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SUBJECT: Technical Highlights of Space and Terrestrial Systems Programs at Oak Ridge National Laboratory for September 1980

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FROM: R. H. Cooper

This monthly report is intended to inform the Space and Terrestrial Systems Division, DOE, and their contractors of significant technical highlights of technology and systems support programs in progress at Oak Ridge National Laboratory. A detailed technical presentation of information will be published in topical reports and open literature publications.

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SOLAR-POLAR MISSION MATERIALS SUPPORT

(Activity AE 15 15 20 0, WPAS 02313)

R. L. Heestand

The purpose of this task is to provide direct materials support on work specific to the General Purpose Heat Source (GPHS) design. The scope of this work includes (1) determining the impact properties and optimum weld parameters for the DOP-26 iridium alloy fuel cladding material, (2) thermal conductivity and emissivity data on cladding and thermal insulation materials, (3) fabrication and characterization of test samples of carbon-bonded carbon-fiber (CBCF) insulation developed by ORNL and Y-12 which may be used for GPHS, and (4) determination of creep properties of the 2219 aluminum alloy housing. Data on the impact properties and welding of iridium are integrated with complementary work reported in the Materials Technology section of this report.

CBCF-3 Insulation Fabrication (J M Robbins)

During the September 9, 1980, Heat Source Review Meeting held at DOE, ORNL received an action item to submit all procedures associated with the CBCF fabrication process to Mound Facility by September 30, 1980. In addition to the fabrication process, these are to include determination of the room temperature thermal conductivity reported in the next section, and preparation of a radiographic sensitivity standard. All the above were completed with the exception of determination of the radiographic techniques using the sensitivity standard.

CBCF sleeves previously supplied to machining contractors and intended for the safety verification tests were recalled due to excessive density of the characterization samples. All nine parts were found to have densities greater than 0.23 Mg/m^3. In addition, the sleeves machined for the impact and aging tests were also found to be high in density.

To replace the above parts, four additional molding runs, C-27 through C-30, were made. Little or no cracking of the parts was noted during carbonization. To qualify machining, parts from these runs will be machined at Thermo Electron Engineering, Eagle Picher, and Teledyne.

A major difficulty in the CBCF activity is the inability to machine and inspect dimensionally acceptable parts. To solve this problem, a machining tool for beveling, similar to that used at GE, will be built and an electronic device for measuring length has been developed. Initial evaluation of the measuring device indicates considerable improvement in reproducibility. The device is currently being evaluated at other facilities in the GPHS community. The high capacity vacuum pump installed last month is adequate but not specifically designed for handling large volumes of water vapor on a continuous basis. A new liquid-ring vacuum pump has been ordered as a replacement.

CBCF-3 Characterization (G. C. Wei)

Least squares fit of 46 data points of thermal conductivity in vacuum (21 data points at RT, 21 data points at 2000°C, 2 data points at 800°C, 2 data points at 1400°C) of outgassed ORNL-processed CBCF-3 parts (C-6s, C-15s, C-16s, C-18s, C-20s, P-C-2, and P-3s) with densities ranging from 0.201 to 0.245 E3 kg/m^3 described in last monthly report showed the following relationship:

$$k_V = -0.06988 + 7.543 \times 10^{-5}\,T - 1.200 \times 10^{-11}\,T^3 + [0.4364 + 2.128 \times 10^{-4}\,T + 4.000 \times 10^{-11}\,T^3]\rho$$

where

k_V = thermal conductivity in vacuum (W/m·K),
T = temperature in Kelvin, and
ρ = density in E3 kg/m^3.

This represents about 30% increase over previous data. This change is due to the higher carbonization temperature (1600°C) used in the fabrication of ORNL-processed CBCF-3. The increased carbonization temperature is required for dimensional stability during 1500°C/36 h outgassing.

