_2$, its decay products or impurities.
3. There is no compound formation between components of the containment materials.

All three assumptions are invalid to some degree because complex compounds, solid solutions and alloy compounds can form at the temperature range of interest (800-1100°C). The assumptions are necessary, however, to permit the thermodynamic analysis to be completed in a reasonable time period.

The $^{90}\text{SrF}_2$ -Tungsten System

Even though the $^{90}\text{SrF}_2$ -tungsten system is the simplest of the nine systems being investigated, a complete analysis of the system could involve literally hundreds of reactions if all potential reactions between tungsten, $^{90}\text{SrF}_2$, its decay products and contained impurities are considered. Tungsten is reported to form five fluorides (WF_4 , WF_5 , WF_6 , W_4F and W_5F) and two principal oxides (WO_2 and WO_3). It also forms several oxyfluorides, a number of intermediate oxide phases depending on temperature as well as a great many complex fluorides, complex oxyfluorides and tungstates. There is little free energy of formation data available on the oxyfluorides, complex fluorides, tungstates, and intermediate oxide phases; attempting to estimate ΔG_f° data for these compounds is beyond the scope of this program. Therefore, for this study, it has been assumed that WF_4 , WF_5 , WF_6 , WO_2 , and WO_3 are the probable reaction products.

Strontium forms two fluorides — SrF_2 and SrF , but the latter is stable only at very high temperatures. Strontium also forms two oxides — SrO and SrO_2 . No oxyfluorides have been reported for strontium but it does form a few complex fluorides and a large number of mixed oxides. For this study it was assumed that only SrF_2 , SrO and strontium metal could be present in the system.

The other cations present in the $^{90}\text{SrF}_2\text{-W}$ system all form oxyfluorides (except sodium), complex fluorides, mixed oxides and mixed oxyfluorides in addition to the simple fluorides and oxides. Little or no thermochemical data are available on the complex compounds and only the simple fluorides and oxides are considered in the thermodynamic analyses.

The free energy of formation (ΔG_f°) of the fluorides of interest are presented in Table 6; the ΔG_f° values are given in kilocalories per gram-atom of fluorine. The data in Table 6 were obtained primarily from Rosenqvist,⁽²⁾ Glassner,⁽³⁾ Smithells,⁽⁴⁾ and Kubaschewski and Evans.⁽⁵⁾ The accuracy of the thermochemical data for even the most common fluorides is rather poor. For example, the following values have been published for the free energy of formation of sodium fluoride at 298°C.

<u>Value, kcal/mole</u>	<u>Reference</u>	<u>Reference Date</u>
-128.5 $\pm$ 3	Smithells ⁽⁴⁾	1967
-130 $\pm$ 10	Rosenqvist ⁽²⁾	1970
-129	Glassner ⁽³⁾	1957

The poor accuracy of the data makes any free energy of reaction (ΔG_R°) calculations for reactions involving fluorides of limited value, especially when the value of ΔG_R° is near zero. Where different references gave significantly different free energy of formation values for a given compound, an average value was used (unless one value appeared to be more reliable than the others).

In the case of metal oxides, the same difficulties apply, although to a lesser degree than with the fluorides. Over-all the thermochemical data

TABLE 6. Free Energy of Formation of Metal Fluorides

Compound	$-\Delta G_f^\circ$, kcal/g-atom of fluorine					
	25°C	600°C	800°C	1000°C	1100°C	1200°C
SrO	134	121	116	111	108	106
ZrO ₂	123.0	110.0	105.0	101.0	99.0	97.0
Al ₂ O ₃	126.0	112.0	106.0	101.0	99.0	96.0
BaO	129	116	111	105	103	100
CaO	144	131	126	121	118	116
CdO	54	41	36	25	20	16
Cr ₂ O ₃	83.0	71.0	67.0	63.0	61.0	59.0
Cu ₂ O	35.0	24.0	21.0	18.0	16.0	14.0
CuO	30	19	15	11	9	7
FeO	58	49	46	43	42	40
Fe ₃ O ₄	59.7	49.0	45.3	41.3	39.3	37.5
Fe ₂ O ₃	59.0	48.0	43.0	39.0	37.0	35.0
K ₂ O	76.0	58.0	52.0	44.0	40.0	36.0
MgO	137	122	117	112	109	104
MnO	87	77	73	70	68	66
Mn ₃ O ₄	77.0	64.0	60.0	56.0	53.0	52.0
Mn ₂ O ₃	72.0	59.0	55.0	51.0	49.0	47.0
Na ₂ O	90.0	70.0	64.0	51.0	46.0	40.0
NiO	52	38	33	29	26	24
PbO	45	31	26	23	21	19
SiO ₂	102.0	90.0	86.0	81.0	79.0	77.0
WO ₂	63.5	53.5	49.5	46.0	44.0	42.0
WO ₃	60.7	49.3	45.7	42.0	40.0	38.0
R ₂ O ₃ *	137.0	125.0	121.0	117.0	115.0	113.0
H ₂ O	55.0	48.0	45.0	42.0	41.0	39.0

