19. Materials Development for Isotopic Power Programs

R. G. Donnelly

Research and development on materials for encapsulation of isotopic power fuels is being carried out for space and terrestrial (including undersea) applications. The space oriented programs are: Curium-244 Isotopic Power Fuels and Materials Development and Cladding Materials for Space Isotopic Heat Sources. The terrestrial power programs include: Strontium-90 Isotopic Power Technology, SNAP-21 System Support – Radioisotope Fuel, SNAP-23 System Support – Radioisotope Fuel, and the Isotope Kilowatt Program.

On the Curium Program, the immediate concern is for thermionic generator applications in the range of 1600 to 2000°C, but we are also interested in high-temperature SiGe thermoelectric and Brayton Cycle conversion applications in the range 900 to 1400°C. Because of the high temperatures involved, we are primarily engaged in testing refractory metals and alloys that might operate in contact with an oxide fuel ($^{244}\text{Cm}_2\text{O}_3$) and in a space environment.

The Cladding Materials Program is concerned with the evaluation of Haynes alloy No. 25, which has been the capsule material of primary use on low-temperature (<900°C) space thermoelectric generators. In addition, we have undertaken to develop improved encapsulation materials, which meet not only operating requirements but the much more stringent safety criteria that require the fuel capsule to survive the extreme conditions of launch-pad abort, earth reentry, and postreentry.

The purpose of the Strontium Program is to select optimum encapsulating materials and develop capsule sealing techniques for ^{90}Sr -fueled isotopic heat sources designed to power thermoelectric generators. These generators require fuel capsule operation at temperatures to about 1000°C for extended periods of time. Iron-, nickel-, and cobalt-base alloys are the primary candidate encapsulation materials.

The SNAP-21 generators are designed for undersea applications, and the SNAP-23 generators are for on land. Qualified and reproducible welding and inspection procedures are necessary to better ensure the integrity

of the fuel containers for both normal and possible accident conditions.

On the Isotope-Kilowatt Program design study, an evaluation of thermal electric converter concepts for large-scale 2 kw(electrical) uses was undertaken. We also provided consultation on materials and fabrication.

CURIUM PROGRAM

Sublimation of W–25% Re in Low-Pressure Oxygen¹

R. L. Wagner

The alloy W–25% Re is a candidate container material for nuclear oxide fuels. Data on its stability in low-pressure oxygen (<10⁻⁴ torr) to temperatures approaching 2000°C are desirable to qualify the alloy for thermionic conversion applications.

The sublimation characteristics of 0.040-in. resistively heated W–25% Re wires were determined between 1650 and 1950°C in the pressure range of 10⁻⁷ to 10⁻⁴ torr of oxygen. Tungsten is preferentially lost as volatile oxides under all conditions, and at higher pressures a surface layer of the tungsten-rhenium sigma phase is formed.

At a given temperature the sublimation rate increases with pressure; however, at a given pressure the rate exhibits a maximum as a function of temperature. Weight loss data show that container wall removal rates of 2×10^{-5} in./hr are possible at 1850°C and 3×10^{-5} torr of oxygen. This rate is $2\frac{1}{2}$ orders of magnitude greater than in vacuum. The pickup of oxygen is negligible and the exposed wires are bright and free of surface oxide, indicating that oxide vaporized as soon as it was formed.

¹ Abstract of paper to be presented at the AIME Meeting in Philadelphia, October 13–16, 1969.

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Effect of Low-Pressure Gases on the Creep Properties of Refractory Metals²

H. Inouye

The creep behavior of tungsten and W-50 wt % Mo alloy during their interaction with 10^{-5} and 10^{-6} torr oxygen was determined between 1500 and 2000°C to simulate interaction of cladding with oxide fuel in a thermionic device. The results were compared with their creep behavior at a base pressure of 10^{-8} torr. The creep rates of these metals were up to 4.4 times as high in oxygen as at the base pressure. The reversibility of the creep rates during cycling between the base pressure and in oxygen suggests that the creep degradation results from either dissolved oxygen or an enhanced growth rate of cavities. Stress-induced sublimation and the preferential loss of tungsten were observed.