For thermal conductivity of outgassed CBCF-3 in 0.1 MPa or 1.0 atm nitrogen, the following relation was derived from data for two densities (0.19 E3 kg/m^3, Purdue data, and 0.25 E3 kg/m^3, Dynatech data).

$$k_N = -0.06988 + 7.543 \times 10^{-5}\,T - 1.200 \times 10^{-11}\,T^3 + [0.4364 + 2.128 \times 10^{-4}\,T + 4.000 \times 10^{-11}\,T^3]\rho + [3.816 \times 10^{-3} + 1.7807 \times 10^{-2}\,(\rho - 0.19)]T^{1/2}$$

where

k_N = thermal conductivity in 0.1 MPa or 1.0 atm nitrogen (W/m·K),
T = temperature in Kelvin, and
ρ = density in E3 kg/m^3.

Based on the density data of the ORNL-processed CBCF-3 the density specification should be 0.20 to 0.23 E3 kg/m^3 for a 95% confidence level and a 95% probability. This density specification will correspond to thermal conductivity (at room temperature in vacuum) from 0.045 to 0.072 W/m·K for a 90% confidence level.

Densities of as-fabricated tubes C-27s and C-28s were determined as 0.235–0.242 and 0.224–0.231 E3 kg/m^3, respectively. However, these density values measured on rough billets can only serve as rough estimation of the actual densities. Characterization samples for

precise determinations of density and strength from these billets are being prepared. In response to this situation and at the request of C. O. Tarr, two developmental multi-mandrels runs, C-25 and C-26 which employed a lower binder content (43 wt%) in the formulation of slurry, were performed. The purpose of these two runs was to establish material and processing parameters for a 0.20 E3 kg/m^3-density.

In this period, the tungsten heating elements and molybdenum heat shields of the outgassing furnace were not operating and had to be replaced with new ones for future outgassings of test samples. Quality assurance procedures for sampling, outgassing, thermal conductivity determination, and density and strength measurements were revised and approved. Some CBCF-3 plates were sent to Battelle, Columbus Laboratory for use as insulators in their contact conductance measuring system. Information about pyrolytic graphite coating on FWPF (Fine Weave Pierced Fabric) 3D carbon-carbon was provided to GE (General Electric) for analysis as a design option to achieve acceptable normal operating, peak reentry, and impact temperatures for the iridium capsules.

Creep Properties of 2219 Aluminum Housing Materials (J. P. Hammond)

The purpose of this task is to develop creep and tensile data on the 2219-T6 aluminum forging and to aid GE, Valley Forge, in the design of the shell component of the RTG generator. The essential requirement of the shell will be to firmly retain the RTG generator under elastic stress during ground tests and storage in air (condition II), and subsequent flight in vacuum (condition I).

The creep tests reported on in the technical highlights report for July are continuing. At the request of George Ambrose of General Electric, work was initiated to determine the effects of specific aging treatments on the tensile properties of 2219-T6 aluminum. The test matrix for these tests is shown in Table 1.

Table 1. Aluminum 2219-T6 Tensile Test Matrix

Test No.	Material Condition	Test Parameters		
		Temperature	Direction	Quantity
A-1L A-2L	as received	121°C	L	2
A-1T A-2T			T	2
B-1L B-2L	age 270°C for 100 h	121°C	L	2
B-1T B-2T			T	2
C-1L C-2L	age 270°C for 600 h	121°C	L	2
C-1T C-2T		121°C	T	2
D-1L D-2L	age 270°C for 600 h + 177°C for 100 h	121°C	L	2
D-1T D-2T			T	2

L = parallel to axis of outer shell.

T = hoop direction.

Specimens for tensile tests were machined from the forging from which the creep specimens were taken. Mr. Ambrose suggested that the tests on the longitudinal specimens be evaluated before initiating tests on the transverse specimens. The former tests were completed and the results are presently being examined by GE for impact on the shell design. These results are tabulated in Table 2.