* R₂O₃ Rare earth oxide - typically Nd₂O₃

on oxides has somewhat better accuracy than the data on the fluorides and a larger fraction of the data has been obtained experimentally. Free energy of formation data for the oxides of interest are presented in Table 7 (as kilocalories per gram-atom of oxygen). The bulk of the data were obtained from Richardson and Jeffes⁽⁶⁾ and from References 2 through 5.

A comparison of ΔG_f^0 data presented in Table 6 for the three tungsten fluorides shows that the free energy of formation per g-atom of fluorine is the least negative for WF_6 throughout the temperature range of interest (25 to 1200°C). Therefore, in any reaction involving tungsten and metal fluorides, either WF_4 or WF_5 is the probable reaction product rather than WF_6 . A comparison of the data in Table 6 also shows that only a few of the fluorides will react with tungsten to any appreciable degree in a closed system. However, for this study, even those reactions which were obviously unfavorable thermodynamically were evaluated to demonstrate the various types of reactions which must be considered in other systems.

Potential reactions involving the fluorides present in the $^{90}\text{SrF}_2$ -W system are presented in Table 8. Calculated free energies of reaction, obtained using the data given in Table 6, are shown in Table 9. From Table 9 it can be seen that the free energy of reaction for most of the reactions is so greatly positive at all temperatures of interest that in a closed system the reactions will not proceed to any measurable degree. The calculations do show, however, that some of the reactions are potentially possible, especially those involving the polyvalent ions (Mn, Cu, Fe). If CuF or CuF_2 are present in the system they should react to an appreciable degree with the tungsten as will any FeF_3 or MnF_3 present. Any NiF_2 , CdF_2 , PbF_2 or CrF_3 present should react with the tungsten to a limited extent at the higher temperatures. Fortunately, the troublesome compounds should be present in very low concentrations in the WESF $^{90}\text{SrF}_2$.

The free energy calculations show that if free zirconium metal is present in the $^{90}\text{SrF}_2$, as a decay product, it should react with any impurity fluoride present (except the rare earth, alkali metal and alkaline earth fluorides) to form ZrF_4 and the appropriate metal. The metal thus formed

TABLE 7. Free Energy of Formation of Metal Oxides

Compound	$-\Delta G_F^\circ$, kcal/g-atom of oxygen					
	25°C	600°C	800°C	1000°C	1100°C	1200°C
SrF ₂	138.0	127.2	122.5	119.0	117.5	115.5
ZrF ₂	109.0	99.0	95.5	92	90	88.5
ZrF ₄	108.0	97.0	93.3	91.0	90.0	89.0
AlF ₃	113.0	101.3	97.3	93.3	91.3	89.3
BaF ₂	137.0	125.0	122.0	118.5	117.0	115.5
CaF ₂	140.0	128.5	124.5	121.0	119.0	117.0
CdF ₂	76.5	66.0	62.5	56.0	53.0	50.0
CrF ₂	86.0	77.0	73.5	70.0	68.5	67.5
CrF ₃	83.3	73.3	70.0	67.0	65.0	63.7
CuF	56	48	45	43	43	42
CuF ₂	59.0	50.0	47.0	44.5	43.5	42.5
FeF ₂	79.0	69.5	66.5	63.5	62.0	60.5
FeF ₃	73.0	63.0	60.0	56.7	55.0	53.7
KF	129	114	109	102	99	95
MgF ₂	127.5	116.0	112.0	107.5	105.5	102.5
MnF ₂	90.0	80.5	77.5	75.5	74.5	73.5
MnF ₃	74.3	64.0	61.0	58.0	57.0	56.0
NaF	129	115	110	104	101	97
NiF ₂	73.5	64.0	61.0	58.0	56.5	55.0
PbF ₂	73.5	62.0	58.5	55.0	54.0	52.5
WF ₄	57.5	48.25	46.7	45.25	44.5	43.7
WF ₅	52.0	47.2	46.4	45.4	44.6	43.8
WF ₆	46.8	41.0	38.8	36.7	35.7	34.7
RF ₃ *	130.7	120	117.0	113.2	111.0	109.1
HF	65	65.3	65.9	66.2	66.5	67

