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PLUTONIA/CURIA COMPATIBILITY TESTING

OCTOBER - DECEMBER 1970

QUARTERLY REPORT NO. 9

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ABSTRACT

Microhardness measurements reaffirmed previously reported metallographic and electron beam microprobe results for plutonia/refractory metal combinations exposed at 1800° and 2000°C. Curia exposed at 2000°C for 1000 hours is being examined metallographically. Exposure continues at 1800° and 2000°C on plutonia-238/refractory metal, curia-244/refractory metal, and plutonia-molybdenum cermets. Test matrices have been established and materials ordered for more systems-oriented test programs utilizing several plutonia fuel forms in contact with a variety of materials.

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Section 1 INTRODUCTION

Absolute containment of radioisotope fuels in high temperature heat sources requires establishment of fuel/container compatibility under all normal and abnormal conditions which may be encountered. Plutonium-238 is currently being used at moderate temperatures in space, but further knowledge concerning its containment is essential for more advanced applications at higher temperatures. Similarly, curium-244 has been proposed as the fuel for advanced non-manned interplanetary missions requiring long-duration use at high temperatures.

Original goals for this program were first to define the best refractory alloy containers for both plutonia and curia under accelerated testing conditions at 1800° and 2000°C and second to determine the rates at which they interact, the intent being to extrapolate reaction rates to lower temperatures and long times. The basic program was devised to test plutonia and curia in contact with a monometallic capsule containing discs in intimate contact with the fuel. Eighteen plutonia-refractory alloy capsules were fabricated using production grade plutonia containing approximately one percent non-actinide cationic impurities. Twelve specimens have completed exposure and evaluation. The remaining six specimens continue exposure. A matched set of 18 higher-purity (~0.23% non-actinide cationic impurities) plutonia-refractory metal specimens was added to the program because it was believed that the original low-purity plutonia would produce erroneously high attack. Twelve of the higher-purity plutonia specimens have completed exposure and have been evaluated. Six capsules continue exposure. Eighteen curia-refractory metal capsules have been fabricated; six have completed exposure and twelve continue exposure.

A small supplemental effort was added in 1969 to evaluate high-temperature stability of plutonia-molybdenum cermets fabricated at Battelle-Columbus

Laboratories. Six cermet bodies were encapsulated in W-25Re for high-temperature exposure. Four have completed exposure; two have completed evaluation.

Recently added program goals include:

1. Determination of the best container materials for PMC (plutonia-molybdenum cermet) using a more systems-oriented testing configuration.
2. A comparison between PMC and SSC (plutonia-thoria-molybdenum or solid-solution cermet) as to differences in compatibility with refractory alloys.
3. Evaluation of barrier materials between pressed plutonia (PPO) and noble metals for use in the Multi-hundred Watt Radioisotope Thermoelectric Generator Program (MHW-RTG).

All materials have been ordered for these added tasks. The SSC fuel is on hand, and some of the capsules have been delivered. Sixteen PMC, four SSC, and ten PPO capsules will be assembled during the next quarter.

Section 2

RESULTS

Work is proceeding on several tasks. These are now defined as: Task 1 - Current program including the original and pure plutonia work, curia testing, and Battelle-Columbus Laboratories plutonia-molybdenum cermet; Task 2 - PMC and SSC testing program which is more systems oriented and incorporates study of both fuel liner and structural member combinations; and Task 3 - Barrier tests for MHW-RTG which is also systems oriented and is to be performed in conjunction with tests underway at Los Alamos Scientific Laboratory.

A status summary of all compatibility capsules is given in Table 2-1. Specific details of the program are discussed in this section. Table 2-1 will be updated in subsequent quarterly reports.

2.1 TASK 1 - CURRENT PROGRAM

2.1.1 Original Plutonia (1 w/o metallic impurities)

A topical report containing the compatibility results reported to date is being prepared. This report should be published early in February. No new experimental data were obtained during this report period. Six capsules still being exposed at 1800°C have attained 11,800 hours toward the scheduled 15,000 hours.

2.1.2 Pure Plutonia (~0.23 w/o metallic impurities)

Results reported to date are included in the topical report to be published in February. Six capsules still being exposed at 1800°C have accumulated 8800 hr toward the scheduled 15,000 hr.

