# A Physical and Chemical Analysis of Fast Quenched Corium Particles

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## 1. Introduction

The risk of a steam explosion due to a molten fuel and coolant interaction during a hypothetical accident in a nuclear power plant has been investigated during last two decades. It turns out that the strength of the steam explosion highly depends on the composition of the molten fuel. While a non-prototypic material such as alumina did results in an energetic explosion, a prototypic material led to a rather weak explosion [1]. More importantly, the composition of the fuel highly affected the explosion strength[2]. It was a very important finding from a nuclear reactor safety point of view. However, the physical mechanism behind this phenomenon is still beyond understanding. So, a physical and chemical analysis of the fast quenched corium particles, which were produced from several experiments performed at different $UO_2$ and $ZrO_2$ compositions, was performed to provide a clue to this mystery.

## 2. Cases Analyzed

The fast quenched particles were sampled after the fuel and coolant interaction experiments. The experiments were performed in the TROI test facility [2]. A molten liquid jet at around 3000 K was poured into a pool of liquid at room temperature. The liquid jet is broken into particles by a hydrodynamic stability at first. Then, they are broken up further by an energetic steam explosion, which are called debris. A typical particle size distribution is shown below for TROI-36 experiments.

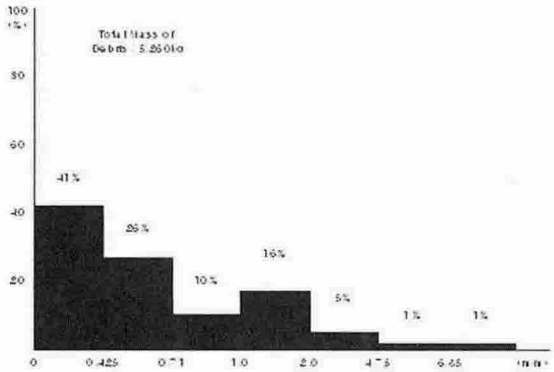


Fig. 1 Debris Size distribution(TROI-36)

If there is an energetic steam explosion, the amount of the smallest particles at sizes below 0.425 mm is substantial. To investigate the effect of the composition, seven cases are selected. Mainly, the composition of the molten fuel is changed, while other initial and boundary conditions of the tests are maintained as almost the same. The charged composition, occurrence of steam explosion, hydrogen generation during the experiment, and percentages of the debris at sizes below 0.425 mm are indicated.

Table 1. A Summary of the Test Cases

| Test | Weight Ratio of $UO_2/ZrO_2$ | Occurrence of Steam Explosion | $H_2$ generation (ppm) | Percentage of debris < 0.425 mm |
|---|---|---|---|---|
| TROI-13 | 70:30 | Yes | 165 | 18.9 |
| TROI-17 | 78:22 | No | 789 | 1.53 |
| TROI-23 | 78:22 | No | 438 | 2.74 |
| TROI-29 | 50:50 | No | 619 | 8.69 |
| TROI-32 | 90:10 | No | 1010 | 5.32 |
| TROI-36 | 70:30 | Yes | 14200 | 40.8 |
| TROI-37 | 78:22 | Yes | 17100 | 29.34 |

## 3. Physical and Chemical Analysis

We used a Scanning Electron Microprobe (SEM) to figure out the morphology. The wet analysis using ICP-AES and an elementary analysis using an Electron Probe Micro Analysis (EPMA) were performed to identify the chemical composition. And the X-ray diffraction (XRD) patterns were measured for the phase characterization. To make the comparison meaningful, the samples were taken from the particles at sizes below 0.425 mm.

### *3.1 Morphologies*

The morphologies for the particles are taken by a SEM at 40, 200, 500, and 1000 magnifications for each sample.

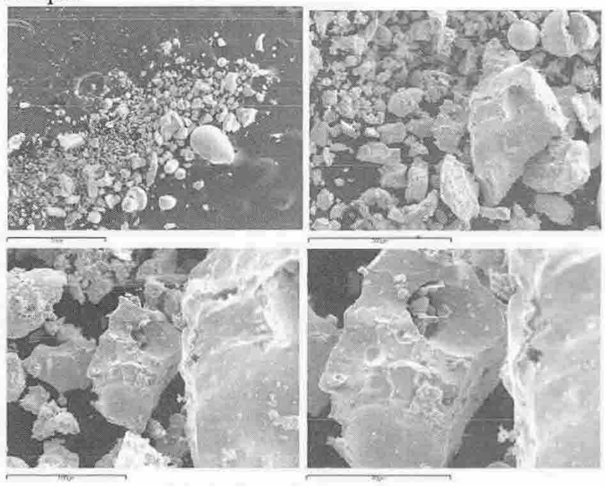

Fig. 2 Magnified view of the particles for TROI-36

In Fig. 2, the morphologies for a steam explosion case, TROI-36 are shown. Most of the particle sizes are less than 0.05 mm, the shapes of the particles are rather irregular and the surface is rough. This explains that the prototypic molten material is finely fragmented and leads to a steam explosion as strong as 17.0 MPa of a dynamic pressure. The TROI-13 case at the same composition showed a similar trend. A comparative case of TROI-37, which was at a 80:20 weight percent, did not lead to an energetic steam explosion(7.7 MPa). This reason is that a particle size of less than 0.425 mm is large, but the most of the particles are fragmented at as large as 0.25 mm. The shapes of the particles are a regularly pattern, almost spherical, and the surface is smooth.

