Nuclear and Emerging Technologies for Space, American Nuclear Society Topical Meeting
Richland, WA, February 25 – February 28, 2019, available online at http://anstd.ans.org/

IMPACT TEMPERATURE DETERMINATION FOR GPHS SAFETY TESTING

Jonathan Teague and Roberta N. Mulford
Los Alamos National Laboratory, Los Alamos, New Mexico 87545
(505)664-0190 jteague@lanl.gov and (505)667-7909 mulford@lanl.gov

Abstract: Impact Testing of General Purpose Heat Sources (GPHS) is done to benchmark extensive safety calculations quantifying launch safety. Efforts to conduct an impact test at the extreme low end of the temperature range for launch highlights uncertainties in determining the GPHS clad temperature during impact tests. Direct measurement of clad temperatures in the impact configuration are described, and the effect of emissivity of the various components indicated. Calculation of the experimental clad impact temperature using the ANSYS thermal transport model indicates that the clad temperature at impact was outside the relevant range for launch safety modelling of GPHS behavior.

I. IMPACT TESTING OF GPHS CLADS

General Purpose Heat Sources (GPHS) incorporated into a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) are subjected to extensive model-ling of possible insults during a failed launch, to support the required safety analysis. Impact of actual GPHS at specified temperatures and velocities are conducted to confirm the verisimilitude of the model to reality, from the materials modelling through the Finite Element description of the GPHS.

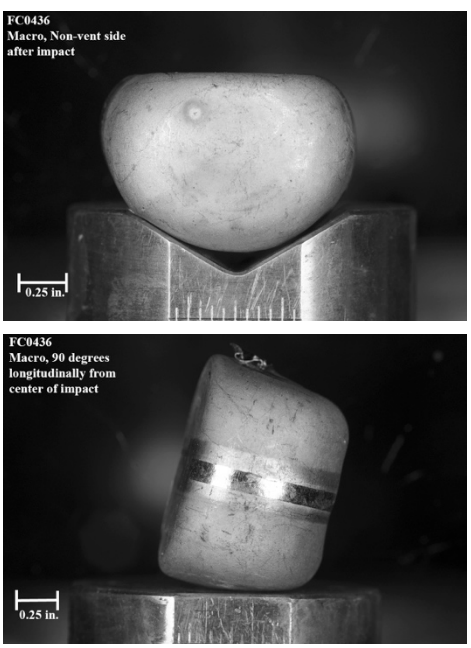

Fig. 1. Typical impacted clad showing deformation without fracture of iridium clad

Accurate modelling of GPHS performance supports dynamic and thermal modelling of larger components in a large variety of scenarios.

A recent impact test scheduled at 730°C, at the extreme low end of the relevant temperature range for the launch, resulted in unexpected cracking of the iridium leading to questions as to whether the exact impact temperature was lower than the calculated value. The GPHS clad temperature cannot be measured directly because of the several layers of radiological and fragment confinement required for a safe impact test.

I.A. Iridium Ductility at Temperature

Iridium is used as the cladding material for the GPHS heat source because of its high temperature strength, which far exceeds that of other metals. In the MMRTG assembly, the iridium temperature is always well above the thermal region in which iridium begins to exhibit an increasing degree of brittle failure. While iridium does not exhibit a well-defined ductile-brittle transition, inter-granular fracture increases with decreasing temperature, particularly below 800°C.[1]

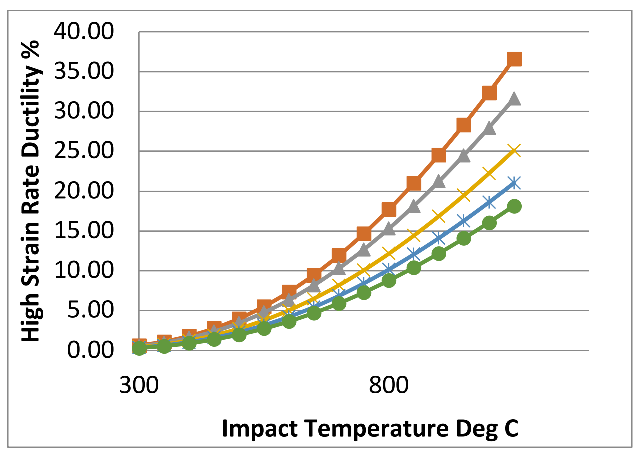

Fig. 2. The ductility of iridium as function of temperature. The several curves describe grainsizes, from 25 μm (top curve) to 30, 40, 50, and 60 μm (bottom curve)

Grain size, texture, and alloying agents are very carefully controlled in the GPHS clad material to maximize ductility and minimize intergranular fracture. Ductility also depends on strain rate, and selection of data at the proper strain rate is required for prediction of impact performance.[1]