Table 2. Tensile Test Results[a] on 2219-T6 Forging

Test No.	YS (psi)	UTS (psi)	FS (psi)	TE (%)	UE (%)	ROA (%)
A-1L	35,698	49,351	34,990	20.2	7.6	45.5
A-2L	35,622	49,362	35,622	20.4	9.6	46.4
B-1L	24,981	41,636	25,086	19.6	6.9	60.0
B-2L	25,967	42,272	26,671	19.2	6.3	57.0
C-1L	25,343	42,640	27,756	18.3	6.4	53.1
C-2L	24,781	42,336	28,091	18.8	6.4	48.4
D-1L	25,403	42,171	26,507	19.4	5.7	59.4
D-2L	25,342	41,570	28,448	16.4	6.1	50.5

[a]Performed on Instron machine at head speed of 0.05 in./min. YS = yield strength (0.2% offset), UTS = ultimate tensile strength, FS = fracture strength, TE = total elongation, UE = uniform elongation, and ROA = reduction of area. Conditions of test pieces are given in Table 1.

It will be noted that the aging treatments lower the strength properties of 2219-T6 considerably but do not very appreciably effect the ductility.

Iridium Management (R. H. Cooper and W. O. Graves)

Plans have been finalized for a meeting of all personnel associated with Iridium Management for DOE's Advanced Nuclear Systems and Projects Division. The meeting is to be conducted at ORNL on October 30, 1980. The meeting is primarily for representatives from all contractor sites who are associated with business, accounting, and inventory control.

Meetings

R. J. Beaver reviewed CBCF handling procedures and inspection techniques at Mound Facility, September 4–5, 1980.

R. H. Cooper and R. L. Heestand participated in the Heat Source Review at DOE, Germantown, September 9, 1980.

R. H. Cooper, W. O. Harms, and A. C. Schaffhauser presented the Iridium Blank Production Status at DOE, Germantown, September 17, 1980.

R. H. Cooper and A. C. Schaffhauser conducted a briefing for STS at DOE, Germantown, September 30, 1980.

FLIGHT SYSTEMS HARDWARE

(Activity AE 15 20 00 0, WPAS 01322)

D. E. Harasyn

The objective of this task is to supply Mound Facility with flight quality hardware components for use in the assembly of isotope heat sources. The major activity is on fabrication of iridium alloy forming blanks for isotope fuel capsules along with iridium foil for vents, decontamination covers, and weld shields. We have completed fabrication of iridium for the Galileo mission MHW heat source and have initiated fabrication of 1255 iridium blanks and associated foil for Solar-Polar Mission General Purpose Heat Source for delivery in FY 1980 and FY 1981. The task on fabrication of carbon-bonded carbon-fiber (CBCF) thermal insulation for Light Weight Radioisotope Heating Units (LWRHU) has been deleted due to selection of pyrolytic graphite for the application.

Iridium Forming Blank Fabrication (D. E. Harasyn and R. L. Heestand)

Sixty-two forming blanks were fabricated for Mound Facility during the month of September. Discs shipped consisted primarily of rework of "L" blanks and recycle "L" material which should provide six to seven ingots. Due to low impact ductility associated with the "M" batch, a decision was made to put first priority on all other materials in order to continue production with second priority on "M" batch. A 13 kg batch of powder "N" was received in the last quarter of the month and processing on 18 ingots, approximately 108 blanks was initiated. It was also decided at this time to grind all subsequent blanks in order to minimize surface defects. In order to facilitate grinding, tooling was developed and utilized to flatten bare rolled blanks for more efficient grinding. In addition, removal of surface defects by lapping using WC abrasive was demonstrated on twenty reject blanks. This technique is subject to approval by the ORNL material review board.