* RF₃ Rare earth fluoride - typically NdF₃

TABLE 8. Potential Fluoride Reactions in the $^{90}\text{SrF}_2$ System

1.	$2\text{SrF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Sr}$	41.	$4\text{AlF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_4 + 4\text{Al}$
2.	$5\text{SrF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Sr}$	42.	$5\text{AlF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_5 + 5\text{Al}$
3.	$2\text{ZrF}_4 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{ZrF}_2$	43.	$2\text{CdF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Cd}$
4.	$\text{ZrF}_4 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + \text{Zr}$	44.	$5\text{CdF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Cd}$
5.	$5\text{ZrF}_4 + \text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{ZrF}_2$	45.	$2\text{CrF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Cr}$
6.	$5\text{ZrF}_4 + 4\text{W}$	$\rightleftharpoons$	$4\text{WF}_5 + 5\text{Zr}$	46.	$5\text{CrF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Cr}$
7.	$2\text{ZrF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Zr}$	47.	$4\text{CrF}_3 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{CrF}_2$
8.	$5\text{ZrF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Zr}$	48.	$4\text{CrF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_4 + 3\text{Cr}$
9.	$\text{SrF}_2 + \text{ZrF}_2$	$\rightleftharpoons$	$\text{ZrF}_4 + \text{Sr}$	49.	$5\text{CrF}_3 + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{CrF}_2$
10.	$2\text{SrF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Sr}$	50.	$5\text{CrF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_5 + 5\text{Cr}$
11.	$\text{SrF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_2 + \text{Sr}$	51.	$2\text{NiF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Ni}$
12.	$\text{Zr} + 2\text{W}$	$\rightleftharpoons$	ZrW_2	52.	$5\text{NiF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Ni}$
13.	$4\text{NaF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{Na}$	53.	$4\text{KF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{K}$
14.	$5\text{NaF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{Na}$	54.	$5\text{KF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{K}$
15.	$2\text{CaF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Ca}$	55.	$4\text{NaF} + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + \text{Na}$
16.	$5\text{CaF}_2 + \text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Ca}$	56.	$2\text{CaF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Ca}$
17.	$2\text{BaF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Ba}$	57.	$2\text{BaF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Ba}$
18.	$5\text{BaF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Ba}$	58.	$2\text{MgF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Mg}$
19.	$2\text{MgF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Mg}$	59.	$2\text{MnF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Mn}$
20.	$5\text{MgF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Mg}$	60.	$4\text{MnF}_3 + 3\text{Zr}$	$\rightleftharpoons$	$3\text{ZrF}_4 + 4\text{Mn}$
21.	$2\text{MnF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Mn}$	61.	$4\text{MnF}_3 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 4\text{MnF}_2$
22.	$5\text{MnF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Mn}$	62.	$2\text{PbF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Pb}$
23.	$4\text{MnF}_3 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{MnF}_2$	63.	$2\text{CuF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Cu}$
24.	$4\text{MnF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_4 + 4\text{Mn}$	64.	$4\text{CuF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 4\text{CuF}$
25.	$5\text{MnF}_3 + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{MnF}_2$	65.	$4\text{CuF} + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 4\text{Cu}$
26.	$5\text{MnF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_5 + 5\text{Mn}$	66.	$4\text{FeF}_3 + 3\text{Zr}$	$\rightleftharpoons$	$3\text{ZrF}_4 + 4\text{Fe}$
27.	$2\text{PbF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Pb}$	67.	$4\text{FeF}_3 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 4\text{FeF}_2$
28.	$5\text{PbF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Pb}$	68.	$2\text{FeF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Fe}$
29.	$4\text{CuF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{CuF}$	69.	$4\text{AlF}_3 + 3\text{Zr}$	$\rightleftharpoons$	$3\text{ZrF}_4 + 4\text{Al}$
30.	$2\text{CuF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Cu}$	70.	$2\text{CdF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Cd}$
31.	$5\text{CuF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{CuF}$	71.	$2\text{CrF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Cr}$
32.	$5\text{CuF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Cu}$	72.	$4\text{CrF}_3 + 3\text{Zr}$	$\rightleftharpoons$	$3\text{ZrF}_4 + 4\text{Cr}$
33.	$4\text{CuF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{Cu}$	73.	$4\text{CrF}_3 + 3\text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 4\text{CrF}_2$
34.	$5\text{CuF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{Cu}$	74.	$2\text{NiF}_2 + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 2\text{Ni}$
35.	$4\text{FeF}_3 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 4\text{FeF}_2$	75.	$4\text{KF} + \text{Zr}$	$\rightleftharpoons$	$\text{ZrF}_4 + 4\text{K}$
36.	$4\text{FeF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_4 + 4\text{Fe}$	76.	$4\text{RF}_4 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_4 + 4\text{R}$
37.	$5\text{FeF}_3 + \text{W}$	$\rightleftharpoons$	$\text{WF}_5 + 5\text{FeF}_2$	77.	$5\text{RF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_5 + 5\text{R}$
38.	$5\text{FeF}_3 + 3\text{W}$	$\rightleftharpoons$	$3\text{WF}_5 + 5\text{Fe}$	78.	$4\text{RF}_3 + 3\text{Zr}$	$\rightleftharpoons$	$3\text{ZrF}_4 + 4\text{R}$
39.	$2\text{FeF}_2 + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{Fe}$	79.	$4\text{HF} + \text{W}$	$\rightleftharpoons$	$\text{WF}_4 + 2\text{H}_2$
40.	$5\text{FeF}_2 + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{Fe}$	80.	$10\text{HF} + 2\text{W}$	$\rightleftharpoons$	$2\text{WF}_5 + 5\text{H}_2$