I.B. Impact Testing Configuration

Impact Testing of GPHS is done in the Isotope Fuels Impact Tester (IFIT) facility at Los Alamos National Laboratory, a 7” gas-propelled gun configuration capable of sealing and containing the impact region before impact of the GPHS.[2] The GPHS resides from launch to recovery in a sealed radiological container made of Ta, which precludes direct measurement of the GPHS surface at launch or impact. The exterior temperature of the Ta can is measured, and the GPHS clad surface temperature calculated using an analytical thermal transport model.[3] The model is appropriate to the usual launch temperature of 1050°C. Selection of emissivities determines the applicability of the model at low temperatures, as seen below. To determine the true GPHS clad temperature at the Ta can temperature of 550°C, a non-launchable test assembly was built with a perforated can and thermocouples contacting the GPHS clad as well as the exterior of the Ta can.

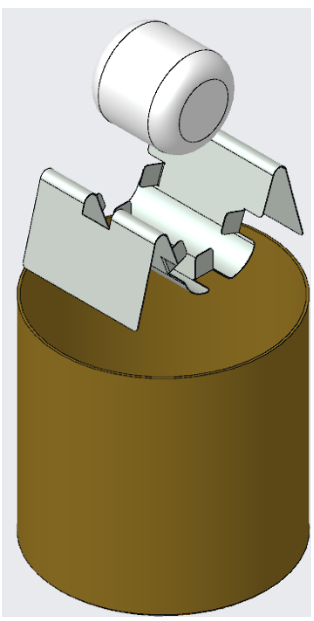

Fig. 3. GPHS clad in side-on impact configuration is placed into Ta impact can

The rate of heating was critical to maintaining thermal equilibrium between the Ta can and the GPHS clad, and allowing accurate modelling.

I.C. Observed and Calculated GPHS Temperature

Observed temperatures of the Ta can and the GPHS clad conformed well to the historical analytical thermal model, as long as the correct emissivity was selected, as shown in Figure 4. At temperatures below the GPHS surface temperature, radiation from the GPHS to the Ta can requires use of an emissivity of about 0.1. At temperatures above about 550°C, an emissivity of about 0.5 is necessary in the calculation to describe radiation from the surface of the Ta can to the GPHS clad.[4]

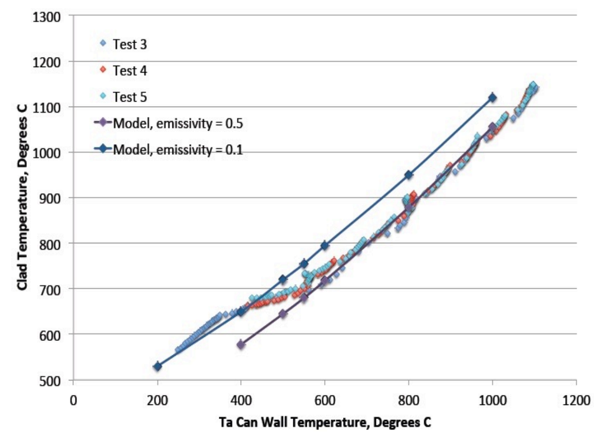

Fig. 4. Observed temperature of GPHS as a function of Ta can temperature and fit of analytical predictive model.

Comparison of the Ta can heating profile obtain in the impact test with similar profiles obtained in the heating tests suggests a clad temperature of about 700°C in the impact test, well below the anticipated impact temperature of 730°C.

I.D. ANSYS Thermal Modelling

The ANSYS modelling package[5] was used to model thermal transport with the inclusion of detailed material properties for the Ta can, the iridium of the GPHS clad, and the molybdenum cradle used in the side-on impact configuration, as shown in Figure 5.[6]

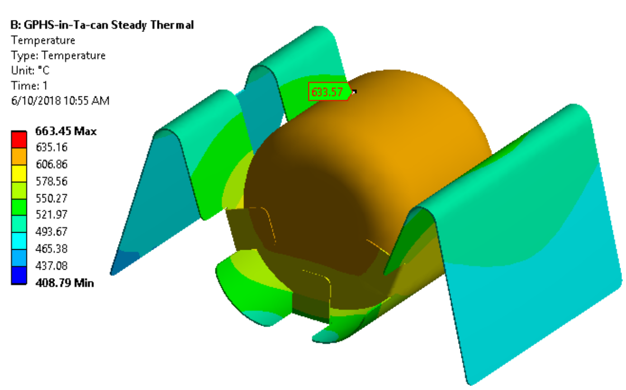

Fig. 5. ANSYS Output for Steady State temperature

Given the Ta can temperature, thermal modelling of the GPHS clad temperature with the ANSYS package corresponded well with the measured clad temperature, particularly at longer times as the heating rate decreased and thermal equilibrium between the can and the clad improved, as seen in Figure 6.[6]

