FINITE ELEMENT ANALYSIS OF TEMPERATURE AND STRESS FIELDS DURING FABRICATION OF $^{238}PuO_2$ FUEL PELLETS. R. A. Brockman[1], D. P. Kramer[1], C. D. Barklay[1], and D. Cairns-Gallimore[2], [1]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469, [2]Space and Defense Power Systems, U.S. Department of Energy, 19901 Germantown Road, Germantown, MD 20874

Introduction: Recent deep space missions utilize the thermal output of the radioisotope 238-plutonium as the fuel in the thermal to electrical power system that powers the spacecraft. Since the application of plutonium in its elemental state has several disadvantages, the fuel employed in these deep space power systems is typically in the oxide form such as 238plutonium dioxide ($^{238}PuO_2$). As an oxide the processing of the plutonium dioxide into fuel pellets is performed via "classical" ceramic processing unit operations such as the sieving of the powder, pressing, sintering, etc. (Figure 1). Modeling of these unit operations can be beneficial in the understanding and control of processing parameters with the goal of further enhancing the desired characteristics of the $^{238}PuO_2$ fuel pellets. For example, any cracking of the fuel pellets can make next assembly operations such as subsequent iridium encapsulation and welding much more difficult to perform. The fabrication of more robust integral $^{238}PuO_2$ fuel pellets will facilitate these and other unit operations.

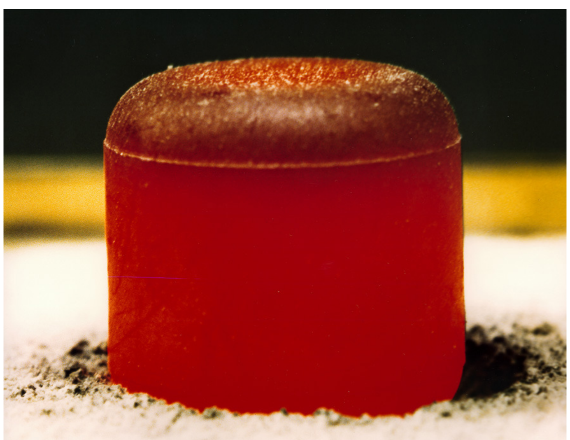

Figure 1. Example of a $^{238}PuO_2$ pellet processed using standard ceramic processing techniques.

Modeling Development: A finite element model has been developed that helps to identify the time-temperature-stress profile within a pellet during a furnace operation taking into account that the $^{238}PuO_2$ pellet has a significant thermal output of about 0.41 watts/gm. Thermal and stress analysis of the cooling process reveals that, for standard processing conditions, significant thermal stresses are induced in the pellet due to the cooling rate, and the relatively high coefficient of thermal expansion of plutonium dioxide which has a reported alpha value of ~13×10^{-6} cm/cm/°C (20°C–1425°C)[1].

Standard ceramic processing parameters employed during cooling after a high temperature thermal operation (hot pressing, sintering, etc.) typically requires careful thermal control that results in a "slow" cooling rate. This is desired since it will tend to minimize thermal induced stresses when cooling from a high to low temperature. This is especially true when cooling a ceramic compact that has a relatively high coefficient of thermal expansion which is the case for plutonium dioxide. However, recent work shows that the hot press environment can result in potential chemical reactions between the fuel and materials within the hot press[2]. Therefore, there are two main competing requirements; 1) to slowly cool to minimize thermal stresses within the fuel pellet, and 2) to fast cool the fuel pellet to minimize any chemical reactions. By calculating the anticipated thermal stress as a function of cooling rate after the hot press operation it is possible to ultimately reduce fracture formation while minimizing undesirable chemical reactions.

The developed model allows the dependence of the maximum transient thermal stress upon the cooling rate to be studied in detail. Since the thermal output of $^{238}PuO_2$ is a function of age proportional to its half-life, the time dependency of diminished thermal output from the isotope upon temperature and stress distributions expected during cooling has also been evaluated.

Results: A finite element model of a $^{238}PuO_2$ pellet has been developed using PuO_2 mechanical and physical property data available in the literature. The model has been used to estimate the internal stresses within a pellet as a function of cooling rate, and as a function of fuel age by taking into account that thermal output decreases as a function of time. This information can be used to determine an optimum cooling rate that minimizes the likelihood of internal flaw formation and/or cracking of the pellets during manufacturing. Model predictions indicate that slower cooling rates after hot pressing are desirable in terms of minimizing the likelihood of crack initiation in the $^{238}PuO_2$ fuel pellets which will have a second beneficial action of reducing the extent of chemical reactions between the fuel and the hot pressing environment. Thermal stress levels are calculated to increase very rapidly for shorter cooling times. Even with extended cooling times, the peak stress levels and probable stress intensity levels are high enough to warrant further investigation. The steady-state calculations suggest that the thermal boundary conditions used in the model, while highly idealized, are sufficient to provide reasonable estimates of the thermal stress behavior.

References:

[1] Touloukian Y.S. et. al. (1977) *Thermophysical Properties of Matter*, v.13*,* 331-335. [2] Whiting C.E. et. al. (2012) *Extended Abstracts of the Nuclear and Emerging Technologies for Space (NETS 2012)*, in press.