TABLE 9. Calculated Free Energies of Reactions for Reactions 1-78 (from 25°C to 1200°C)

Reaction No.	ΔG_p° (for reactions as written), kcal						Reaction No.	ΔG_p° (for reactions as written), kcal					
	25°C	600°C	800°C	1000°C	1100°C	1200°C		25°C	600°C	800°C	1000°C	1100°C	1200°C
1	322	315	300	295	292	287	41	666	637	607	577	563	547
2	860	798	761	736	729	717	42	915	812	764	719	701	683
3	198	187	177	179	182	183	43	76	71	63	43	34	25
4	202	195	186	183	182	181	44	245	188	161	106	84	62
5	550	478	446	446	455	457	45	114	115	107	99	96	95
6	1120	996	937	912	908	904	46	340	298	271	246	239	237
7	209	203	195	187	182	175	47	82	71	65	63	54	49
8	570	518	491	466	454	447	48	310	301	299	261	256	239
9	62	64	63	58	55	52	49	130	94	83	78	67	61
10	120	120	117	112	110	106	50	470	392	354	324	306	298
11	58	56	54	54	55	54	51	64	53	57	51	48	45
12	- 2	- 3	- 3	- 4	- 4	- 5	52	215	168	146	126	119	112
13	286	267	253	235	226	213	53	286	263	249	227	218	205
14	385	339	318	293	282	266	54	385	334	313	283	272	256
15	330	321	311	303	298	293	55	84	72	67	52	44	32
16	880	833	781	756	744	732	56	128	126	125	120	116	112
17	318	307	301	293	290	287	57	116	112	115	110	108	106
18	850	778	756	731	488	485	58	78	76	75	66	62	54
19	280	271	261	249	244	235	59	- 72	- 66	- 63	- 62	- 62	- 62
20	755	688	656	621	609	587	60	- 404	-396	-397	-396	-396	-396
21	130	129	123	121	120	119	61	- 260	-264	-261	-272	-272	-272
22	380	333	311	301	299	297	62	- 138	-140	-139	-144	-144	-146
23	- 58	- 60	- 75	- 89	- 90	- 91	63	- 196	-188	-185	-186	-186	-186
24	202	189	181	173	150	147	64	- 184	-180	-177	-180	-184	-184
25	- 45	- 81	- 92	-112	-113	-114	65	- 208	-196	-193	-192	-188	-188
26	335	252	219	199	186	183	66	- 420	-408	-399	-412	-420	-424
27	64	55	47	39	38	35	67	- 188	-188	-185	-192	-196	-196
28	215	148	121	96	94	87	68	- 116	-110	-107	-110	-112	-114
29	18	15	9	3	- 2	- 3	69	60	52	49	28	16	4
30	6	7	1	- 3	- 4	- 5	70	120	-124	-123	-140	-148	-156
31	50	24	13	3	- 3	- 4	71	- 88	- 80	- 79	- 84	- 86	- 86
32	70	28	6	- 9	- 11	- 13	72	- 296	-284	-279	-288	-200	-304
33	- 6	- 1	- 7	- 9	- 6	- 7	73	- 120	-124	-121	-120	-128	-132
34	20	4	- 8	- 12	- 8	- 9	74	- 138	-132	-129	-132	-134	-136
35	14	7	1	- 9	- 14	- 15	75	84	68	63	44	36	24
36	202	177	169	137	126	119	76	878	861	843	817	789	783
37	45	14	3	- 12	- 18	- 19	77	1180	1092	1059	1019	996	978
38	387	237	204	169	156	148	78	272	276	285	268	252	240
39	86	85	79	73	70	67	79	30	67	77	83	86	93
40	270	223	201	181	174	167	80	130	178	196	206	214	232