As a secondary effort, evaluation of "M" material was initiated to determine means of salvaging the batch. This was approached by assembling a team of ORNL personnel to review the problem and continuing fabrication of a series of "M" ingots for the evaluation. High temperature impact elongation results were M-401, 5%; M-406, 10%; and M-411, 12%. Other than impact ductility and an increased number of cracks in the material, other indicators such as powder chemistry, sheet chemistry, grain size, and hardness were normal. These impact values were below those required for GPHS, however the increasing trend shows increased ductility on remelting. Double electron beam melted ingots of "M" material showed an impact ductility of 17% indicating the batch could be recycled through electron beam melting and redoping by arc melting. No reason for this improvement has been determined as no difference in chemical analysis was noted, however the increase in ductility indicates a contaminant is removed on melting.

MATERIALS TECHNOLOGY SUPPORT

(Activity AE 15 35 00 0, WPAS 01495)

C. T. Liu

The primary objective of this task is to characterize and improve the metallurgical and mechanical properties of noble base alloys, mainly DOP-26 (Ir-0.3% W doped with 60 ppm Th and 50 ppm Al), to meet the requirements of cladding material in radioisotope heat resources for the Galileo and Solar-Polar space missions. The current efforts are concentrated on four areas: (1) to characterize the impact properties of Ir alloys in the temperature range 800–1400°C, (2) to improve the low-temperature impact properties of welds in the DOP-26 alloy, (3) to identify the mechanism and sources that degrade the mechanical and metallurgical properties of doped Ir alloys under heat-source environments, and (4) to develop ductile high-temperature alloys acceptable for future flight missions.

Effect of Laser-Marking on Impact Ductility of DOP-26 Alloy (C. T. Liu)

GPHS capsules were marked with a 4-digit identification number by laser beam. To evaluate the effect of laser marking on impact ductility, tensile specimens L-243-2-B were heat-treated for 19 h at 1500°C, marked with a number of 2432 at Mound Lab., and then impacted at 980°C and 61 m/s (200 fps) at ORNL. The specimen had an impact elongation of 15.3%, indicating that laser marking does not affect the impact properties of DOP-26 alloy at 980°C.

Impact Properties of DOP-26 Production Sheets (C. T. Liu)

Impact Properties of DOP-26 production sheets L-294, L-298 and LR-300 were evaluated for flight systems hardware. In order to eliminate the source of zirconium contamination, the alloy ingots were prepared by arc melting without using a zirconium getter. The impact specimens prepared from the sheets were annealed 19 h at 1500°C and then impacted at 980°C and 61 m/s. The impact data are presented in Table 3 together with those on other L sheets. The impact data of L-294, L-298 and LR-300 fall in the same range of other L sheets, indicating that the impact ductility is not affected by zirconium getter. The average impact elongation of all L sheets is 17.9 ± 3.2% at 980°C.

Our previous work indicated that the impact ductility of M lot was distinctively lower than that of L lots when impacted at 980°C and 61 m/s. We currently evaluated the impact properties of M sheets produced from double electron-beam melts (i.e. electron-beam melt for 8 times prior to arc melts) or multiple arc melts (i.e. arc melts for 12 times prior to drop-casting). The impact data are present in Table 4 together with those on M and L sheets produced from normal electron-beam and arc melts. Table 4 indicates that the M sheets produced from normal electron-beam

Table 3. Tensile Impact Data on L-Batch DOP-26 Production Sheets Tested at 980°C and 61 m/s (200 fps)

Sheet Number	Uniform Elongation (%)	Average Elongation (%)	Remarks
L-216	18.7, 19.8	19.3	Surface Inclusions
LR-231	20.4		IRG-87
LR-238	16.8		
L-242R	19.8		IRG-88
L-243	15.3		Laser Marked, IRG-87
L-246	16.7		
L-261	15.2		
L-264	17.8, 19.9	18.9	C-Brale Indentions
L-268	15.5, 14.7	15.1	Linear Liquid Penetrant Indications
L-275	18.3		Fe = 200 ppm, Cr = 70, Ni = 40
L-294	21.0		No Zr Getter
L-298	15.9		No Zr Getter
Lr-300	20.7		No Zr Getter
	Total	17.9 ± 3.2	