Mechanical Properties of Capsule Materials

R. W. Swindeman R. L. Stephenson

Creep experiments are usually performed at constant load and temperature. In actual service, materials are usually subjected to varying stresses and temperatures. A capsule containing an alpha-emitting isotope is subjected to an increasing stress as a result of helium release and a decreasing temperature as a result of the decay of the isotope. We need to predict the integrity of such capsules for several half-lives of the isotope to avoid significant activity release. We therefore sought to devise a method of determining from conventional creep data the life of a capsule under predictably varying conditions of stress and temperature.

We developed an analytical model that uses conventional creep data taken at constant load and temperature, to predict failure times under conditions where stress and temperature vary according to simple, monotonic functions of time. The validity of this method has been examined experimentally for T-111 at an initial temperature of 1315°C. The results are shown in Fig. 19.1. The dashed line represents the predicted failure times for a linearly increasing stress and an exponentially decaying temperature.³ The circles represent experimental determination under these condi-

tions. The solid line was predicted from the same temperature function but a stress that increased at a decreasing rate. (This condition would prevail where complete release of helium from the fuel was observed.) The triangles represent the experimental duplication of these conditions. In both cases, the agreement is gratifying.

Compatibility

J. R. DiStefano

For thermionic applications of $^{244}\text{Cm}_2\text{O}_3$ heat sources at temperatures of 1650°C and higher the choice of container materials is limited to high-strength refractory metals and alloys. The materials chosen for

Fig. 19.1. Rupture Life of T-111 as a Function of Initial Stress Rate for a Constant Stress Rate and for a Decreasing Stress Rate. In both cases the temperature is decreased exponentially from 1315°C.

² Abstract of paper to be published in the transactions of Vacuum Metallurgy Conference 1969.

³ R. W. Swindeman and R. L. Stephenson, *Metals and Ceramics Div. Ann. Progr. Rept. June 30, 1968*, ORNL-4370, pp. 92-93.

investigation were Ta, Ta-10% W, T-111, Mo, TZM, W, and W-26% Re, and the test system is shown schematically in Fig. 19.2. Tests have been conducted for 1000 hr at 1650 and 1850°C and evaluated. Now in progress are tests for 10,000 hr at 1650°C and 5000 and 10,000 hr at 1850°C.

For applications of $^{244}\text{Cm}_2\text{O}_3$ at lower temperatures such as in thermoelectric or Brayton-cycle devices we have also begun to determine the compatibility of potential container materials. Because of the complexity in interpreting tests involving radioactive components, a range of materials including several pure metals that are major components in alloys of interest have also been included as well as some binary systems.

Tests now under way include capsules of Ni, Ni-10% Cr, Ni-20% Cr, Co-10% Cr, Hastelloy C, Hastelloy N, and Haynes alloy No. 25, and these are scheduled to operate for 1000 hr at 750°C. A second series of materials to be tested for 1000 hr at 1200°C includes Nb, Nb-1% Zr, Ta, Ta-10% W, Mo, V, and Zr.

Welding Development for Compatibility Program

G. M. Goodwin R. W. Gunkel

We have successfully developed conditions for seal welding the 750°C, 1000-hr (Hastelloy C, Hastelloy N, Haynes alloy No. 25, Ni, Ni-10% Cr, and Co-10% Cr)

Fig. 19.2. Curium Compatibility Capsule Test System.

and 1200°C, 1000-hr (Zr, V, Nb, Mo, Ta, Ta-10% W, and Nb-1% Zr) compatibility test capsules.

We used a program-controlled power supply, ensuring reproducibility of test results with a minimum possibility of operator error. The entire welding sequence, including initial current, upslope time, welding current, welding time, downslope time, and rotational speed, is automatically controlled.

The procedures and conditions developed were used successfully in the glove-box encapsulation of $^{244}\text{Cm}_2\text{O}_3$ in these materials.

