GE Hitachi Nuclear Energy

Use of Gadolinium as a Primary Criticality Control in UO_2 Fuel Fabrication Process

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Overview

- Introduction
- Methodology
- Results
- Conclusions

Introduction

Global Nuclear Fuel – Americas (GNF-A) fuel fabrication facility involves in production, processing, handling, and storage of uranium oxide enrich

Wilmington Site

Introduction (cont)

Gad Fabrication Process

- UO_2/Gd_2O_3 powder → pellets → 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_2O_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.

Introduction (cont)

Mechanical mixing of Gd_2O_3 with UO_2

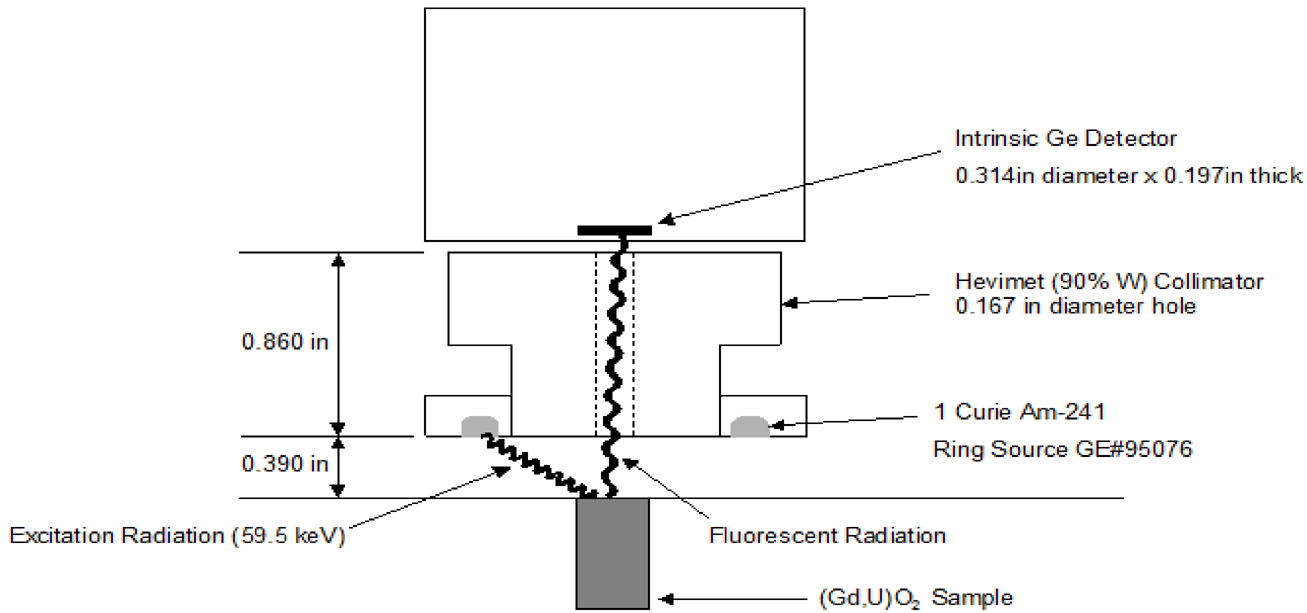
Vibromill

Introduction (cont)

Vibromill (media)

Introduction (cont)

- Multiple samples of UO_2/Gd_2O_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.