could alloy with the tungsten to form a solid solution or intermetallic phase. The free zirconium could also react directly with the tungsten to form ZrW_2 . In similar fashion, if ZrF_2 was present in the $^{90}SrF_2$, as a decay product, it could react with any impurity fluorides present, except the rare earth, alkali metal and alkaline earth fluorides, to form ZrF_4 and the appropriate metal.

It is interesting to compare the results of the free energy calculations with the compatibility test results for the SrF_2 -W system presented in Table 1. It is apparent that the presence of impurity fluorides such as CuF_2 and FeF_3 in the SrF_2 did not increase the attack of the tungsten as greatly as one might expect from the free energy calculations. This could result from any one of or combinations of these three factors: 1) the free energy calculations are in error because of inaccuracies in the ΔG_f° data, 2) the reaction kinetics are very slow, and 3) the reaction is limited by rates of diffusion.

Potential reactions involving the oxides which may be present in the $^{90}SrF_2$ are listed in Table 10. The calculated free energies of reaction, obtained using the data given in Table 7, are presented in Table 11. Since the free energy of formation of WO_2 is more negative (per gram-atom of oxygen) than that of WO_3 throughout the temperature range of interest, only the reactions involving WO_2 are given.

From Table 11 it can be seen that several metal oxides would react with tungsten if they are present in the fluoride. Fortunately, the analytical data show that oxygen present in the fluoride is present primarily as water, and the concentration of metal oxides should be very low. Any water present in the fluoride, however, should react with the tungsten forming WO_2 and hydrogen.

Oxides could also be formed in the $^{90}SrF_2$ by reaction of water present with impurity fluorides. Potential hydrolysis reactions are listed in Table 12 and the calculated free energies of reaction are given in Table 13.