Brazing Alloy Development

N. C. Cole D. A. Canonico

In fabricating an isotopically powered thermionic generator, brazing has several advantages for certain applications.⁴ It is ideally suited for joining small parts in regions of limited access. Also, the efficiency of such a generator depends on good heat transfer from the capsule to the emitter. A continuous metallurgical bond, as can be obtained by brazing, enhances this heat transfer. We have developed several braze alloys, listed in Table 19.1, most of which meet the stringent requirement that they wet and flow on tungsten between 2000 and 2400°C. For the joint between the capsule and emitter, stability in vacuum at high temperature is required. A simulated capsule-to-emitter joint brazed with several of these alloys was designed and tested in vacuum at 1650°C for 100 hr. Three brazing alloys (Nb-25% Ir-25% W, Nb-3% Ti-2% Ir, Nb-2% Ti-1% Si) survived the vacuum exposure with no appreciable weight loss from vaporization.

Chemical Vapor Deposition of Test Components

W. C. Robinson, Jr.⁵

Several tungsten components, shown in Fig. 19.3, were prepared by chemical vapor deposition for evaluating the design of heat sources. The capsule in (a) measured about 2.5 in. long $\times$ 0.7 in. diam $\times$ 0.065 in. wall thickness, had an integral tube, and was made for pressure testing. In a first attempt to prepare the capsule, tungsten deposited on a copper substrate cracked during cooling to room temperature because of

⁴N. C. Cole and D. A. Canonico, *Metals and Ceramics Div. Ann. Progr. Rept. June 30, 1968*, ORNL-4370, p. 94.

⁵Present address, Lockheed California Co., Burbank, Calif. 91503.

Fig. 19.3. Chemically Vapor Deposited Tungsten Components for Isotope Capsules and Related Studies. (a) Capsule with integral pressurizing tube. (b) Capsule vent tube. Half size. (c) Vapor transport test tube. Full size.

a difference in thermal contraction. The capsule was then successfully deposited on a molybdenum substrate, which was removed by acid dissolution. Creep-rupture testing was conducted at 1650°C by pressurizing with helium. The maximum circumferential strain was 11%.

Five vent tubes (b) measuring 0.122 in. ID $\times$ about 0.02 in. wall were prepared for a study of problems involved in welding such tubes to capsules and to other materials. Seven loop tubes (c) measuring 0.25 in. ID $\times$ about 0.025 in. wall were also deposited. After end closures are made the vapor transport of Cm_2O_3 from the loop into the cooled straight section will be studied.

Fluid-Bed Coating for Isotopic Fuel Particles

W. C. Robinson, Jr.⁵ J. I. Federer

Metal coatings on isotopic fuel particles could aid in controlling contamination, inhibiting gas release, acting as a binder in pressed compacts, and increasing the thermal conductivity of a fuel form. Coatings are being applied by CVD in a fluidized bed. So far, only tungsten and tantalum coatings have been studied. Sol-gel ThO_2 microspheres were used as a substitute for isotopic fuel particles, such as Cm_2O_3 , Pm_2O_3 , and SrTiO_3 . Tungsten coatings 10 to 15 μ thick were

Table 19.1. Experimental Brazing Alloys

Composition (wt %)	Approximate Melting Temperature (°C)
Nb-25Ir-25W	2400
Nb-3Ti-2Ir	2400
Ir-30Pt	2250
Nb-3Ti-1Si	2400
Nb-2Ti-2Si	2400
Nb-2Ti-1Si	2400
Nb-3Ti-2Si	2400
Ir-45Pt-10W	2200
Ir-50Rh	>2400
Mo-25Ir-25W	>2400
Ir-45Rh-10W	>2400
Pt-30W	2300
Pt-15Re-15W	2250
Pt-45Rh-10W	2150
Pt-50Rh	2050

successfully applied to ThO_2 microspheres by hydrogen reduction of WF_6 at about 600°C . Typical coated particles are shown in Fig. 19.4. Efforts to apply tantalum coatings by hydrogen reduction of TaCl_5 have been less successful. Reduction of TaCl_5 requires temperatures in the range 900 to 1000°C to achieve reasonable deposition rates. Only extremely thin or very rough tantalum coatings have been obtained, and gross losses of ThO_2 were observed.