New information on microhardness is listed in Table 2-2 combined with information previously reported in the Fifth Quarterly Report (MDC G1675).

Table 2-1
COMPATIBILITY CAPSULE STATUS SUMMARY

Fuel Form		Container		Exposure		Status
Material	Oxygen to Actinide Ratio	No.	Alloys	Temp (°C)	Time (hr)	
Original Plutonia	2.0	3	W, W-25Re, Re	2000	1000	Completed
	1.8	3	W, W-25Re, Re	2000	1000	Completed
	2.0	6	Above + Mo-50Re, Mo, W-Mo-Re	1800	2000	Completed
	2.0	6	Above + Mo-50Re, Mo, W-Mo-Re	1800	15,000	In furnace-11, 800 hr
Pure Plutonia	2.0	3	W, W-25Re, Re	2000	1000	Completed
	1.8	3	W, W-25Re, Re	2000	1000	Completed
	2.0	6	Above + Mo-50Re, Mo, W-Mo-Re	1800	2000	Completed
	2.0	6	Above + Mo-50Re, Mo, W-Mo-Re	1800	15,000	In furnace-8800 hr
Curia	1.5	6	W, W-25Re, Re, Mo-50Re, Mo, W-Mo-Re	2000	1000	In Metallography
	1.5	6*	W, W-25Re, Re, Mo-50Re, Mo, W-Mo-Re	2000	10,000	In furnace-4400 hr
	1.5	6*	W, W-25Re, Re, Mo-50Re, Mo, W-Mo-Re	1800	10,000	In furnace-6100 hr
Battelle-Columbus Plutonia-Molybdenum Cermet	1.85	1	W-25Re	2000	1000	Completed
	1.85	1	W-25Re	2000	5000	He release to be measured
	1.85	1	W-25Re	2000	10,000	In furnace-8400 hr
	1.85	1	W-25Re	1800	1000	Completed
	1.85	1	W-25Re	1800	5000	He release to be measured
	1.85	1	W-25Re	1800	10000	In furnace-9800 hr

Table 2-1

COMPATIBILITY CAPSULE STATUS SUMMARY (Continued)

Fuel Form		Container		Exposure		Status
Material	Oxygen to Actinide Ratio	No.	Alloys**	Temp (°C)	Time (hr)	
PMC	1.85	4	TZM/W-25Re, W-25Re/ W-25Re, Mo-47Re/W-25Re, W-Mo-Re/W-25Re	2000	1000	Materials ordered
	1.85	2	Ta-10W/T-111	1800	100	&*** Materials ordered
	1.85	3	TZM/TZM, W-25Re/T-111, Mo-47Re/TZM	1800	1000	Materials ordered
	1.85	4	TZM/Mo-47Re, W-25Re/ TZM, Mo-47Re/TZM, W-Mo-Re/T-111	1800	5000	Materials ordered
	1.85	3	TZM/T-111, W-25Re/ T-111, Mo-47Re/T-111	1500	5000	Materials ordered
	Unknown	1	Ta-10W/T-111	1800	***	Materials ordered
SSC	Unknown	3	TZM/T-111, W-25Re/ T-111, W-Mo-Re/W-25Re	1800	5000	Materials ordered
PPO	2.0	1	Ir	1500	1000	Materials ordered
	1.8	3	Ir, Pt-30Rh, Pt-Rh-W	1500	1000	Materials ordered
	2.0	1	Ir	1500	5000	Materials ordered
					****	Materials ordered
	1.8	5	Ir (3), Pt-30Rh, Pt-Rh-W	1500	5000	**** Materials ordered

- Notes: * Three specimens will be examined from each group of six.
 ** Alloy/alloy indicates primary and secondary container, respectively.
 *** Test duration based on results of PMC/Ta-10W/T-111 1800 °C, 100-hr specimen.
 **** May be reduced to 1000 hr plus reentry thermal pulse instead of 5000 hr.