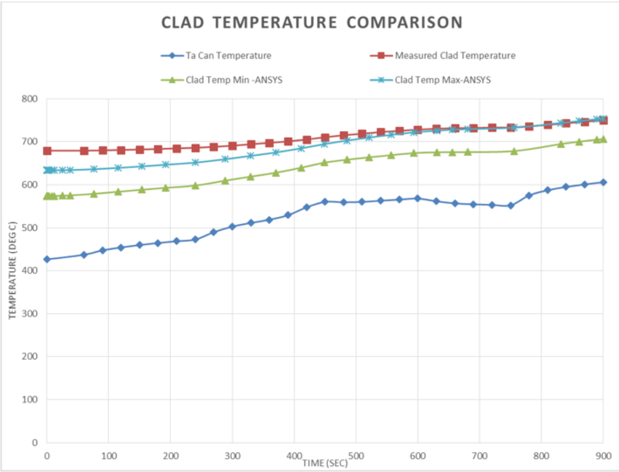

Fig. 6 Match of ANSYS to observed temperatures during active heating

Determination of the temperature of the impacted GPHS clad from the Ta can temperature which was measured during the impact experiment was done with the ANSYS package.[6] The result is shown in Figure 7. An experimental clad impact temperature of between 669°C and 721°C was determined from the ANSYS modelling. This temperature is below the 730°C minimum impact temperature that is relevant to launch safety calculations, and is consistent with the observed iridium behavior.

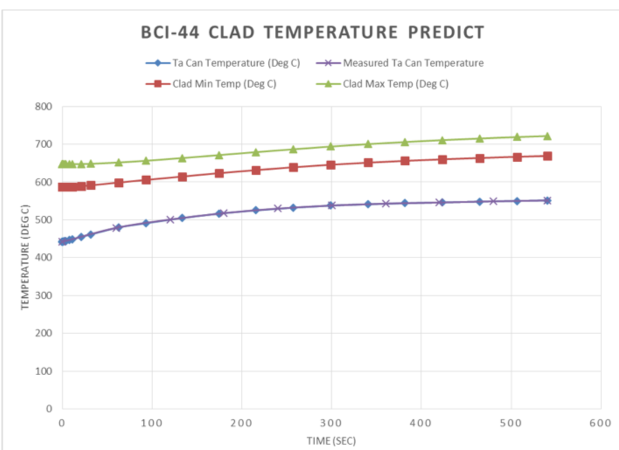

Fig. 7. Steady State result ANSYS modelling of Ta can and GPHS clad

II. CONCLUSIONS

Thermal modelling of the low temperature launch configuration suggests the temperature of the GPHS clad in the low temperature impact experiment was somewhat below the anticipated temperature of 730°C. Estimation of the clad temperature at impact from the heating test data also suggests an impact temperature well below 730°C. Fracture of the iridium clad at this lower temperature is not an unanticipated result, nor is the fracture relevant to launch conditions.

ACKNOWLEDGMENTS

A large number of skilled people are required to construct and execute an impact test, and we thank them; Paul Richardson, Joey Sanchez, David E. Clark, Brian Berger, Karl Krenek, Ben Hollowell, Stan Pierce, and Allen Arellano.

REFERENCES

1. E. P. GEORGE, H. BEI, E. H. LEE, and J. D. BRADEN, “Tensile Impact Ductility and Fracture Behavior of DOP-26 Iridium at 500-900°C,” Oak Ridge National Laboratory Report ORNL/TM-2004/239, 2004.
2. C. E. FRANTZ, J.W. TAYLOR, and D.B. COURT, “Isotope Fuels Impact Tester,” Los Alamos Report LA-6013, Los Alamos National Laboratory, (1976).
3. R. J. LIPINSKI, white paper, “BCI and GPHS Impact Testing Pretest Predictions,” Sandia National Laboratories, July 28, 2010. (2010.)
4. R. N. MULFORD, B. BERGER, K. KRENEK, B. HOLLOWELL, R. M. WINGO, P. D. RICHARD-SON, J. SANCHEZ, and D. E. CLARK, “IFIT Bare Clad Impact Heating Tests,” Los Alamos Report LA-CP-18-20174, Los Alamos National Laboratory, (2018).
5. ANSYS Engineering Simulation Software, v.19.0.
6. J. G. TEAGUE, “IFIT Pre-Launch Clad Temperature Prediction,” *Proc. Title*, Los Alamos Report LA-CP-18-20680, Los Alamos National Laboratory, (2018).