

UO₂/Magnetite Concrete Interaction and Penetration Study*

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The concrete structure represents a line of defense in safety assessment of containment integrity and possible minimization of radiological releases following a reactor accident. The penetration study of hot UO₂ particles into limestone concrete¹ and basalt concrete² highlighted some major differences between the two concretes. These included penetration rate, melting and dissolution phenomena, released gases, pressurization of the UO₂ chamber, and characteristics of post-test concrete. The present study focuses on the phenomena associated with core debris interaction with and penetration into magnetite type concrete.

The real material experiment was carried out with UO₂ particles and magnetite concrete in a test apparatus similar to the one utilized in the UO₂/limestone experiment¹. For experimental detail see Ref. 1. A cylindrical cast of magnetite concrete, 17.8 cm deep and 8.9 cm in diameter, prepared in a graphite container, was allowed to cure over two months before the experiment was conducted. Compressive strength of this concrete after 43 days of curing was 4.96×10^7 Pa (7205 psi). Two high-temperature thermocouples, 2.54 cm apart, embedded along the axis and 2.54 cm below the concrete surface was added to the array of other thermocouples along the axis. A mixture of 5500 g UO₂ and 50 g of each lanthanum oxide, barium oxide, and zirconium oxide powder was placed on the top of the concrete. The lanthanum, barium, and zirconium oxides were added to simulate fission products. These oxides increased both

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the volume of the charge and the effective dielectric constant of UO_2 considerably. For a successful melting and penetration experiment, the test section was heavily insulated.

Heating of UO_2 was achieved by the initial ignition of a uranothermic mixture, followed immediately by the input of continuous electric power into UO_2 . A steady-state power input of 2 W/g was achieved about 55 min. into the experiment. However, melting of concrete did not occur until 35 min. later. The melting point of this concrete as determined from the thermocouple data is about 1670°C.

Post-test analysis of the test sample revealed that the top surface of the solidified UO_2 had remained in its original position but contained equally spaced entrapped gas bubble caps which had not been broken through. The gas escape route was from around the tungsten electrode. The UO_2 /concrete mixture was porous and multicolored. The different colors could have resulted from different chemical elements such as Fe, Al, Mg, Si, Ca, La, and Zr that were present in the molten mixture. The solidified mixture appeared to have been fully molten, unlike the UO_2 /basalt mixture, which contained full-size aggregates. The dehydrated concrete beneath UO_2 /concrete solidified mixture preserved its strength and did not appear to be hygroscopic a few days later. A melting rate of about 0.18 cm/min was determined from both the high-temperature thermocouples data and the overall penetration distance measurements.

X-ray fluorescence analysis of samples taken from different locations in UO_2 /magnetite concrete mixture contained the following elements: U, Fe, Cr, Ca, W., Zr, Ba, La, and Th. Lanthanum, barium, and zirconium were the oxides added to the UO_2 charge; W is from the electrode, and other elements are constituents of the magnetite aggregate. The amount of Ba was very minute, indicating dispersal.

Spectral analysis of the elements captured by an external filter in the released gases manifold are given in Table 1. Among the detectable elements, Al, Ba, Ca, Fe, U, and Zn were the highest. Aluminum, calcium, and iron were from the magnetite rock, and barium was the tracer element. It appeared that zirconium oxide and lanthanum oxide had dissolved in the molten mixture and were not vaporized or sparged, whereas barium oxide did migrate and was deposited on the array of filters. The dissolution of Zr and La in molten concrete was confirmed by the x-ray fluorescence.

Results of the analyzed gas samples are given in Table 2. These samples were obtained when the concrete temperature 2.54 below the surface reached values of 191°C, 657°C, 930°C and 1208°C. The idealized form of this concrete is free of any CO₂ gas. Thus the measured CO and CO₂ could have resulted from the reaction of water vapor with hot graphite container and/or UO₂. The minute amount of H₂ comes from the dissociation of the water vapor. In conclusion, this concrete appears to be the most stable type as to reaction and penetration by UO₂ and its integrity is well preserved throughout the extreme condition.

References

1. R. Farhadieh, R. Purviance, and N. Carlson, "Downward Penetration of UO₂ into Limestone Concrete," Trans. ANS, 43, 516 (Nov 1982).
2. R. Farhadieh, R. Purviance, and N. Carlson, "Downward Penetration of Hot UO₂ into Basalt Concrete," Trans. ANS, 44, (June 1983)

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Table 1

Spectral Analysis of Elements Present in Aerosol Filter in Micrograms

| | | | | | | | | |
|------|------|------|-----|------|-----|------|-----|------|
| Ag | Al | Ba | Be | Ca | Co | Cr | Cu | Fe |
| 29.5 | 3093 | 6860 | < 1 | 3040 | < 5 | 570 | 265 | 5200 |
| La | U | Mg | Mn | Mo | Ni | Zn | Zr | |
| 40 | 3000 | 190 | 61 | 295 | 30 | 4690 | < 3 | |

Table 2
 Analyzed Gas Samples and Their Rate at Different Concrete Temperatures

| Sample # | Time (Min) Temp (°C) | Percent/cc/min | | | | |
|----------|-------------------------|----------------|----------------|-------|----------------|-----------------|
| | | H ₂ | N ₂ | CO | O ₂ | CO ₂ |
| 1 | 25 | <.1 | > 76.9 | < .7 | 20.5 | .5 |
| | 191 | <.87 | >669.03 | <6.09 | 178.35 | 4.35 |
| 2 | 62 | <.05 | > 76.8 | <1.2 | 20.7 | .03 |
| | 657 | <.125 | >192 | <3 | 51.75 | .075 |
| 3 | 78 | <.06 | > 77.1 | < .4 | 21.2 | .03 |
| | 930 | <.15 | 192.75 | 1 | 53 | .075 |
| 4 | 97 | <.05 | > 77.5 | < .6 | 20.7 | .04 |
| | 1208 | <.125 | >193.75 | <1.5 | 51.75 | .1 |