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Title: AGING PHENOMENON IN METALLIC PLUTONIUM

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Aging Phenomena in Metallic Plutonium

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1. Plutonium properties of relevance to nuclear weapons

By its very radioactive nature, metallic plutonium is a dynamic material which continually evolves in both physical structure and chemical makeup. In addition, there is a strong economic and environmental incentive to use plutonium-containing components for as long as feasible since the processing of plutonium into weapon components requires a complex and expensive facility. Thus, by extending the lifetime of plutonium components, a considerable savings in production costs and environmental impact is realized. However, because of the complexity and hazards associated with plutonium processing, lead-times of up to several years are required to develop an appropriate "fix". Thus, the challenge of understanding aging in metallic plutonium is two-fold: 1) the predictive assessment of changes to plutonium with at least a decade warning of deleterious effects; and ultimately, 2) lifetime determination of individual plutonium components on a system-by-system basis.

Why such a focus on plutonium when there are hundreds of other unique materials in a nuclear weapon? Plutonium is a key ingredient in modern, "hollow-boosted" primaries. The primary is the first stage of a nuclear weapon in which chemical energy in the form of high explosives is used to compress nuclear fuel and produce fission and fusion reactions. These nuclear reactions in turn provide energy in the form of radiation which is used to drive the secondary stage. Plutonium in the form of two mated hemishells is the fissile fuel within the primary. The entire function of the nuclear weapon relies on the integrity of the primary, especially the plutonium contained within it. During storage, the plutonium metal must not undergo any changes which alter its form, shape, or mechanical properties, otherwise the reliability of the component is in question.

From an engineering standpoint, a great deal is known about techniques for producing plutonium shells of the exact dimensions and physical attributes necessary for weapon use, but surprisingly little is known about the specific properties of plutonium which determine the performance of the primary. From the above description of implosion and nuclear events which occur in a nuclear weapon primary, it is evident that a variety of nuclear, mechanical, and metallurgical properties of plutonium must be known in order to design and certify such a devise. However, due to the difficulty of making such measurements in laboratory scenarios and the necessity of confirming the integral performance of overall weapon systems, such properties were rarely studied in the past. Instead, plutonium properties were inferred from both nuclear yields of underground tests and the use of surrogate materials for plutonium in hydrodynamic tests used to qualify performance codes. Today, we find it necessary to go back and determine the more fundamental properties of plutonium, such as its equation-of-state under shock conditions, in order to refine the predictive hydrodynamic codes used for certification.

2. Enhanced Pu and Pit Surveillance Technologies

Today, as with weapons science issues, the monitoring of plutonium aging becomes an important issue for surveillance. The reasons for this are many-fold. First, and perhaps most important, plutonium is radioactive, primarily through the process of alpha decay. In this process, an unstable plutonium atom nucleus emits an alpha particle, consisting of two neutrons and two protons, hence possessing a net +2 charge. This particle is ejected with a high level of energy, approximately 5.1 MeV. The remaining atom, now minus the two neutrons and two protons, is now a uranium atom, and it recoils in the opposite direction with approximately 70 keV of energy. This process takes place with a half-life of 24,400 years, meaning that in this time period, half of the plutonium remains from the starting time. This process has many consequences. One pragmatic one is that the alpha particles ejected near the surface can be used with an ionization gauge-type detector to assess the presence of fine plutonium particulates, allowing plutonium handlers and facilities to detect the presence of contamination in virtual real time. But this alpha decay has other consequences for weapon integrity which are not well known. The same surface alpha particles which allow it's detection, can also cause a variety of problems with materials which may be found in contact with plutonium over extended time periods.

However, when this alpha emission occurs within the bulk of the plutonium metal, it is essentially trapped. Within the metal atom lattice, it acquires valence electrons and becomes a helium atom. At the same time that these helium atoms accumulate within the lattice, atomic displacements and damage to the plutonium lattice occurs due to collisions with the energetic uranium and alpha particles. At the current time, we have insufficient data to either assess or postulate how or when such defect structures may cause a deleterious change in the plutonium (such as blisters, voids, dimensional distortions, etc.) or effect other indirect changes (such as affecting phase stability, mechanical properties, compressibility, spall strength, etc.). The Laboratory is currently initiating a variety of enhanced surveillance technologies to assess such effects. Results of these studies to understand aging phenomena in plutonium will be reviewed.