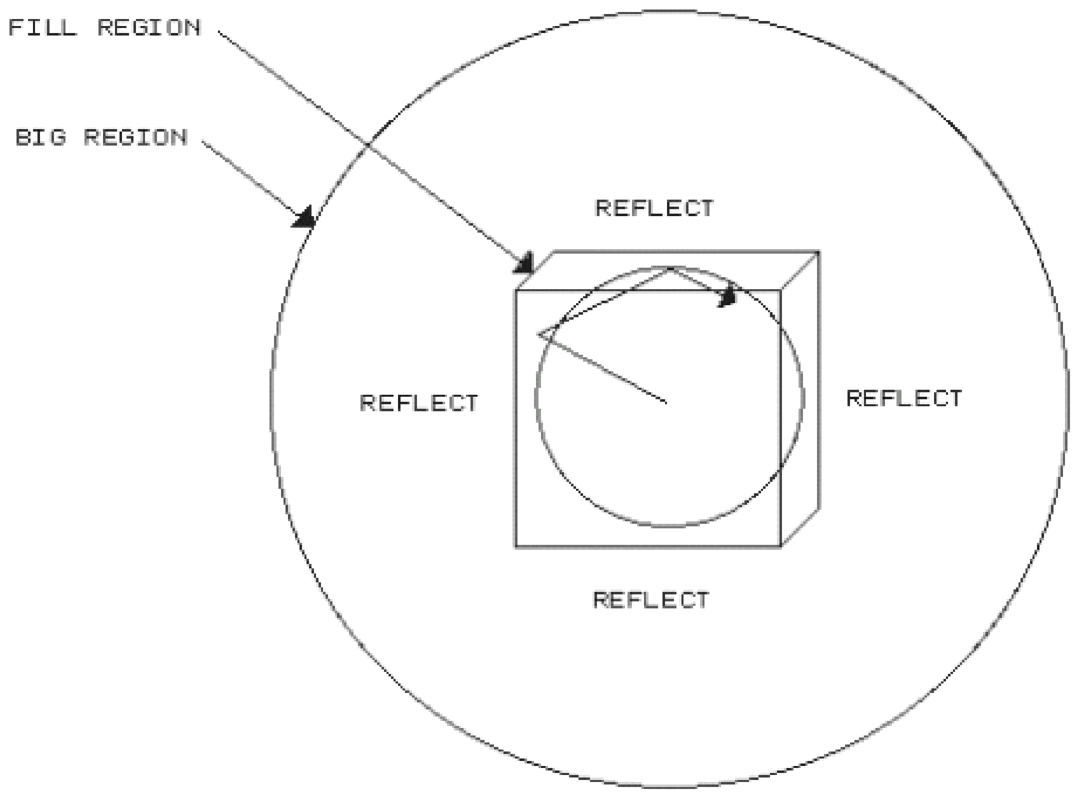
X Ray Fluorescence Diagram

Methodology

- Two Monte Carlo codes, GEMER and SCALE6.1/KENO-VI, are used to calculate the minimum amount of Gd_2O_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



Methodology (cont)

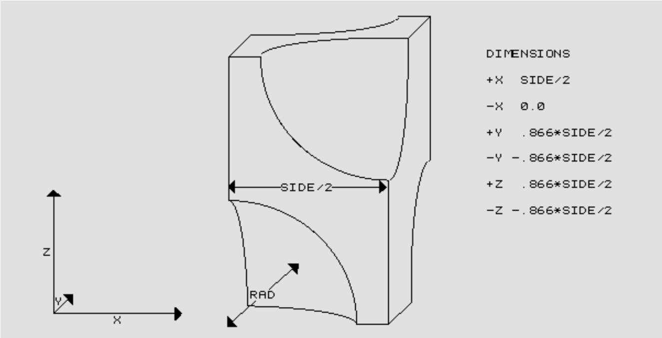
Virtual Fill Option

- 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.

