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HEAT-SOURCE SPECIFICATION

500 WATT(e) RTG

TES-3164

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For P. 1111
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1.0 SCOPE

1.1 General

This specification establishes the requirements for the radioisotope fuel and its encapsulation for application in a 500 Watt(e) thermoelectric generator.

1.2 Description

The completed heat source assembly consists of the fuel in the form of sintered agglomerates of irregular granule size, or cylindrical pellets fabricated by hot pressing techniques, or cast in-place billets, sealed in the Waste Encapsulation and Storage Facility (WESF) inner capsule or liner, which, in turn is inserted and sealed in an outer strength member. The inner capsule, or liner, serves only as a compatible containment barrier for the fuel and facilitates contamination control for the subsequent assembly. The outer strength member provides the structural integrity and oxidation and corrosion resistance to prevent release of the isotope in specified accident situations.

2.0 APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between this specification and the documents referenced herein, the requirements of this specification shall govern.

2.1 Specifications and Standards - of the issue in effect on the date of this specification.

ASTM E-493, "Test Method for Leaks Using the Mass Spectrometer Leak Detector in the Inside-out Mode. "

ASME Boiler and Pressure Vessel, Code V, "Non-destructive Examination. "

ASME - Boiler and Pressure Vessel Code, Section IX "Qualification Standard for Welding and Brazing Procedures, Welders, Brazers and Welding and Brazing Operations. "

2.2 Drawings - (Teledyne Energy Systems) of the latest issue in effect at time of fuel encapsulation:

BUP-01-0003 Proposed outer strength member WESF capsule - 500 Watt RTG.

3.0 REQUIREMENTS

Each heat source assembly and its components shall meet the requirements of this section.

3.1 Fuel

The basic fuel, for purposes of this specification, shall be the radioisotope strontium-90.

3.1.1 Chemical Form

The fuel shall be in the sintered fluoride form ($^{90}\text{SrF}_2$).

3.1.2 Fuel Composition

The fuel composition, for purposes of this specification, shall be $^{90}\text{SrF}_2$ as synthesized and stored at the WESF at Richland, Washington. The WESF $^{90}\text{SrF}_2$ is precipitated and further processed from a feed solution whose composition is given in Appendix A.

3.1.3 Fuel Quantity

The total quantity of Strontium-90 per heat source, at the time of encapsulation shall be TBD watts. The total quantity of fuel (thermal inventory) is to be determined by source calorimetry. The absolute thermal inventory is to be measured to within 2%.

3.2 Heat Source Components

3.2.1 Fuel Liner Assembly and Components

The liner or inner capsule assembly and components are those currently being utilized in the existing WESF storage capsule. The inner capsule is fabricated from 'Hastelloy C-276' alloy to the dimensions shown in Figure 3-1. The new heat source assembly covered by this specification uses the existing WESF inner capsule without modification.

Quality Control measures and acceptance criteria governing the WESF inner liner are not part of this specification and are assumed to be as specified by the appropriate WESF Facility personnel.

Dimensions of the WESF $^{90}\text{SrF}_2$ Hastelloy C-276
Inner Capsule

3.2.2 Strength Member Assembly and Components

The strength member assembly or outer capsule consists of a housing and two end caps. One end cap is tapped to accept a capsule "Handling Knob" used to lower the capsules into an RTG shield. The other end cap is machined to accept a tapered pin, which is to be welded in place after backfilling the void between inner and outer capsules with helium. The helium serves both to aid in the heat transfer and to facilitate leak testing. Component dimensions are depicted on TES Dwg. BUP-01-0003.

3.2.2.1 Materials

The strength member housing, end caps and taper pins are to be fabricated from "Hastelloy" Alloy 'S' procured in the solution heat treated condition and certified to AMS-5711. Hastelloy Alloy S is a nickel-base, high-temperature alloy with the desired combination of properties produced by Cabot Corporation, Kokomo, Indiana.

3.2.2.2 Qualification Testing

Prior to use in an RTG, the new outer strength member must be subjected to "Special Form" testing as a minimum requirement for licensing. The recommended strength member qualification test requirements are specified separately in Appendix B. The tests described in Appendix B shall be applied to samples or prototype capsules to qualify the capsule design. Subsequent to satisfactory conclusion of the tests, quality control measures must be carried out during production of capsules for operational use to ensure that the standards achieved by the test specimens are maintained.