Table 4. Effect of Melting Procedure on Impact Ductility of M-Batch DOP-26 Production Sheets (Test Condition = 980°C and 61 m/s)

Sheet Number	Impact Elongation (%)	Remarks*
M-422	14.8 17.9 18.8	Double EB & normal arc melts
M-423	15.5	Double EB & normal arc melts
M-425	12.8	Normal EB & multiple arc melts
M-426	13.7	Normal EB & multiple arc melts
M-401 -406 -411 -415 -427	Avg. 9.3	Normal EB & arc melts
L-Sheets	Avg. 17.9	Normal EB & arc melts

*Normal EB melt: EB melt for 4 times.
Double EB melt: EB melt for 8 times.
Multiple arc melt: arc melt for 12 times.
Normal arc melt: arc melt for 5 ~ 6 times.

and arc melts have the lowest impact elongation (avg. 9.3%) while the M sheets from double electron-beam melts and normal arc melts have the best elongation (avg. 16.8%). In fact, the double electron-beam melts raise the impact ductility of M sheets to a normal level, i.e. 17.9 ± 3.2%, which has been established based on impact of L sheets. Comparison of the results suggests that the low impact ductility of M sheets is probably due to harmful impurities in M-batch powder and that the impurities can be essentially removed by double electron-beam melts.

Development of Laser Welds (S. D. David)

We have continued to make DOP-26 butt welds using 6 KW laser power at a welding speed of 75 cm/min for impact property evaluations. The welds were made using an AVCO High Power Laser system. The welds were made by operating the laser in an annular beam mode with F-18 telescope for beam focusing. The welding fixture was modified to minimize distortion during welding. The welds were narrow and with minimum distortions.

For the future laser welding work is being planned to evaluate fusion zone refinement by beam oscillation and vibration of the work piece during welding.

Molybdenum Base Alloys (H. Inouye)

Exploratory work to determine whether molybdenum can be used as the cladding for the RTG fuel has continued. Currently the work emphasizes the impact properties between 400 and 1350°C. Table 5 shows no difference between the impact ductility of electron-beam welded specimens and the base metal at 1350°C and only a slight reduction in the temperature range 600–980°C. Table 6 similarly shows very small differences in the ductility of the base-metal after annealing at 1200 or 1500°C. These results indicate that the impact ductility of molybdenum is insensitive to the impact temperature, grain size, and is virtually unaffected by welding.

Table 5. Comparison of the Impact Ductility of Electron Beam Welded Molybdenum Specimens with the Base Metal[a]

Impact Temperature at 85 m/s (°C)	Elongation (%)	
	Base Metal	E. B. Welded[b]
600	35.0	33.7
800	37.8	27.5
980	46.7	33.4
1350	38.2	38.3

[a]Annealed 1 h at 1500°C.

[b]Transverse welds in 0.51 mm thick sheet.

Table 6. Effect of Annealing Temperature on Impact Ductility of Molybdenum

Impact Temperature at 85 m/s (°C)	Elongation (%)	
	Annealed 1 h at 1200°C	Annealed 1 h at 1500°C
400	34.9	
600	25.6	35.0
800	38.7	37.8
980	—	46.7
1350	37.2	38.2

TERRESTRIAL RADIOISOTOPE APPLICATION DEVELOPMENT

(Activity AE 15 35 00 0, WPAS 01367)

F. N. Case, K. W. Haff, and F. J. Schultz

Cesium-137 Low Solubility Compounds

Leaching of the unsectioned, fully loaded ^{137}Cs aluminosilicate pellets continued this month. The leach rates are given below in Table 7.