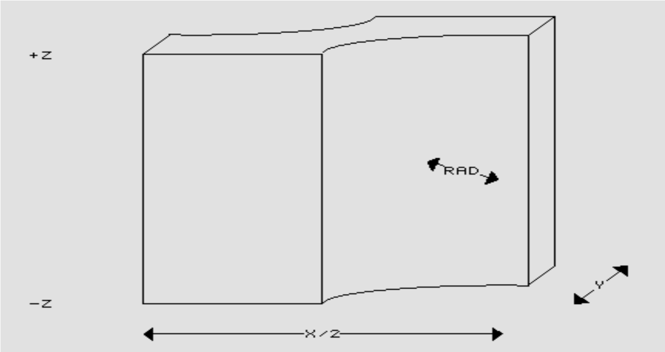
Methodology (cont)

Heterogeneous Modeling with GEMER

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

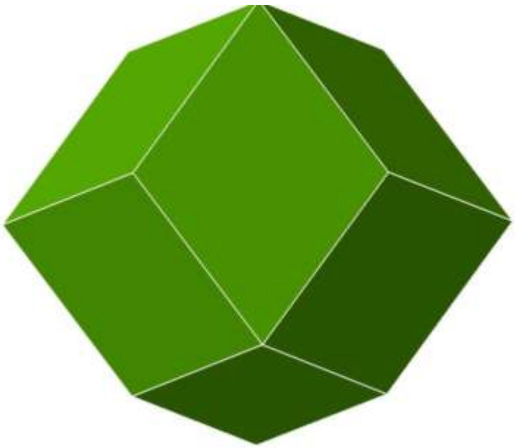


- INTER geometry construct allows a triangular-pitched array of fuel pellets.

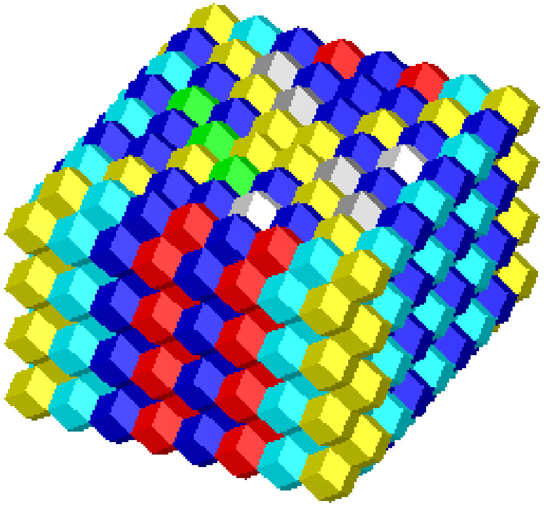


Methodology (cont)