TABLE 10. Potential Oxide Reactions in the $^{90}\text{SrF}_2$ -W System

81.	2SrO	+	W	$\rightleftharpoons$	WO_2	+	2Sr
82.	ZrO_2	+	W	$\rightleftharpoons$	WO_2	+	Zr
83.	$2\text{Al}_2\text{O}_3$	+	3W	$\rightleftharpoons$	3WO_2	+	4Al
84.	2BaO	+	W	$\rightleftharpoons$	WO_2	+	2Ba
85.	2CaO	+	W	$\rightleftharpoons$	WO_2	+	2Ca
86.	2Cd	+	W	$\rightleftharpoons$	WO_2	+	2Cd
87.	$2\text{Cr}_2\text{O}_3$	+	3W	$\rightleftharpoons$	3WO_2	+	4Cr
88.	$2\text{Cu}_2\text{O}$	+	W	$\rightleftharpoons$	WO_2	+	4Cu
89.	4CuO	+	W	$\rightleftharpoons$	WO_2	+	$2\text{Cu}_2\text{O}$
90.	2CuO	+	W	$\rightleftharpoons$	WO_2	+	2Cu
91.	2FeO	+	W	$\rightleftharpoons$	WO_2	+	2Fe
92.	$2\text{Fe}_2\text{O}_3$	+	W	$\rightleftharpoons$	WO_2	+	4FeO
93.	$2\text{Fe}_3\text{O}_4$	+	W	$\rightleftharpoons$	WO_2	+	6FeO
94.	$2\text{Fe}_2\text{O}_3$	+	3W	$\rightleftharpoons$	3WO_2	+	4Fe
95.	Fe_3O_4	+	2W	$\rightleftharpoons$	2WO_2	+	3Fe
96.	2MgO	+	W	$\rightleftharpoons$	WO_2	+	2Mg
97.	2MnO	+	W	$\rightleftharpoons$	WO_2	+	2Mn
98.	$2\text{Mn}_3\text{O}_4$	+	W	$\rightleftharpoons$	WO_2	+	6MnO
99.	Mn_3O_4	+	2W	$\rightleftharpoons$	2WO_2	+	3Mn
100.	$2\text{Mn}_2\text{O}_3$	+	W	$\rightleftharpoons$	WO_2	+	4MnO
101.	$6\text{Mn}_2\text{O}_3$	+	W	$\rightleftharpoons$	WO_2	+	$4\text{Mn}_3\text{O}_4$
102.	2NiO	+	W	$\rightleftharpoons$	WO_2	+	2Ni
103.	2PbO	+	W	$\rightleftharpoons$	WO_2	+	2Pb
104.	SiO_2	+	W	$\rightleftharpoons$	WO_2	+	Si
105.	$2\text{R}_2\text{O}_3$	+	3W	$\rightleftharpoons$	3WO_2	+	4R
106.	$2\text{H}_2\text{O}$	+	W	$\rightleftharpoons$	WO_2	+	2H_2

TABLE 11. Calculated Free Energies of Reaction for Reactions 81-106 (from 25°C to 1200°C)

Reaction No.	ΔG_R° (for reactions as written), kcal					
	25°C	600°C	800°C	1000°C	1100°C	1200°C
81	141	135	133	130	128	128
82	119	113	111	110	110	110
83	502	458	438	422	418	408
84	125	125	123	118	118	116
85	161	155	153	150	148	148
86	- 19	- 25	-	- 42	- 48	- 52
87	117	105	105	102	102	102
88	- 57	- 59	- 57	- 56	- 56	- 56
89	- 77	- 79	- 81	- 84	- 84	- 84
90	- 67	- 69	- 69	- 70	- 70	- 70
91	- 11	- 9	- 7	- 6	- 4	- 4
92	- 5	- 15	- 25	- 30	- 22	- 20
93	3	- 9	- 13	- 20	- 26	- 24
94	- 27	- 33	- 39	- 42	- 42	- 42
95	- 15	- 18	- 17	- 19	- 19	- 14
96	147	137	135	132	130	124
97	47	47	47	48	48	48
98	- 33	- 57	- 57	- 64	- 72	- 64
99	54	42	42	40	36	40
100	- 43	- 61	- 61	- 66	- 66	- 66
101	- 63	- 69	- 69	- 70	- 70	- 70
102	- 23	- 31	- 33	- 34	- 36	- 36
103	- 37	- 45	- 47	- 46	- 46	- 46
104	77	73	72	70	70	70
105	441	429	429	426	426	462
106	- 17	- 11	- 19	- 8	- 6	- 6