Table 7. Unsectioned, Fully Loaded Cesium-137 Aluminosilicate Pellet Leach Rates

Sample No.	Leaching Period Interval (days)	Accumulated Leaching Period (days)	Leach Rate ($kg/m^{-2} \cdot s^{-1}$)
1-16	3.043	13.968	2.187×10^{-12}
1-17	3.026	16.994	1.546×10^{-12}
1-18	4.926	21.920	3.808×10^{-12}
1-19	3.050	24.970	2.483×10^{-12}
1-20	6.988	31.958	2.248×10^{-12}
2-16	3.052	13.928	6.535×10^{-12}
2-17	3.024	16.952	1.806×10^{-12}
2-18	4.927	21.879	3.579×10^{-12}
2-19	3.050	24.929	2.664×10^{-12}

The leach rates obtained from sample pellet 1 appear to be at or near steady-state. However, the leach rates obtained from sample pellet 2 are decreasing but have not attained a constant or near-constant value.

Leaching of the sectioned, fully loaded ^{137}Cs aluminosilicate pellets in the Soxhlet extractors continued this month. The leach rates of each pellet are presented in Table 8.

The Soxhlet leach rates obtained to this date are slightly decreasing but have not yet attained steady-state values.

Leaching of the irradiated tracer level ^{137}Cs aluminosilicate pellets in Soxhlet extractors continued this month. Malfunctioning of the ND-4420 gamma-ray spectrometer system, however, prevented assaying of the tracer level samples. These leach rates will be reported next month.

Results from X-ray diffraction studies of stable and fully loaded ^{137}Cs aluminosilicate pellet sections confirms the pollucite crystal lattice structure. A comparison of the three most intense sample lines measured with the three most intense known pollucite ($CsAlSi_2O_6 \cdot nH_2O$) spectral lines is given in Table 9.

Table 8. Soxhlet Leach Rates of Fully Loaded Cesium-137 Aluminosilicate Pellets

Sample No.	Sampling Period Interval (days)	Accumulated Leaching Period (days)	Leach Rate ($kg/m^{-2} \cdot s^{-1}$)
5-10/25	6.901	47.226	4.18×10^{-9}
5-11/25	12.974	60.200	4.61×10^{-10}
6-10/25	6.901	47.226	3.15×10^{-9}
6-11/25	12.974	60.200	1.10×10^{-9}
7-10/25	6.901	47.226	5.64×10^{-10}
7-11/25	12.974	60.200	7.16×10^{-10}
8-10/25	6.901	47.226	3.23×10^{-9}
8-11/25	12.974	60.200	3.44×10^{-9}

Table 9. Comparison of Sample Cesium Aluminosilicate and Cesium Pollucite Spectral Line Positions

Sample Crystal Lattice Spacing (Å)	Pollucite Crystal Lattice Spacing* (Å)	Normalized Intensities (I/I_1)
2.91	2.913	45
3.42	3.42	100
3.65	3.65	30

*Obtained from Joint Committee on Powder Diffraction Standards, 1975, card file 25-193 and 25-194.

Krypton-85 Light Source Development

A meeting was held at ORNL with Air Force and DOE personnel to discuss the scope of work required to meet Air Force contracting requirements.

A technical committee with representatives from General Electric Lighting Laboratory, National Bureau of Standards, Wright-Patterson Air Force Base, and Tyndall Air Force Base was established and the first meeting will be held at DOE Headquarters in October. This committee will provide guidance in phosphor technology, light measurement and optics, and serve for the term of the work effort.

A spherical type quartz capsule was fabricated and will be used to test the potential for small intense high pressure sources.

A technology transfer document is in final stages of preparation. Editing and review by the Air Force is required before distribution.

BENEFICIAL APPLICATIONS OF RADIATION TECHNOLOGY

(Activity AE 15 35 00 0, WPAS BART001)

C. S. Sims

The BART document entitled Program Plan and Funding Requirements for FY 1981, ORNL/CF-80/277, was distributed in mid-September.

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