Heterogeneous Modeling with KENO-VI



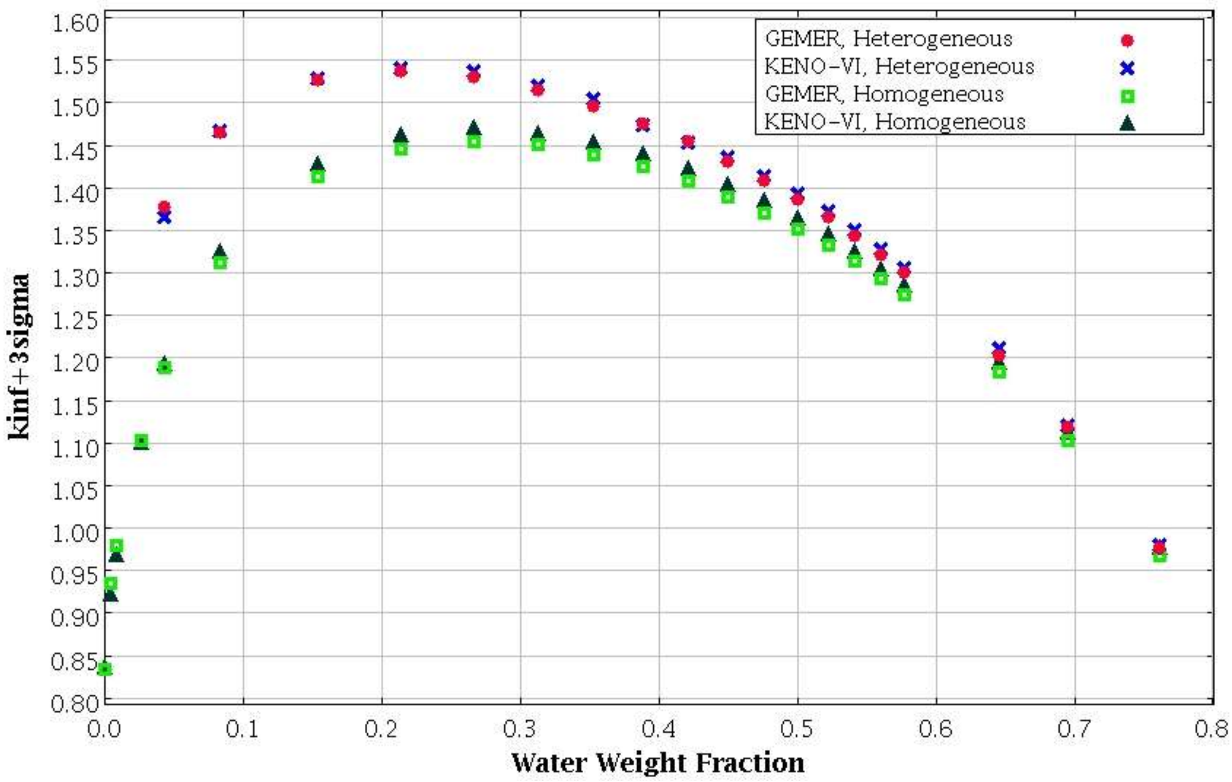
Rhombic Dodecahedron



Dodecahedral Array

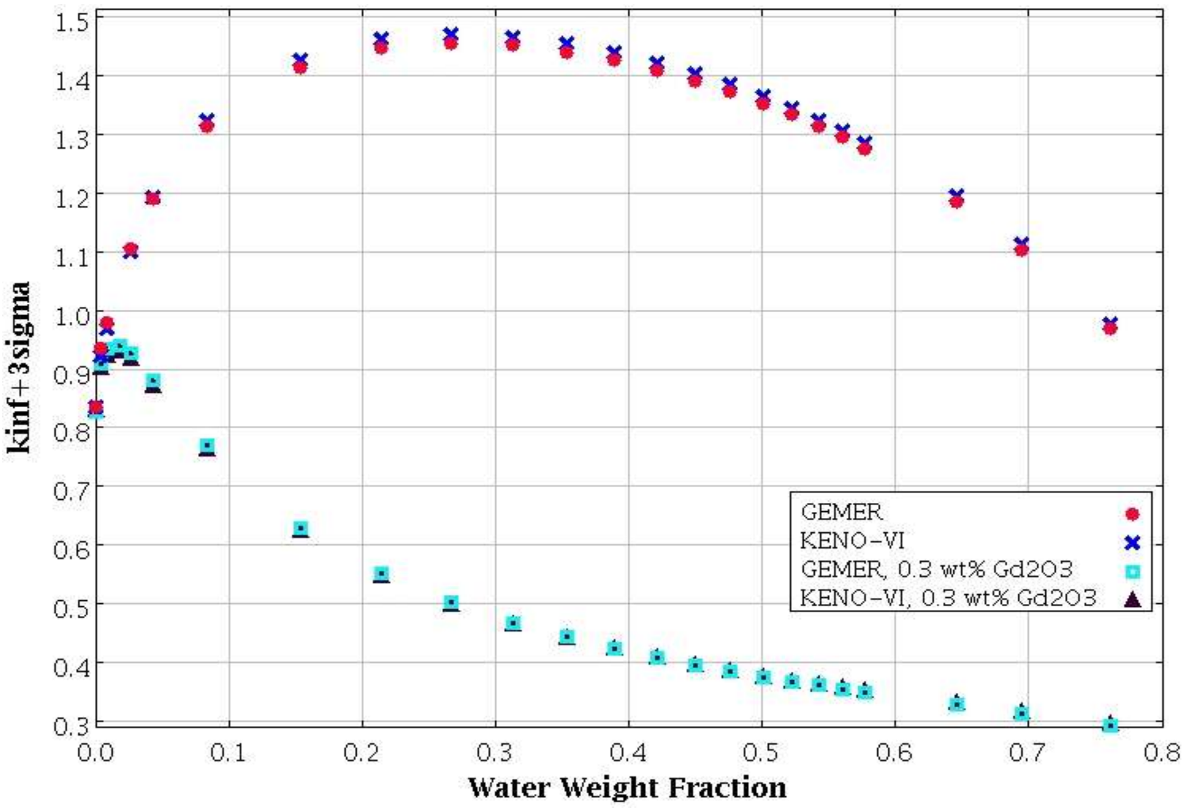
Results