Fig. 3 shows the morphology of the TROI-17, in which a steam explosion did not occur. The portion below 0.425 mm is as small as 1.53% and the most abundant size is 0.5 mm. The shapes are a cylindrical and spherical type, and their surfaces are regular and smooth. The non-steam explosion cases such as TROI-17, 23, 29 and 32 show a similar trend.

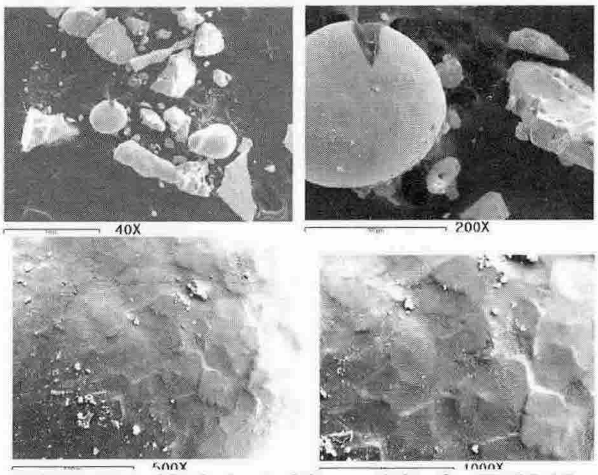


Fig. 3 Magnified view of the particles for TROI-17

*3.2 Chemical Analysis*

Since the chemical composition of the particles could be different from that of the charging, chemical analyses were performed and the results are shown in Table 2. The results indicate that the charged composition was close to the fast quenched melt in the water. The small difference comes from using $ZrO_2$ as a lining material, because $ZrO_2$ remains at the inner surface crust in the cold crucible. Since the EPMA analyzes only the surface of the samples, its result is different from that of the wet analysis. The quenched melt is believed to be a uniform solid solution, because of the almost same composition for the same samples. The relationship between the surface phenomena and the steam explosion is under study, and this will make it clearer.

Table 2. Results of Chemical Analysis

| Test | Weight Ratio of $UO_2/ZrO_2$ | Wet Analysis | EPMA |
|---|---|---|---|
| TROI-13 | 70:30 | 70.09/27.22 | 54.94/45.06 |
| TROI-17 | 78:22 | | 69.17/30.83 |
| TROI-23 | 78:22 | 78.62/20.40 | 70.85/29.15 |
| TROI-29 | 50:50 | | 61.01/38.99 |
| TROI-32 | 90:10 | 85.65/12.02 | 83.87/16.13 |
| TROI-36 | 70:30 | 73.97/25.26 | 67.44/32.56 |
| TROI-37 | 78:22 | 76.80/24.86 | 71.15/28.85 |

To look at the possibility of the oxidation of molten $UO_2$ to $U_3O_8$ during a melting and quenching in the water, a XRD analysis was performed for the particles. As shown in Fig.4, the result indicates that the peaks of the debris were quite close to $UO_2$.

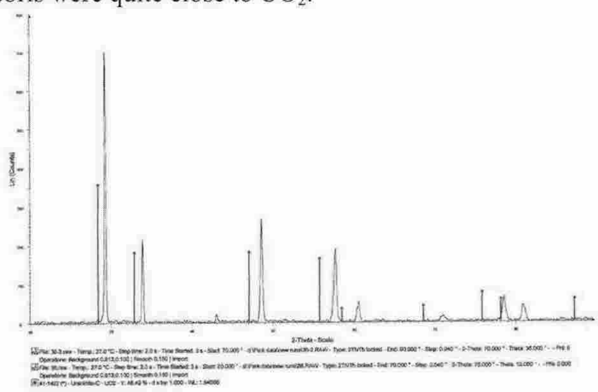

Fig. 4 XRD for TROI-36 debris

## 4. Conclusion

A physical analysis of the fast quenched particles during the molten fuel and coolant interaction clearly indicated the difference in the morphology whether a steam explosion occurred, or not. The wet chemical analyses indicated that there was a good-mixing during the melting in the crucible. The fundamental mechanism, which affects the strength of the steam explosion, will be investigated further based on this data.

## ACKNOWLEDGMENTS

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## REFERENCES

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[2] J. H. Song and J. H. Kim, The Effect of Composition on the Fuel and Coolant Interaction, to appear in Nuclear Technology, 2004.