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IGNITION AND BURNING CHARACTERISTICS
OF ZPPR FUEL ALLOY

By

R. E. Felt

Plutonium Chemistry Laboratory
Research and Engineering
Chemical Processing Division

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IGNITION AND BURNING CHARACTERISTICS OF ZPPR FUEL ALLOY

I. INTRODUCTION

A study of the ignition and burning characteristics of ZPPR (Zero Power Plutonium Reactor) fuel was requested by R. L. McVean of Argonne National Laboratory, Idaho Falls, Idaho. The concern prompting the study was the behavior of clad reactor fuel should core melting or fire occur, with subsequent disperions of plutonium and fission products to the environment.

II. SUMMARY AND CONCLUSIONS

The burning hazard associated with ZPPR fuel is less than anticipated. The alloy was found to be more difficult to ignite than plutonium and burns at a lower temperature and rate. The peak burn temperature of the alloy (825 °C) is the same as for plutonium, but is not above the alloy melting temperature (980 °C). Particle release from an alloy fire is much less, due to the nature of the oxide formed and the rigid shape of the burning metal. This property makes the ZPPR fuel much safer than pure plutonium.

Because of the lower burning rate, the extinguishing effect of heat-removal is greater for ZPPR fuel than for plutonium. It is difficult to maintain the burning metal in contact with a heat-removal surface such as stainless steel cladding or hood floors. A sustained burn can only be obtained by holding the alloy temperature about 500 °C with an external heat source, or by insulating the fire after ignition.

III. EXPERIMENTAL EQUIPMENT

The equipment used to conduct the metal fire tests is the same as reported in ISO-756.⁽¹⁾ The effect of two different heat-removal surfaces was determined on a metal fire. The first was Transite*, which provided an insulated test-surface. The second was a 3/16 in. stainless steel plate supported by bolts above the hood floor. This provided heat removal from a burning test by conduction through the steel plate and convection to the air.

A carbon-arc torch was used to ignite the alloy. Torch-application temperatures were probably above 1500 °C, although measured temperatures never exceeded 900 °C.

IV. DISCUSSION

A total of four ignition and burning tests were made on ZPPR fuel. The alloy for three tests was cast in the Plutonium Chemistry Laboratory in support of fuel element development studies.⁽²⁾ The fourth test used a declad ZPPR fuel plate supplied by Argonne National Laboratory. The alloy composition was approximately 69% uranium, 3% molybdenum, and 28% plutonium. The cast metal was in the form of plates 2 in. wide and 3/16 in. thick, with lengths varying from 1 1/2 to 12 in.

A. Ignition And Burning Characteristics

The first test used a 136.5 g section of fuel plate 1 1/2 in. long. The burn was made on Transite with normal torch ignition. The temperature of the plate rose rapidly to 720 °C before the heating was discontinued. The metal was not

* Transite is the trade name for an asbestos-cement board made by Johns-Manville.

able to maintain the temperature, which dropped to 500 °C before gradually rising. A comparison with a corresponding quantity of plutonium is shown in Figure 1.

The alloy burned at a slower rate than plutonium. It was also more difficult to ignite, as shown by the relatively-long period required to reach a maximum temperature (25 min). The small molybdenum content was known to retard the rate of oxidation (Figure 2).⁽³⁾ Uranium metal tested under comparable conditions was found to be self-extinguishing and not capable of sustained burning. Therefore, the 28% plutonium content of the alloy was sufficient to give burning characteristics more closely resembling plutonium than uranium.

B. Burning On Stainless Steel Surface

The second and third burning tests were designed to measure the effect of heat removal on burning alloy. This effect could then be compared with plutonium tests. A direct correlation between the characteristics of the two materials should be possible.

Burning Test 2 used two fuel plates. The smaller plate (127 g) was placed on top of the large plate (561 g). The two fuel plates were supported by a 3/16 in. SS plate elevated at each corner to allow air flow under the plate. Stainless steel-sheathed, chromel-alumel thermocouples were placed between the two fuel plates, and between the bottom fuel plate and simulated SS hood floor.

Ignition with the carbon-arc torch was concentrated on the top flat surface of the smaller fuel plate. Sixty seconds of heating produced a well-established burning condition, which reached 925 °C before heating was discontinued. Spread of burning through the small piece was rapid, with the sustained temperature dropping to 515 °C after 4 min and then gradually increasing to 835 °C after 55 min of burning. From this peak, the temperature gradually dropped to 100 °C at

Ref. D. M. Poole, et al., Plutonium 1960, p. 630. Cleaver-Hume Press
 Ltd., London. 1961

120 min burn time (Figure 3).