3.3 Heat Source Assembly

The complete heat source assembly, for purposes of this specification, consists of the $^{90}\text{SrF}_2$ fuel with a nominal thermal inventory of TBD watts, sealed within a Hastelloy C-276 inner capsule or liner, which, in turn is inserted into and sealed within a Hastelloy S outer strength member. This heat source utilizes the existing WESF inner capsule design and specifications

governing the fabrication and testing of the inner capsule are not included as part of this specification. Prior to inserting the inner capsule into the strength member, one end cap of the strength member must be welded in place, as a sub-assembly. This initial weld need not be a remote weld but should be accomplished and tested in accordance with Section 3.4 prior to insertion into the final heat source weld facility. The inner capsule is to be inserted in a clean outer strength member and some degree of thermal equilibrium, as established by development testing, achieved prior to welding in the second end cap. Welding of the end cap is to be in accord with Section 3.4 herein. Following completion of the end cap weld, the capsule should be evacuated and backfilled with helium, through the small tapered hole provided in one end cap. The close fitting tapered pin is then to be inserted and seal welded in place. Minimum weld penetration of the end cap weld is to be as specified on TES Dwg. BUP-01-0003.

3.3.1 Identification

Each outer capsule body and both end caps of the completed heat source are to be identified by a serial number, unique to each heat source, applied in a permanent manner (electro-chemical etch, metal stamp or vibro-etch).

3.3.2 Heat Source Surface Contamination

Removable radioactive contamination of the exterior surfaces of the completed heat source assembly shall not exceed 10,000 DPM per 100 square centimeters as determined by a wipe test in accordance with para. 4.3.1.

3.4 Welding

The method of welding the heat source assembly (TIG, plasma arc or electron beam) shall be at the discretion of the encapsulating facility provided sufficient penetration (see TES Dwg. BUP-01-0003) and the additional requirements of this section are satisfied.

3.4.1 Welder and Welding Operator Qualification

The welders and welding operators for the heat source assembly shall be qualified according to the requirements of the ASME Boiler and Pressure Code, Section IX, except that for welding operators:

- a. The three foot length of test weld required by the ASME code shall be in the form of circumferential welds of four (4) capsule weld test specimens and
- b. Examination of the weld test samples, shall be as indicated in Section 3.4.2 and verified by the radiography methods of the ASME code.

Renewal of qualification of a welder or welding operator is required (1) when the welder or weld operator has not used the specific process for a period of three months or more, or (2) when there is a specific reason to question the ability to make welds that meet the requirements of this specification.

3.4.2 Weld Testing

All outer strength member weld joints shall be welded using processes, welders and/or welding operators qualified under Section 3.4.1. All weld joints shall be subjected to the following tests:

A. Helium Leak Test -

The completed heat source assembly is to be leak tested in accordance with ASTM E-493 "Test Methods for Leaks using the Mass Spectrometer Leak Detector in the Inside-Out Testing Mode" the maximum allowable leak rate shall be 1×10^{-7} STD cc/sec helium.

B. Ultrasonic Tests

All welds except the tapered pin weld shall be tested to determine the depth of weld penetration and weld integrity. The weld joints are to be tested in accordance with ASME Boiler and Pressure Vessel Code, Section V "Nondestructive Examination," Appendix 12 "Ultrasonic Examination of Welds." Acceptance-Rejection Criteria are to be as specified in ASME code - Appendix 12, except that the maximum discontinuity length is to be 0.020 inch.

3.4.3 Weld Acceptance Criteria

All welds, when tested in accordance with para. 3.4.2 herein, shall meet the following criteria:

- A. Leakage - The leak rate on tested heat source assemblies shall not exceed 1×10^{-7} STD cc/sec helium.

- B. Penetration - The weld penetration shall not be less than that specified by TES Dwg. BUP-01-0003.
- C. Weld Defects - As determined by ultrasonic testing, any discontinuities interpreted to be cracks, lack of fusion, or incomplete penetration, are unacceptable regardless of discontinuity or signal amplitude. Discontinuities are also unacceptable if the amplitude exceeds the reference level, and the discontinuities have lengths which exceed 0.020 inch.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection System Requirements

The Fueling Facility shall establish and maintain a system of Quality Control Inspection and Documentation to verify compliance with the requirements of this specification and the appropriate Teledyne Energy Systems drawings.

