UCRL-ID-106866

THULIUM HEAT SOURCE
IR&D Project 91-031

Second Trimester Status Report

Carl E. Walter, Judith E. Kammeraad, John G. Newman
Richard Van Konynenburg, and James H. Vansant

April 10, 1991

Lawrence Livermore National Laboratory

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.
Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

DISCLAIMER

UCRL-ID--106866

DE91 012138

THULIUM HEAT SOURCE
IR&D Project 91-031

Second Trimester Status Report

TM170 POWER SYST

Carl E. Walter, Judith E. Kammeraad, John G. Newman,
Richard Van Konynenburg, and James H. VanSant

Thulium Heat Source

Carl E. Walter
Judith E. Kammeraad
John G. Newman
Richard Van Konynenburg
James H. VanSant

BACKGROUND

The goal of the Thulium Heat Source study is to determine the performance capability and evaluate the safety and environmental aspects of a thulium-170 heat source. Our approach is to study parametrically the performance of thulium-170 heat source designs in the power range of 5-50 kW_{th}. At least three heat source designs will be characterized in this power range and integrated with various power conversion subsystems to assess their performance, mass, and volume. We will determine shielding requirements, and consider the safety and environmental aspects of their use.

SIGNIFICANT ACCOMPLISHMENTS

On January 16 we published our first trimester report of progress on the Thulium Heat Source study under IR&D Project 91-031. The study now has a nickname, limited to 16 characters: Tm170_Power_Syst. This nickname is used for identification in the IR&D office data base. This second trimester report follows an internal mid-year review which was held on March 5. We have achieved a good understanding of our conceptual design. Its features have crystalized and we are in the process of optimization. Significant accomplishments include:

1. In our first trimester report we indicated that we were considering a homogeneous mixture of Tm_2O_3 and low-Z materials as a means of reducing shielding thickness. While calculations indicate that this is indeed the result, the overall mass of the shield actually increases as low-Z diluent material is added and a larger volume must be shielded. Accordingly, we are returning to our original concept of alternate layers of discrete disks of Tm_2O_3 and graphite. If both types of disks are of equal thickness there appears to be adequate heat transfer capability. We may be able to further reduce the graphite thickness. Heat flows in the thickness direction in the thulia disk and radially in the graphite disk since the thermal conductivity of thulia is about a factor of ten lower than for graphite.

2. Westinghouse Hanford Company performed a number of calculations to assess the net production capability of FFTF for Tm-170. Although additional calculations could be performed to optimize irradiation conditions, it does not

appear that the FFTF flux is high enough in the energy range of the Tm-169 resonance integral to provide a high conversion fraction of Tm-169 to Tm-170. The results of the calculations were insensitive to the choice of low-Z diluent (carbon or beryllia) but were strongly dependent on thulium number density. For example, in a single target assembly the amount of Tm-170 produced in Tm_2O_3/carbon irradiated for 125 days (typical FFTF fuel cycle) and the corresponding conversion fractions of Tm-170 are:

Relative volume of thulia, %	Production, g	Conv. frac., %
5	81	12.9
50	227	3.6

As a result of these calculations by Westinghouse Hanford Co., we conclude that irradiation in a high-flux thermal reactor will be a better approach for producing high conversion fractions in short irradiation times.

Experimental irradiations were conducted at one of the Savannah River reactors in the late 1960s. At a thermal flux of 2.3×10^{15} n/cm^{2}s a net conversion fraction of 0.21 was obtained in 36 days. From the coupled set of Bateman equations that describe the production, decay, and transmutation of the thulium and ytterbium isotopes, we have determined the Tm-170 conversion fractions that are obtained for various irradiation times and irradiation fluxes.

	Thermal Flux, n/cm^2 s	
Irradiation Time, d	1×10^{15}	5×10^{15}
10	8	29
20	15	37
30	19	35
40	23	30
50	26	24

We neglected self-shielding in these survey calculations as the expected thulia disk thickness is less than half the mean free path (3.5 mm) for thermal neutrons. This is another advantage of irradiating in a thermal flux, the thulia disk thickness is not unreasonably thin.