The recorded temperature of the thermocouple between the bottom fuel plate and the SS plate reached a maximum of 350 °C (Figure 3). This showed the bottom alloy plate to be a very good insulating surface, and the SS plate to be an effective heat radiator. The large temperature rise in the top plate indicates the insulating effectiveness of the oxide being formed on the burning surfaces. The maximum temperature (835 °C at 55 min) was obtained at nearly-complete combustion. The insulating effect of the oxide was sufficient to raise the metal temperature 315 °C.

The black oxide from the burned metal was removed from the larger plate, which had flaked and scaled on its exposed surfaces and edges, broken where it rested on the lower thermocouple, but had not ignited. Without moving or disturbing the unburned plate, the carbon-arc torch was applied at the broken ends of the plate. Three torch heatings of 80, 70, and 90 sec failed to establish a sustained burning condition. A broken end was then raised on top of the other end and the torch again applied for 120 sec. A sustained burning was established with the temperature rising from 500 to 680 °C. The lower plate showed no signs of burning.

Accumulated oxides on the burning upper plate were removed and the unburned lower plate was placed directly over the burning surface. After 90 min, the new top plate had not ignited, although burning continued in the lower plate. The torch was applied for 45 sec to the top plate before it was ignited.

The following observations are considered significant:

- Oxide from ZPPR fuel alloy was black, brittle, granular flakes similar to pure uranium, as contrasted with green-brown, powdery oxides from plutonium.

- . Ignition of the alloy was more difficult than plutonium, but much easier than uranium.
- . The burning rate (oxidation rate) of alloy plates was 60 to 65 g/hr, compared with plutonium at 150 to 180 g/hr. The lower burning rate explains the difficulty in maintaining the alloy fire.
- . Alloy in contact with another metal surface is extremely hard to ignite and maintain in a burning condition when heat dissipation to the second metal surface is possible.
- . The burning temperature of the alloy is 300 °C below its melting (1980 °C). Therefore, the metal is not molten--but remains brittle and subject to high-temperature fracture.

C. Burning On Insulated Surface

The third burning test was to duplicate Test 2, but on an insulated surface. Two alloy plates (481 and 209 g) were stacked on a Transite surface with the smaller plate on top. Thermocouples were placed between the plates and between the Transite and bottom plate.

The carbon-arc torch was concentrated on the smaller top plate for 60 sec, paralleling the ignition of the previous test. A momentary ignition temperature of 935 °C decreased to 560 °C in 3 min; then gradually increased to a peak of 830 °C at 26 min. From this point, the temperature gradually decreased to 160 °C in 310 min elapsed time. A comparison of the burning characteristics of the two-plate configuration is shown in Figure 4.

The temperature between the test material and the Transite surface gradually increased from 300 °C at the point of ignition of the upper plate to 650 °C at 130 min. The increase was due to the gradual spread of the burning through the larger

lower plate. As the burn spread through the upper plate, flaking and scaling were evident on the lower plate. The burning spread to the center of the lower plate caused the plate to bow and warp at its center. The plate ends were approximately 1 in. out-of-level.

The following observations are considered significant:

- . The coarse, granular oxide was denser than plutonium dioxide. This could best be illustrated by boiler scale compared with cinder-like sand.
- . Both alloy plates burned to complete combustion with one ignition. The lack of a heat sink definitely helped burning.
- . This material burned at a rate of 130 g/hr as compared with 60 to 65 g/hr on SS.
- . The alloy will warp if not heated uniformly.

D. Alloy Scrap

The fourth test consisted of burning scrap alloy pieces and accumulated oxide from storage. The test was made on Transite and duplicated previous conditions. Burning results and characteristics were identical to Test 1. No new significant observations were made other than that the test provided a convenient way of disposing of the alloy scrap.

E. Ignition Requirements Of Clad Fuel Plates

The fire hazard with a ZPPR fuel plate clad in SS is very limited. A fuel element fire could occur only with a ruptured element. The amount of oxygen necessary to sustain an alloy fire is approximately 18 g/hr per fuel plate. However, an equally-important requirement is maintaining an alloy temperature of 500 °C (932 °F), which would correspond to a fuel element exterior temperature of approximately 600 °C (1112 °F). The quantity of SS in a reactor core associated with support

structure control rods and the containment vessel itself would be a sufficient heat sink to prevent any fuel fire, unless the reactor core temperature rises above 600 °C in an oxygen environment. Such an accident analysis is beyond the scope of this report.

V. REFERENCES

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R. E. Felt