4.2 Certification

The Fueling Facility shall certify, in writing, the following items:

- a. Fuel Chemistry - The fuel contained in the completed fuel capsules has been processed from feed solution that complies with the composition shown in Appendix A.
- b. Fuel Quantity - The quantity of fuel in thermal watts as measured by source calorimetry and the possible error tolerance.
- c. Outer Capsule Weld Quality - Outer capsule welds shall comply with the requirements of para. 3.4.3 as established by testing in accordance with para. 3.4.2.
- d. Surface Contamination - The completed fuel capsule shall comply with the requirements of para. 3.3.2 established by testing in accordance with para. 4.3.1.

4.3 Testing

Tests performed by the Fueling Facility to verify conformance with the requirements specified herein shall be as follows:

4.3.1 Wipe Test - Removable contamination on the exterior surface of the completed capsule shall be evaluated using the wipe technique as follows:

- a. Wipe an absorbent paper/asbestos Health Physics wipe with moderate pressure over an area of approximately 100 square centimeters. Wipes should cover the weld and surface, the body area and the capsule bottom.
- b. Evaluate the wipes in a calibrated, shielded detector scaler assembly. Results shall be reported as DPM per 100 cm².

4.3.2 Leak Test

Testing of all completed heat source assemblies shall be performed in accordance with ASTM E-493 "Test Methods for Leaks Using the Mass Spectrometer Leak Detector in the Inside-out Testing Mode."

4.3.3 Ultrasonic Examination

Heat Source Weld Joints (except tapered pin weld) are to be examined in accordance with a procedure prepared by the Fueling Facility to encompass the intent of ASME Boiler and Pressure Vessel Code, Section V, "Non-Destructive Examination" - Appendix 12 "Ultrasonic Examination of Welds."

4.3.4 Heat Source Calorimetry

The thermal inventory of each completed heat source shall be determined in accordance with a procedure prepared or developed by the Fueling Facility.

4.4 Non-Compliance Items

Any item which does not comply with the requirements or Quality Assurance provisions of this document or the appropriate Teledyne Energy Systems drawing shall be properly documented and submitted to a Review Board. This Review Board is to be established to review these discrepant items to determine the cause of event, to propose corrective action to prevent recurrence, and to determine the disposition of affected hardware. The operation of this Review Board is to be defined by the Fueling Facility.

4.5 Deliverable Data

The following data items shall be delivered by the Fueling Facility to Teledyne Energy Systems covering all heat sources used in the 500 watt RTG:

- a. Fuel chemistry certification (4. 2a)
- b. Fuel quantity certification (4. 2b)
- c. Leak rates as measured (4. 3. 2) on applicable capsules
- d. Verification of compliance to Sections 3. 4. 3 and 3. 3. 2
- e. Verification of process controls on welding and leak testing.

APPENDIX B

RECOMMENDED OUTER STRENGTH

MEMBER QUALIFICATION TESTING

1.0 INTRODUCTION

A Radioisotope-Fueled Thermoelectric Generator (RTG) is a device in which heat given-off by the decay of a radioactive fuel is transmitted through a number of thermoelectric couples where a portion of the heat is converted to electrical energy. In order to obtain proper Nuclear Regulatory Commission (NRC) Licensing for approval to transport an RTG, the heat source or fuel capsule must meet certain environmental, test and hypothetical accident conditions as specified in a number of national and international guides and regulations. The 500 watt RTG is designed to utilize the existing Waste Encapsulation and Storage Facility (WESF) $^{90}\text{SrF}_2$ inner capsule, but with a new outer strength member designed to meet all applicable licensing requirements. Much use was made of the work performed at Battelle's Pacific Northwest Laboratory (PNL) (Ref. 1), both in material selection and general sizing of the outer strength member.

2.0 DESIGN PARAMETERS

The major design constraint imposed on the outer strength member was that it accept the existing WESF inner capsule as is. An added constraint is that the outer capsule meet the qualification test requirements without support from the inner capsule.