CLADDING MATERIALS PROGRAM

Mechanical Properties of Haynes Alloy No. 25

R. W. Swindeman

Superalloys have potential as canning materials for isotopic heat sources that operate in the 650 to 870°C range. However, the heat source could be exposed to conditions that differ from those of normal operation for superalloys, and some supplementary data are desirable on these materials to assure reliable design. We are collecting short-time creep-rupture data in the range 980 to 1200°C , suitable for use in the safety analyses pertaining to launch pad abort and sub-orbital re-entry situations. Also of interest in this respect are the impact and tensile properties of aged superalloys. We are also concerned with the long-time creep-rupture behavior of weldments at operating temperatures in the 650 to 870°C range.

Creep-rupture data for a cobalt-base superalloy, Haynes alloy No. 25, are summarized in Fig. 19.5. Literature data on five heats of base metal are correlated in (a) over the range 650 to 1050°C by the Manson-Haferd parameter. Our data on three heats are compared in (b) to the 99% confidence band from (a). Weldment data in (b) were obtained on sheet specimens that include base metal and a transverse TIG weld in the test section. The weldments apparently are about as strong as the base metal. However, most weldments failed near the fusion line in the 650 to 870°C range.

The effect of aging at several temperatures on the tensile properties of Haynes alloy No. 25 is illustrated in Fig. 19.6. After aging at 700°C for 2000 hr we find an appreciable increase in the yield and ultimate strengths and a corresponding loss of ductility. A less dramatic increase in strength occurs after the 800°C age. Losses in ductility occur at all temperatures. When tensile tests are performed at the aging temperatures, similar changes in strength are apparent. Ductility is a minimum at 700°C and improves at 800 and 850°C .

Fig. 19.4. Sol-Gel ThO_2 Microspheres ($400\ \mu$ in diameter) Coated with 10 to $15\ \mu$ Tungsten in a Fluidized Bed. $75\times$.

Fig. 19.5. Comparison of the Rupture Strength of Haynes Alloy No. 25 Weldments with the Scatterband Generated by Rupture Tests on Base Metal. Time-temperature correlation is based on the Manson-Haferd parameter, $P_{MH} = \log \text{time} + ST_{\circ}C$.

The properties of aged specimens are affected by the composition and morphology of the precipitating phases. Of these, the precipitation of the Laves phase Co_2W is generally considered⁶ to be the embrittling reaction at 800 and 850°C. The pronounced aging response at 700°C is possibly associated with the precipitation of an ordered hexagonal structure,⁷ β - Co_3W .

Interaction of Stress and Vacuum on Properties of Superalloys at Elevated Temperatures⁸

D. T. Bourgette

Capsules of Haynes alloy No. 25 for the containment of isotopic oxide fuels in space power devices might be exposed to high vacuum while under stress. High evaporation rates exhibited by this alloy in vacuum necessitate the determination of its creep behavior in

this environment in terms of evaporation losses, wall thickness, stress, and temperature. Creep tests were conducted in high vacuum, argon, and air at 785°C and stress levels of 2000 to 15,000 psi on specimens 0.007, 0.012, 0.030, and 0.060 in. thick. Additional tests were conducted with 0.030- and 0.060-in.-thick specimens at 900°C in vacuum and argon. The creep life of this alloy at 785°C in vacuum is improved with an increase in thickness at all stress levels; however, the life in argon and air is greater than in vacuum for thicknesses of

⁶S. T. Wlodek, "Embrittlement of a Co-Cr-W (L-605) Alloy," *Trans. Am. Soc. Metals*, 56, 287-303, 1963.