3. Further analysis of sodium heat pipe performance indicates that the heat source can be adequately cooled even under adverse gravity conditions. We are

extending our analyses to include lithium as the heat pipe working fluid for use with higher design temperature heat sources.

4. We are examining the activation of impurities in thulia target material that is irradiated in a thermal neutron flux of 1×10^{15} n/cm^2 s. The principal impurities in commercially available thulia are other rare earths as well as iron, calcium, silicon, magnesium, and aluminum. Fortunately, the principal activators among the rare earths are the lighter ones and are the most easily separated from thulium. Europium (E_u-152, -154, -155) having high cross sections, will be preferentially burned up in the irradiation. Of the other impurities, only iron (Fe-55) has a product radionuclide with a half-life longer than Tm-171 but short enough to have a significant decay rate. Its cross section is fairly low and therefore its activity is expected to be low. It appears that spent thulium power source material could be disposed of as Class A low level radioactive waste, which is the least restrictive category.

5. We have determined that the cost of Tm-170 that we have used ($28/W inflated to 1991 $) may not be valid. We learned that the cost estimated in a chart published by Pacific Northwest Laboratory in 1973 was scaled from the cost of other isotopes and that the cost estimate for those isotopes were based on a number of unspecified assumptions. To obtain an estimate with a known basis we made our own assumptions. This leads us to an estimated cost of $50-75/W. Our estimate assumes the construction of a 3000 MW_{th} reactor that would operate for 30 years. We believe that such a reactor facility would be less expensive than a nuclear electric power plant of equivalent size, and that the reactor would be optimized for Tm-170 production. Sale of low-temperature waste heat (for example for desalination of sea water) would reduce the cost of the Tm-170 product further.

6. We have received a considerable amount of information on several power conversion systems from our industrial partners. It appears that we will be able to achieve high thermal efficiency in dynamic systems. We have designed a very compact configuration for a thermoelectric system that utilizes heat pipes to maintain a constant hot junction temperature at the thermoelectric element as the heat source strength decays over its design life. A simplifying feature of this design is that power conversion takes place in the path for heat loss from the heat source, therefore, high performance insulation is not required.

7. On February 20 we briefed RAdm David Altweeg (ret.) (NAVSEA-06) and VAdm J. Guy Reynolds (OPNAV-098). Both were pleasantly surprised and promised to look into the support that a radioisotope power system development proposal may receive in the Navy.

8. We have selected a compatible set of materials for the heat source in its expected environments. Structural materials are Hastelloy C-4 for low design temperature (1100 K) and ASTAR 811-C for high design temperature (1500 K).

9. Large-scale use of TIP power systems will necessitate a dedicated high-flux production reactor. We have considered what design features would be desirable in such a reactor (see para. 5 and 10).

10. The abstract of a paper for presentation (and inclusion in the proceedings) at the 26th Annual Intersociety Energy Conversion Engineering Conference (IECEC) to be held in Boston on August 4-9, 1991 was accepted. The paper is due on May 10. An abstract was also submitted for presentation at the 7th International Symposium on Unmanned Untethered Submersible Technology. The theme of this symposium is "Multiple AUVs—A Research Challenge". How appropriate for a discussion on how to produce Tm-170 on a continuing basis for a fleet of AUVs!

ACKNOWLEDGEMENTS

We wish to acknowledge valuable technical data from various individuals that we have incorporated in our study thus far. Our list is not all-inclusive:

Sharon Atkin	WHC	Al Harper	Allied Signal
Wayne Brittain	Teledyne	Dick Harty	Rockwell
Roger Carlson	LLNL	Daniel Jordheim	WHC
Bob Carpenter	Fairchild	Ed Mastel	DOE
Bill Determan	Rockwell	Joe Moryl	MTI
Bill Ernst	MTI	Les Norman	Allied Signal