TABLE 12. Potential Hydrolysis Reactions in the $^{90}\text{SrF}_2$ -W System

107.	$\text{H}_2\text{O} + \text{SrF}_2 \rightleftharpoons$	$\text{SrO} + 2\text{HF}$
108.	$2\text{H}_2\text{O} + \text{ZrF}_4$	$\text{ZrO}_2 + 4\text{HF}$
109.	$3\text{H}_2\text{O} + 2\text{AlF}_3$	$\text{Al}_2\text{O}_3 + 6\text{HF}$
100.	$\text{H}_2\text{O} + \text{BaF}_2$	$\text{BaO} + 2\text{HF}$
111.	$\text{H}_2\text{O} + \text{CaF}_2$	$\text{CaO} + 2\text{HF}$
112.	$\text{H}_2\text{O} + \text{CdF}_2$	$\text{CdO} + 2\text{HF}$
113.	$3\text{H}_2\text{O} + 2\text{CrF}_3$	$\text{Cr}_2\text{O}_3 + 6\text{HF}$
114.	$\text{H}_2\text{O} + 2\text{CuF}$	$\text{Cu}_2\text{O} + 2\text{HF}$
115.	$\text{H}_2\text{O} + \text{CuF}_2$	$\text{CuO} + 2\text{HF}$
116.	$\text{H}_2\text{O} + \text{FeF}_2$	$\text{FeO} + 2\text{HF}$
117.	$3\text{H}_2\text{O} + 2\text{FeF}_3$	$\text{Fe}_2\text{O}_3 + 6\text{HF}$
118.	$\text{H}_2\text{O} + 2\text{KF}$	$\text{K}_2\text{O} + 2\text{HF}$
119.	$\text{H}_2\text{O} + \text{MgF}_2$	$\text{MgO} + 2\text{HF}$
120.	$\text{H}_2\text{O} + \text{MnF}_2$	$\text{MnO} + 2\text{HF}$
121.	$3\text{H}_2\text{O} + 2\text{MnF}_3$	$\text{Mn}_2\text{O}_3 + 6\text{HF}$
122.	$\text{H}_2\text{O} + 2\text{NaF}$	$\text{Na}_2\text{O} + 2\text{HF}$
123.	$\text{H}_2\text{O} + \text{NiF}_2$	$\text{NiO} + 2\text{HF}$
124.	$\text{H}_2\text{O} + \text{PbF}_2$	$\text{PbO} + 2\text{HF}$
125.	$3\text{H}_2\text{O} + 2\text{RF}_3$	$\text{R}_2\text{O}_3 + 6\text{HF}$

TABLE 13. Calculated Free Energies of Reaction for
Reaction 107-125 (from 25°C to 1200°C)

Reaction No.	ΔG_R (for reactions as written), kcal					
	25°C	600°C	800°C	1000°C	1100°C	1200°C
107	67	41	42	37	36	30
108	36	4	- 11	- 18	- 20	- 28
109	75	26	5	- 13	- 22	- 37
110	70	52	46	42	40	36
111	61	54	36	31	29	23
112	24	9	2	- 3	- 5	- 11
113	26	- 19	- 42	- 57	- 66	- 80
114	2	- 12	- 18	- 22	- 22	- 23
115	13	- 1	- 8	- 12	- 13	- 17
116	25	8	0	- 6	- 9	- 14
117	36	- 12	- 30	- 47	- 54	- 68
118	107	88	79	70	67	59
119	43	28	20	13	11	6
120	18	2	- 5	- 9	- 10	- 14
121	5	- 39	- 60	- 75	- 78	- 90
122	93	78	69	61	60	59
123	20	8	2	- 3	- 18	- 24
124	27	11	4	- 3	- 4	- 9
125	148	99	78	58	48	31

Free energy calculations show that if free zirconium metal is present in the $^{90}\text{SrF}_2$, as a decay product, it could react with any metal oxide present, except the rare earth and alkaline earth oxides, to form ZrO_2 and the appropriate metal. The metal formed could react in turn with the tungsten.

From the above discussion it is obvious that a thorough thermodynamic analysis of $^{90}\text{SrF}_2$ compatibility is extremely complex because of the great many potential reactions involved. Lack of reliable thermodynamic data further complicates the problem. If complex fluorides, oxyfluorides, and complex oxides are included, the work required for the analysis becomes overwhelming, primarily because very little thermochemical data is available on the complex compounds and has to be estimated. When the complex compounds are not considered in the analysis, the very real possibility exists that the critical reaction(s) affecting $^{90}\text{SrF}_2$ compatibility will be missed, thus greatly reducing the value of the study.

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