Table 2-2
MICROHARDNESS VALUES

(Vickers Diamond Indenter, 100g Load Unless Noted, Values in kg/mm²)

Alloy	Plutonia	O/Pu Ratio	Exposure		As Received	Near Exposed Surface	Metal Disc		
			Temp (°C)	Time (hr)			Half-way	Center	Oxide
W	Pure	2.0	1800	2000	462	401, 373 ^b , 387 ^c		420, 420 ^c	173 ^{f, g}
	Original	2.0	1800	2000		450	450	514	
	Pure	2.0	2000	1000		514, 464 ^b		464, 488 ^b	106 ^g
	Original	2.0	2000	1000		464	514	514	
	Pure	1.8	2000	1000		420		420	
	Original	1.8	2000	1000		464	464	401	
W-25Re	Pure	2.0	1800	2000	600	488		464	919 ^{f, g}
	Original	2.0	1800	2000		542	542	542	1113 ^f , 1113 ^{f, g} , 522 ^{a, f}
	Pure	2.0	2000	1000		542		542	
	Original	2.0	2000	1000		464	464	464	
	Pure	1.8	2000	1000		441		464	1097 ^{f, g}
	Original	1.8	2000	1000		514	514	464	
Re	Pure	2.0	1800	2000	723	383		383	584 ^{f, g}
	Original	2.0	1800	2000		1018, 433 ^c	946	813	
	Pure	2.0	2000	1000		464, 413 ^c		401	1113 ^f
	Original	2.0	2000	1000		642, 274 ^c	665	420, 540 ^d , 503 ^e	1720
	Pure	1.8	2000	1000		464		383	1097 ^g , 1208 ^f
	Original	1.8	2000	1000		464 ^d , 606 ^e	383 ^d , 681 ^e	383 ^d , 681 ^e	
	None	---	2000	1000		(317 ^d , 572 ^e)			
Mo-50Re	Pure	2.0	1800	2000	434	401		401	1018 ^g , 724 ^{f, g}
	Original	2.0	1800	2000		401	383	351	
Mo	Pure	2.0	1800	2000	302	237		221	1374 ^f , 681 ^g , 522 ^{f, g}
	Original	2.0	1800	2000		181	181	170	
W-30Mo-30Re	Pure	2.0	1800	2000	488	548		493	1530 ^f
	Original	2.0	1800	2000		508	566	642	

Note: a. Metal precipitate in oxide
b. Capsule wall
c. Vapor transported metal
d. Dark appearing grains

e. Light appearing grains
f. 15-g load
g. Indention cracked

Major conclusions drawn from the microhardness measurements include:

1. Refractory alloys are harder after exposure at 2000° than 1800°C probably attributable to greater solubility of oxygen.
2. Refractory alloys are harder after exposure at 2000°C in contact with $\text{PuO}_{2.0}$ than $\text{PuO}_{1.8}$ probably because of the greater amount of oxygen present from the $\text{PuO}_{2.0}$.
3. Refractory alloys are softer in contact with pure plutonia than with the original plutonia because the metal impurities originally present in the fuel transfer to and diffuse into the refractory metal causing an additive effect on hardness.
4. Refractory alloys soften by annealing during exposure from the original as-worked structure which is only partially offset by the hardening caused by the diffusion of oxygen and metallic impurities from the fuel.
5. Plutonia microhardness was generally random with a minor increasing trend with decreasing oxygen content.

Metallographic examination was completed on one of the pure $\text{PuO}_{1.8}$ pellets supplied by Mound Laboratory. At the time this particular pellet was being encapsulated, the fixturing slipped causing the capsule to tip over and spill the pellet thereby contaminating the capsule. Rather than reencapsulate the pellet (since there was one spare), it was placed back into the rhenium capsule and bagged into the metallographic line where it sat in air for approximately eight months until metallography was performed. Metallographic results indicate that the pellet did not reoxidize significantly. However, a highly variable structure is exhibited by this fuel pellet attributable to its thermal processing and amount of metallic impurities. The $\text{Pu}_{1.8}$ pellets were cold pressed at Mound in steel dies and sintered/reduced for approximately four hours at 1400°C in a 6% H_2 -94% Ar atmosphere, cooled, stored, and shipped in an inert atmosphere. A single sintering treatment cycle as was used is insufficient for high densification. Thus, the structure shown in A, Figure 2-1 is considered relatively typical. The large black areas are major porosity, the major gray areas are porous plutonia with much smaller size pores (shown better in B, Figure 2-1), and the lighter gray areas are densified plutonia which usually, but not necessarily, contain white precipitates which appear to be multiphase in nature. The sintered plutonia areas exhibit a two-phase structure which appears to correspond to the 1.8 O/Pu ratio. The white precipitates shown in B and C, Figure 2-1 appear to include either a second phase or porosity. The amount of white precipitates is definitely less than one volume-percent but is too small for an accurate determination. Metallic impurities

70-2296

71-113

A

50X

B

200X

71-102

C

500X

Figure 2-1. Pure $\text{PuO}_{1.8}$ Pellet — No Exposure

are reported to be approximately one-quarter weight percent which, with the normal expected atomic weights and densities represented, are equivalent to approximately 1 volume-percent metal.