⁷N. Yukawa and K. Sato, "The Correlation Between Microstructure and Stress Rupture Properties of Co-Cr-Ni-W (HS-25) Alloy," *Trans. Japan Inst. Metals Supplement*, 9, 680-86, 1968.

⁸Abstract of paper to be presented at Fall Meeting of AIME in Philadelphia, Oct. 13-16, 1969.

Fig. 19.6. Effect of Aging for 2000 hr on the Tensile Properties of Cobalt-Base Haynes Alloy No. 25.

0.030 in. and less. The creep behavior of 0.060 in. specimens in vacuum and argon is the same at 785°C over a test period of 2000 hr. This behavior indicates that a significant fraction of the specimen volume was affected by evaporation losses in the thinner vacuum-tested specimens. Literature values from creep tests in air and data from current vacuum tests at 900°C indicate that increased evaporation losses decrease the creep life more severely than the 115°C increase in in-test temperature.

Evaporation of Superalloy Capsule Materials in Vacuum⁹

D. T. Bourgette

The evaporation behavior of stainless steels, superalloys, and refractory alloys was studied. Haynes alloy No. 25 and type 316 stainless steel were tested at 760 to 1150°C and 10^{-10} to 10^{-7} torr for times to 3500 hr. The role of composition was determined by comparing the evaporation results and microstructures after 700-hr tests conducted at 870 and 980°C on these alloys and Hastelloy N, Inconel, and types 304 and 446 stainless steel. The evaporation rates increased with increasing chromium and manganese concentrations and temperature, but for any given alloy the rate decreased with time at constant temperature.

Evaporation resulted in surface enrichment of the less volatile elements and bulk changes in alloy composition. The loss of more volatile elements became diffusion-rate dependent. This evaporation mode eventually resulted in subsurface void formation, concentration gradients, and characteristic changes in the microstructure of each alloy.

The creep-rupture properties of a 0.102-cm-thick sheet of type 316 stainless steel tested in argon in the as-received condition were changed significantly after exposure to vacuums of 10^{-7} to 10^{-9} torr for times to 5000 hr at 870°C, but these changes were attributed to precipitation of carbides and *chi* and *sigma* phases. Haynes alloy No. 25 is being tested at 800°C and 10^{-8} torr while under creep stresses of 2500 to 15,000 psi to ascertain the effect of stress on evaporation behavior. Initial results show that (1) evaporation losses increase with stress, (2) the rate of Laves phase precipitation is enhanced, and (3) rupture occurs sooner than for air-tested specimens.

Tests of evaporation and interstitial stability on second-generation tantalum- and niobium-base alloys in high vacuum at 1200 to 1500°C showed that no serious evaporation problems exist below 1300°C. However, carbon was unstable above 10^{-7} torr and oxygen and nitrogen were unstable at all pressures investigated.

Development of Improved Alloys

C. T. Liu H. Inouye

Alloys for containing radioisotopes in space power devices are being developed to circumvent many of the shortcomings of existing alloys. The evaporation rates of binary alloys of cobalt, nickel, or iron with platinum between 950 and 1050°C at about 10^{-7} torr vacuum decreased as the platinum concentration increased and were one-tenth to one hundredth that of Haynes alloy No. 25. Surface platinum concentration, calculated from the vapor pressure of the alloys and the activity coefficients of the evaporating species, increased due to the preferential evaporation of the solvent (Co, Ni, or Fe). The surface platinum concentration was calculated to be about 100% in CoPt after 500 hr at 1050°C.

Long-range order in Ni_3Co , $(\text{Co,Ni})_3\text{V}$, Fe_3Pt , and CoPt increased their tensile strength, yield strength, and hardness and reduced the ductility. In the ordered state, these properties showed little tendency to change when aged at high temperatures. The strongest alloy, $(\text{Co,Ni})_3\text{V}$, in the ordered state had the following room-temperature tensile properties: ultimate tensile strength, 183,000 psi; yield strength, 117,000 psi; elongation, 14%; Rockwell "C" hardness, 37. The corresponding values in the disordered state (obtained by water quenching from $\sim 1150^\circ\text{C}$) were: UTS, 134,000 psi; YS, 67,000 psi; E, 63%; Rockwell "C" hardness, 10. The increase in the tensile strength is attributed to the formation of numerous micro-twins not resolved by the optical microscope.