The outer strength member is designed to withstand an external hydrostatic pressure of 24,500 psi and this requirement has a profound effect on capsule design. This capability has been demonstrated analytically in Ref. 2. The design criteria such as impact, percussion, puncture, heating, and thermal shock requirements are readily verified by testing, but verification without testing requires complex analytical treatment.

2.1 DESIGN CONFIGURATION

The outer strength member assembly and components are shown on TES Dwg. BUP-01-0003. The assembly consists of a housing and two similar

threaded end caps. The end caps are designed to "bottom" on a shoulder machined in the housing and to be flush with the housing top or bottom surface. The end cap/housing interface is a joint suitable for TIG, plasma arc, or electron beam welding. The joint, as presently configured, assumes that the weld penetration can be obtained without the use of filler wire. The shoulder area is capable of withstanding the external pressure and the threads provide the degree of "fixity" needed to minimize the weld penetration required. This type of end cap closure has been used successfully on capsules tested to 15,000 psi external hydrostatic pressure. The selected end cap design is much simpler to fabricate than the one designed in Ref. 1 and the threads reduce shear stresses in the weld joint to acceptable limits.

All strength member components are to be fabricated from Hastelloy Alloy S bar stock procured in the solution heat treated condition. Because of the length of the housing and the required tolerances on the ID, the double end cap design has a fabricability advantage when compared to a single end cap design.

3.0

QUALIFICATION TESTS RECOMMENDED FOR OUTER STRENGTH MEMBER

The following tests are recommended for qualifying the outer strength member.

- A. Pressure Test - The outer strength member shall be shown to resist an external pressure of 14,500 psi (1000 Bar).
- B. Impact Test - The capsule shall be shown to resist a free drop through a distance of 9 meters (approximately 30 ft) on to a flat essentially unyielding horizontal surface, striking the surface in an orientation as to suffer maximum damage. This test should be performed with an inner capsule or simulated inner capsule in place since such may add to possible damage to the strength member.
- C. Percussion Test - The outer strength member shall resist the impact of the flat face of a steel billet 2.5 centimeters (1 inch) in diameter with the edges rounded off to a radius of not less than 3 millimeters dropped through a distance to produce an impact equivalent to that resulting from the free fall of 7 kilograms through 1 meter. The outer

strength member shall be placed on a sheet of lead, of hardness number 3.5 to 4.5 on the Vickers scale, and not more than 25 millimeters (approximately 1 inch) thick, supported by a smooth essentially unyielding surface.

- D. Thermal Test - The outer strength member shall retain its integrity after being heated to a temperature of 800°C (1472°F) and held at that temperature for a period of 30 minutes before being allowed to cool.
- E. Thermal Shock Test - The outer strength member shall retain its integrity after being heated to 800°C (1472°F) or the maximum operating temperature and then plunged into a 50% by volume water-ethylene glycol solution at 0°C (32°F) where it shall be left for 10 minutes.

A different sample may be used for each of the tests defined.

3.1 Acceptable Criteria

Following each of the tests shown in Para. 3.0, the capsule must show a helium leak rate of less than 1×10^{-7} STD cc/sec helium when tested in accord with any commonly accepted leakage test.

The tests outlined in Para. 3.0 are those defined by current Federal and International Regulations pertaining to a "Package" license for transport.

The PNL report (Ref. 1) states that the American National Standards Institute (ANSI) has defined certain qualification test requirements for sealed radioactive sources which could be adapted in the future as Federal Standards. The pertinent requirements are:

- A. A 20 kg-m percussion test
- B. A 24,500 psi external hydrostatic pressure test
- C. A 1 kg-m puncture test

The proposed outer strength member has been designed to meet requirement B, that requirement deemed to affect the design in the most significant manner.

Indeed it could possibly pass the remaining requirements as well. However, testing to requirements which do not exist would not be justified at this time.

Following the successful completion of the tests herein, the 500 watt RTG license applicant can claim that the $^{90}\text{SrF}_2$ material meets "Special Form Requirements" without additional heat source testing.

REFERENCES

1. PNL-3923, " Design and Qualification Testing of a Strontium-90 Fluoride Heat Source," H. T. Fullam, August 1981.
2. TES-Memorandum-BU-FAS-004, " Structural Analysis of the Fuel Capsule; 500 W Sentinel RTG," F. Schumann, 21 January 1983.

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