2.1.3 Curia

Six curia capsules exposed at 2000°C for 1000 hours have been shipped to Battelle-Northwest Laboratories for metallographic examination. By early in January, all tertiary and secondary containment capsules had been removed and no sign of damage or contamination was detectable on the external surface of the primary containers. Metallography is proceeding under the direction of Dr. J. H. Jarrett and should be complete early in February.

Twelve capsules continue exposure at either 1800° or 2000°C for 10,000 hours. Six of these are to be examined, the selection being based on results of the first six specimens. Expediency dictated the fabrication of extra capsules so that maximum exposure can be acquired during minimum calendar time. The 1800°C specimens have attained 6100 hours exposure and the 2000°C specimens have attained 4400 hours exposure.

2.1.4 Battelle-Columbus Laboratories Plutonia-Molybdenum Cermets

Six plutonia-molybdenum cermets fabricated at Battelle-Columbus Laboratories were encapsulated in W-25Re at DWDL for exposure at 1800° and 2000°C. Specimens exposed for 1000 hours were evaluated and information reported in the 6th Quarterly Report (MDC G1689). Specimens exposed for 5000 hours are at WADCO awaiting helium release measurement. Considerable delay occurred for a variety of reasons all related to the formation of WADCO from Battelle Northwest Laboratories. Equipment has now been set up and checked out. Measurements are scheduled for late January. Specimens will be shipped back to DWDL for further visual, dimensional, and metallographic examination.

Exposure of the 10,000 hour specimens continues with 9800 hours at 1800°C and 8400 hours at 2000°C.

2.2 TASK II - PMC-SSC TESTING PROGRAM

Twenty refractory metal capsules containing PMC (plutonia-molybdenum cermet) or SSC (plutonia-thoria-molybdenum solid solution cermet) are to be evaluated

after exposures ranging from 100 to 5000 hours at temperatures from 1500° to 2000°C. The test matrix shown in Table 2-3 gives test temperature/time conditions as well as fuel liner/structural member combinations. Fuel (both PMC and SSC) configuration is a right circular cylinder 0.23-in. diameter by 0.18-in. tall. The fuel liner is a snug-fitting 30-mil container. Structural members are tight-fitting 80-mil containers. The objective is to simulate the fuel-liner-structural member separations of an actual RTG heat source. Compatibility will be measured on thin polished discs in contact with the fuel pellet ends. However, both the fuel liner and structural member will be examined for gross attack and structural changes caused by presence of the fuel. A sufficient number of control capsules will be assembled for parallel exposure and evaluation to ensure that thermal effects are explainable separately from the fuel effects.

Table 2-3

FUEL FORM/REFRACTORY METAL TEST MATRIX

Fuel Liner: (a)			Ta-10W				TZM				W-25Re				Mo-47Re				W-Mo-Re			
Structural Alloy: (b)			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Fuel Form(c)	Temp (°C)	Time (hr)																				
PMC	1500	5000					1				1				1							
PMC	1800	100	1																			
		(d)	1																			
		1000					1				1				1							
		5000						1			1				1				1			
PMC	2000	1000							1				1				1					1
SSC	1800	(d)	1																			
	5000						1				1											1

- Notes: a. Inner capsule having 0.030-in. walls.
- b. Outer capsule having 0.080-in. walls with A denoting T-111, B denoting TZM, C denoting Mo-47Re, and D denoting W-25Re.
- c. Fuel is a 0.23-in. dia x 0.18-in. high right circular cylinder of plutonia-molybdenum cermet (PMC) or plutonia-thoria-molybdenum solid solution cermet (SSC).
- d. Test duration is dependent upon PMC 1800°C 100-hr results.