The creep rates of ordered alloys between 700 and 1000°C were initially very low and steadily increased with time to a steady-state value, a behavior that is opposite to the first-to-second stage creep transition in conventional alloys. The logarithm of strain rate showed a discontinuous change at the critical ordering temperature T_c . Extrapolation of the creep data of the disordered alloys below T_c gave creep rates significantly higher than the measured rates. An activation energy for creep of 85 kcal was calculated for ordered $(\text{Co,Ni})_3\text{V}$, compared to 95 kcal for evaporation (assumed to be diffusion controlled). Preliminary creep tests indicate that $(\text{Co,Ni})_3\text{V}$ and CoPt are equal in strength or superior to Haynes alloy No. 25 in vacuum.

⁹Abstract of paper presented at 1968 AIME Nuclear Metallurgy Symposium on Materials for Radioisotope Heat Sources Oct. 2-4, 1968, Gatlinburg, Tenn.

STRONTIUM PROGRAM COMPATIBILITY STUDIES

J. R. DiStefano

Compatibility of the strontium compounds SrTiO_3 , Sr_2TiO_4 , and SrO with Haynes alloy No. 25, Hastelloy C, and type 316 stainless steel has been determined by exposures of 1000, 5000, and 10,000 hr at 1100°C and 10,000 hr at 900°C . To measure the extent of interaction we determined changes in weight, composition, microstructure, and mechanical properties. Weight and composition changes in the metal specimens were small and insignificant. Metallographic examination showed that all samples exposed to SrO at 1100°C were attacked up to a maximum depth of 0.008 in., primarily along grain boundaries. At 900°C Haynes alloy No. 25 and Hastelloy C were similarly attacked, but type 316 stainless steel was not. Haynes alloy No. 25 and Hastelloy C exposed to SrTiO_3 showed sub-surface voids, indicating the preferential removal of some element, possibly carbon. Samples exposed to Sr_2TiO_4 appeared similar to those heat treated in argon under similar conditions.

The only significant change observed in the strontium compounds occurred with SrTiO_3 . A surface reaction zone was found in all the tests involving this compound, and it was identified by microprobe analysis to be a $\text{Cr(Mn)}_x\text{Ti}_y\text{O}_z$ phase.

Room-temperature tensile tests showed a drop in yield strength, ultimate tensile strength, and elongation of the metal specimens when heat treated for 1000, 5000, and 10,000 hr at 1100°C and 10,000 hr at 900°C as well as when tested with the strontium compounds. The decline in mechanical properties is, therefore, attributed to increased grain size and phase changes that occur upon heat treatment. Samples exposed to SrO exhibited, on the average, lower tensile strength and elongations than other samples of the same alloy.

These tests have shown that all three superalloys are compatible with both SrTiO_3 and Sr_2TiO_4 up to 1100°C . Further investigation of these materials with SrO is being conducted to determine the nature of the interaction.

SNAP-21 AND SNAP-23 PROGRAMS

Capsule Welding

R. W. Gunkel

The SNAP-21 heat source capsule [200 w (thermal) of $^{90}\text{SrTiO}_3$ fuel] is a 0.200-in.-wall Hastelloy C-276 tube, 3.200 in. in diameter $\times$ 3.310 in. long. The SNAP-23 capsule [1200 w (thermal) of $^{90}\text{SrTiO}_3$] is a thick-walled Hastelloy C tube, 5 in. in diameter $\times$ 7.860

in. long, with 0.400-in.-thick walls and 0.600-in.-thick end caps.¹⁰ Electron-beam welding was chosen to produce the end-closure joints. The desired depth of defect-free weld¹¹ was 0.100 in. in the case of SNAP-21 and 0.110 in. for SNAP-23. In each case the edge of the capsule was not to be melted during welding¹² since it serves as a reference for ultrasonic inspection of the weld area.

