Use of Gadolinium as a Primary Criticality Control in UO$_2$ Fuel Fabrication Process

D. A. Eghbali

david.eghbali@ge.com

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Overview

• Introduction
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• Conclusions
Introduction

Global Nuclear Fuel – Americas (GNF-A) fuel fabrication facility involves in production, processing, handling, and storage of uranium oxide enriched to <5 wt% 235U.

Wilmington Site
Introduction (cont)

Gad Fabrication Process

- $\text{UO}_2/\text{Gd}_2\text{O}_3$ powder $\rightarrow$ pellets $\rightarrow$ Rods

- Uranium is handled and stored in less than a safe mass in favorable geometry containers.

- Fabrication processes are dry and under moderation control.
Introduction (cont)

- Gadolinium Fabrication processing relies on mass, geometry and moderation control for criticality safety.

- There are nearly 100 IROFS protecting against accidental criticality in the Gad fabrication area. Maintaining management measures associated with these IROFS is costly.

- Between 2–10 wt% of Gd$_2$O$_3$ powder is mixed with the UO$_2$ powder to make fuel rods containing gadolinium. Gadolinium is an excellent burnable poison that is used for controlling long-term reactivity in thermal reactors.

- Taking credit for gadolinium could significantly reduce the number of IROFS.
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Introduction (cont)

Mechanical mixing of $\text{Gd}_2\text{O}_3$ with $\text{UO}_2$
Introduction (cont)

Vibromill (media)
Introduction (cont)

- Multiple samples of UO$_2$/Gd$_2$O$_3$ powder are analyzed for Gd uniformity and content before pellet press.
- Pellet samples are also analyzed at the furnace exit for Gd uniformity and content.

**X Ray Fluorescence Diagram**
Methodology

- Two Monte Carlo codes, GEMER and SCALE6.1/KENO–VI, are used to calculate the minimum amount of Gd$_2$O$_2$ required to maintain subcriticality in the event the mixture is moderated.

- GEMER is a patented multi group Monte Carlo code used at GNF–A. GEMER uses 190-group cross sections from ENDF/B–IV.

- GEMER has Virtual Fill Option (VFO) which allows a region (big region) to be filled with a virtual representation of another region (fill region). VFO allows easy modeling of heterogeneous mixtures.

- SCALE6.1/KENO–VI has a dodecahedral array option that can be used for modeling of heterogeneous mixtures.
Methodology (cont)

GEMER Virtual Fill Option Illustration
Virtual Fill Option

- Eliminates the presence of partial fill regions near the big region boundary.
- Allows easy creation of heterogeneous models, including square or triangular pitch cylinder array, simple cubic, body centered cubic, or face-centered cubic array of spheres, and triangular lattice of spheres using lattice geometry constructs (INTERS, SPINTERS, TRITERS).
- Eliminates the need for lengthy input files.
- Results in faster run time.
Methodology (cont)

Heterogeneous Modeling with GEMER

- TRITER geometry construct allows a triangular-pitched array of spheres.

- INTER geometry construct allows a triangular-pitched array of fuel pellets.
Methodology (cont)

Heterogeneous Modeling with KENO–VI

Rhombic Dodecahedron

Dodecahedral Array
Results

Comparison of Homogeneous & heterogeneous Systems of UO$_2$ and water

![Graph showing comparison of Homogeneous and heterogeneous systems of UO$_2$ and water]
Results (cont)

Infinite Homogeneous System of UO$_2$ and water
Results (cont)

Infinite Homogeneous System of UO₂ + Gd₂O₃ (0.3 wt%) and water
Results (cont)

Infinite Homogeneous System of UO$_2$ and water
Results (cont)

Infinite Homogeneous System of UO$_2$+Gd$_2$O$_3$ and water
Results (cont)

Infinite Homogeneous System of UO₂ and water
Results (cont)

Infinite Heterogeneous System of UO$_2$ and water
Conclusions

Gadolinium can be credited for criticality safety provided the following key controls are in place:

• Gadolinium Quality Control

• Gadolinium Addition and Verification

• Uniform Mixing and Verification

• Verification of Gadolinium Content in Fuel
Conclusions (cont)

Key Controls at GNF-A:

• The Quality Assurance program requires a set of specifications for Gd$_2$O$_3$ powder procurement.

• The procured Gd$_2$O$_3$ powder shall be sampled at the site laboratory to verify its isotopic weight percent.

• Augmented administrative controls ensure the correct amount of Gd$_2$O$_3$ (2–10 wt%) is mixed with UO$_2$ powder. Calculations demonstrates 0.5 wt% Gd$_2$O$_3$ is needed for criticality safety.

• Multiple samples of UO$_2$/Gd$_2$O$_3$ mixtures are analyzed using X-Ray Fluorescence Analyzer to verify uniformity and weight percent.
Conclusions (cont)

Favorable Factors in Gad Fabrication Process:

• Fuel is handled and stored in less than a safe mass in safe geometry containers.

• Fabrication processes are dry and the area is under moderation control.

• \( \text{UO}_2 \) and \( \text{Gd}_2\text{O}_3 \) are insoluble in water.

• There are no reactions in the fabrication processes that could preferentially separate \( \text{Gd}_2\text{O}_3 \) from \( \text{UO}_2 \).