All TZM, W-25Re, Mo-47Re, and W-30Mo-30Re capsules have been delivered by the vendor. Both Ta-10W and T-111 capsules have been delayed because of slow delivery of the bar stock but both are due by the end of January. The SSC fuel has arrived; the PMC fuel is scheduled for delivery from Los Alamos Scientific Laboratory by the end of January. Weld parameters will be established by the end of January with all 20 capsules to be assembled early in February.

2.3 MHW-RTG BARRIER TESTS

A test matrix (Table 2-4) has been established for DWDL to conduct systems-oriented barrier tests at 1500°C in support of the Multi-hundred Watt Radioisotope Thermoelectric Generator (MHW-RTG) Program. Los Alamos Scientific Laboratory is to perform basic compatibility tests at 1370° and 1500°C with the two programs being coordinated to provide directly comparable information. The DWDL program is to evaluate two oxygen levels in the fuel, two barrier materials, three container materials, two types of oxygen gettering, and two exposure conditions in a total of 10 tests. Major emphasis is on low oxygen content fuel (1.85 O/Pu as opposed to stoichiometric $\text{PuO}_{2.0}$ high oxygen content fuel) with a hafnia barrier in an iridium container. Both pure hafnia and iridium foil in contact with molybdenum foil will be investigated as barriers to prevent diffusion between the fuel and noble metal cladding. The iridium/molybdenum combination may or may not be pre-diffused to minimize further reactions. Iridium is the primary capsule material with one capsule of Pt-30Rh and one capsule of an Oak Ridge National Laboratory developed platinum-rhodium tungsten alloy. The basic MHW-RTG heat source will be vented to a large internal plenum. Two types of oxygen gettering will be evaluated to simulate the actual heat source. The first type uses graphite as the getter in a manner very similar to what would be encountered in the actual closed system while the second type uses the tantalum-10% tungsten capsule as a getter which more closely approximates a system open to space. All specimens will be exposed at 1500°C with the first group being evaluated after a 1000 hour exposure. Results of the evaluation will determine the length of time and whether a reentry thermal pulse is given to the second set of specimens.

The three DWDL test configurations are shown in Figure 2.2. The configuration shown on the left utilizes (inside to outside) a low oxygen PPO fuel pellet,

Table 2-4
DWDL BARRIER TEST MATRIX

Test Duration	Fuel Oxygen Content	GE-IPSO MHW Capsule Designations				
		Barrier Material ^a →	HfO ₂			
		Capsule Material ^b →	Ir		Pt-30Rh	Pt-Rh-W
		Oxygen Getter ^c →	Ta	Graphite	Ta	Ta
Short (1000 hr)	Low (1.80 ± 0.05 O/Pu)		32	28	30	
	High (1.98 to 2.00 O/Pu)		34			
	None (Dummy)		X	X	X	
Long (5000 hr or 1000 hr plus reentry thermal pulse)	Low (1.80 ± 0.05 O/Pu)		33	29	31	36
	High (1.98 to 2.00 O/Pu)		35			22
	None (Dummy)		X	X	X	X

- Notes: a. Inner 0.003 in. molybdenum foil used plus either 0.003 in. Ir foil or 0.030 in. pure (unstabilized) cold pressed and sintered HfO₂.
- b. These capsules are vented to the next void volume by a hole or a slit machined in the capsule.
- c. Ta and graphite provide variations in gettering oxygen vented from the fuel container. A total of three unvented capsules surround each vented capsule.

INNERMOST NOBLE METAL CAPSULE IS VENTED TO NEXT CONTAINER.
ALL DIMENSIONS ARE EITHER OVERALL LENGTHS OR OUTSIDE DIAMETERS.

*DENOTES COMPONENTS OF A THIRD CONFIGURATION WHICH HAS A HfO₂ BARRIER/Ir, Pt-30Rh OR Pt-Rh-W CAPSULES/Ta-10W GETTER.