Acceptable in-cell welds were made in two practice SNAP-21 capsules and six fueled capsules. Subsequently, two dummy-fueled capsules were welded out-of-cell for future pressure testing. Ultrasonic inspection proved all these welds to be acceptable. In addition, a series of electrically heated mockup capsules were successfully constructed. These resemble the regular SNAP-21 fuel capsule except for the flange attachment, which replaces one of the end caps and contains the electrical leads and thermocouple wires.

The SNAP-23 capsule contains a helium atmosphere to ensure good transfer of heat from the fuel to the capsule wall. A helium entrance hole in each capsule is sealed by the gas tungsten-arc process after the electron-beam cap-to-capsule weld has been made. Acceptable in-cell welds were made in both a practice and a fueled capsule. Three additional capsules were also welded out-of-cell for pressure testing.

Nondestructive Testing

K. V. Cook

Nondestructive testing techniques were applied to the SNAP-21 capsule body, the initial bottom end weld (before fueling) and, by remote techniques, the final capsule closure weld. In a similar manner we applied these techniques for the remote inspection of the SNAP-23 capsule final seal weld.

A paper on this subject has been presented and is to be published.¹³ The abstract is given below.

¹⁰R. W. Gunkel, *Metals and Ceramics Div. Ann. Progr. Rept. June 30, 1968*, ORNL-4370, pp. 99–100.

¹¹R. W. Gunkel, R. G. Donnelly, and G. M. Slaughter, "Electron-Beam Welding of SNAP-21 and SNAP-23 Isotopic Fuel Capsules," paper presented at American Welding Society National Fall Meeting, Cincinnati, Ohio, Oct. 7–10, 1968.

¹²R. W. Gunkel, *Metals and Ceramics Div. Ann. Progr. Rept. June 30, 1968*, ORNL-4370, pp. 97–98.

¹³K. V. Cook, "Remote Ultrasonic Examination of Closure Welds on Isotope Capsules," paper presented at the Seventh Symposium on Nondestructive Evaluation of Components and Materials in Aerospace, Weapons Systems, and Nuclear Applications, sponsored by Southwest Research Institute in San Antonio, Texas, April 23–25, 1969. To be published in the proceedings.

The nondestructive inspection of closure welds on fueled isotope capsules is necessary to ensure high integrity and thus prevent the release of toxic radioactive fuels. We are inspecting closure or seal welds with an ultrasonic pulse-echo technique. This test is performed remotely in a hot cell and has been used on seven strontium-fueled capsules sealed by electron-beam welding. The equipment is discussed along with results of calibration and correlation studies performed before and after hot cell evaluation. Discontinuities as small as 0.015 in. in diameter were detected and recorded. Weld penetration can be determined to an accuracy of 0.010 in. from the x - y recordings.

THERMOELECTRIC CONVERSION SYSTEMS FOR THE ISOTOPE KILOWATT PROGRAM

A. C. Schaffhauser

We have completed a review of thermoelectric conversion systems and conceptual design studies on a 2-kw(electrical) thermoelectric converter for the Isotope Kilowatt Program. The objective is to evaluate

different systems for conversion of heat from ^{90}Sr and ^{60}Co to electrical power in the range of 1 to 10 kw(electrical) for 2- to 5-year terrestrial and undersea applications.

Conceptual converter designs based on pellet and tubular thermoelectric elements were evaluated for systems using either direct conduction or liquid metal circulation heat transfer from the fuel block. Because of their higher heat flux requirements the tubular converters apply only to systems with direct heat conduction from partially shielded ^{60}Co fuel or the liquid metal heat transfer systems. Based on current thermoelectric technology, a pellet converter using direct heat transfer from a tungsten-shielded fuel block would have the highest conversion efficiency — about 8% net heat input to electrical output — for undersea applications. Advanced thermoelectric materials under development, having 20 to 40% higher material efficiency, could result in conversion efficiencies of 10 to 11%.