Figure 2-2. Barrier Test Capsule Configurations

molybdenum foil, hafnia ring and disc set, vented iridium capsule, iridium wire standoffs, graphite container, iridium wire standoffs, an unvented iridium capsule, tungsten wire standoffs, and two Ta-10W containers to provide additional safety containment during furnace exposure. These are listed as capsules 30 and 31 in Table 2-2 as identified by the GE-IPSO (General Electric - Isotope Power Systems Operation) MHW-RTG Program. The configuration shown on the right utilizes (inside to outside) a low or high oxygen PPO fuel pellet, molybdenum foil, iridium foil, vented iridium capsule, tungsten wire standoffs, and three Ta-10W containers with the innermost acting as an oxygen getter. Capsules 32, 33, 34, and 35 will be in this configuration. The third configuration which uses portions of the other configurations is indicated by asterisks. In this configuration, the low oxygen PPO fuel pellet is wrapped in molybdenum foil, a hafnia ring and disc set, a vented noble metal capsule, tungsten wire standoffs, and three Ta-10W containers with the innermost acting as an oxygen getter. Capsules 28 and 29 will use a vented iridium container, capsule 36 will use a vented Pt-30Rh container, and capsule 22 will use a vented Pt-Rh-W alloy container.

Quotations have been requested for all major capsule components, and some orders have been placed. Delivery of components is expected in February. The fuel should be available from Los Alamos Scientific Laboratory in early February. Encapsulation will proceed as components become available.

Two ultra-high vacuum furnaces have been used routinely on this program and will continue to be used. A third ultra-high vacuum furnace has been installed, checked out, and is ready for extended operation at 1500°C to provide the increased program capability for this effort.

Section 3

CONCLUSIONS

Efforts in the current quarter included planning and initiating additional compatibility work with PMC, SSC, and PPO fuel, the latter in direct support of the MHW-RTG program.

An analysis of microhardness data obtained to date on plutonia-refractory alloy test capsules indicates the following.

1. Refractory alloys are harder after exposure at 2000° than 1800°C probably attributable to greater solubility of oxygen.
2. Refractory alloys are harder after exposure at 2000°C in contact with $\text{PuO}_{2.0}$ than $\text{PuO}_{1.8}$ probably attributable to the greater amount of oxygen present from the $\text{PuO}_{2.0}$.
3. Refractory alloys are softer in contact with pure plutonia than with the original plutonia because the metal impurities originally present in the fuel transfer to and diffuse into the refractory metal causing an additive effect on hardness.
4. Refractory alloys soften by annealing during exposure from the original as-worked structure which is only partially offset by the hardening caused by the diffusion of oxygen and metallic impurities from the fuel.
5. Plutonia microhardness was generally random with a minor increasing trend with decreasing oxygen content.

Conclusions concerning plutonia compatibility reached prior to the current quarter include:

1. The most compatible test combination evaluated to date is pure $\text{PuO}_{1.8}$ in contact with Re. W-25Re is almost as good under the same 2000°C 1000-hr exposure conditions.
2. Maximum penetration into any of the refractory metals in contact with pure plutonia was less than 4 mils at both 2000°C for 1000 hr and 1800°C for 2000 hr. Preliminary calculations assuming a diffusion controlled Arrhenius relationship indicate the same penetration would take 10 times as long at 1400° as at 2000°C.
3. Refractory metals are more compatible with the purer grade of plutonia when compared to the original less-pure plutonia.
4. Substoichiometric plutonia is less reactive than PuO_2 in contact with W, W-25Re, and Re.

5. Oxygen loss occurred through all container walls except possibly rhenium. W and W-25Re did not permit measurable loss at 1800° but did at 2000°C. Oxygen loss through molybdenum-containing alloys was a direct function of molybdenum content.
6. Compatibility of molybdenum-containing alloys with stoichiometric $\text{PuO}_{2.0}$ was not determined because of loss of oxygen through the container walls. This oxygen loss may have been responsible for minimizing the reactions between plutonia and the molybdenum-containing alloys.
7. Metallic precipitates present in the plutonia appear to be functions of molybdenum content of the alloys and plutonia purity, with plutonia purity having the more dominant effect.
8. Vapor-phase transport of refractory metal from hot to cold surfaces occurred only when stoichiometric PuO_2 was contained in W or Re. It is believed that Mo-base alloys would have transported if oxygen loss had not occurred so rapidly through the container walls.

Conclusions reached concerning the Battelle-Columbus Laboratories plutonia-molybdenum cermet include:

1. Approximately 40% of stored helium is released from plutonia-molybdenum cermets heated to 1800° or 2000°C for 1000 hr in closed containers.
2. A plutonia-molybdenum cermet exposed at 1800°C for 1000 hr in a closed container was relatively undamaged while a similar cermet exposed at 2000°C for 1000 hr was badly damaged.

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