Comparison of Homogeneous & heterogeneous Systems of UO_2 and water



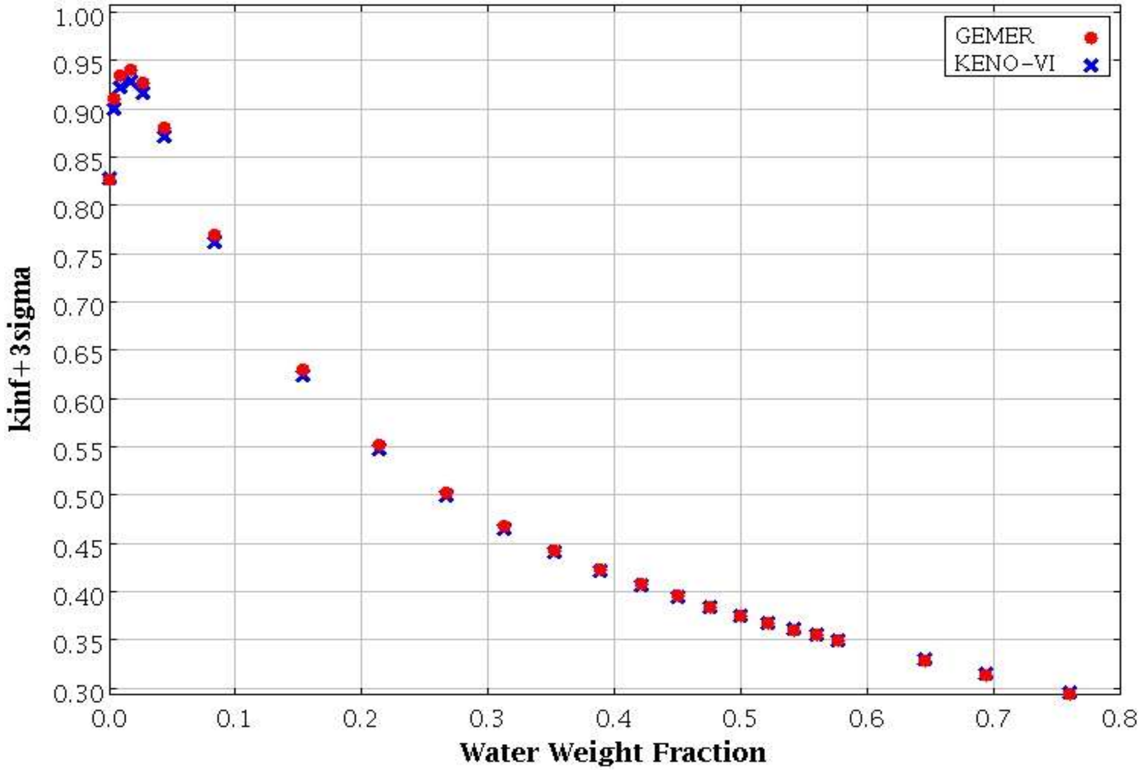
Results (cont)

Infinite Homogeneous System of UO_2 and water



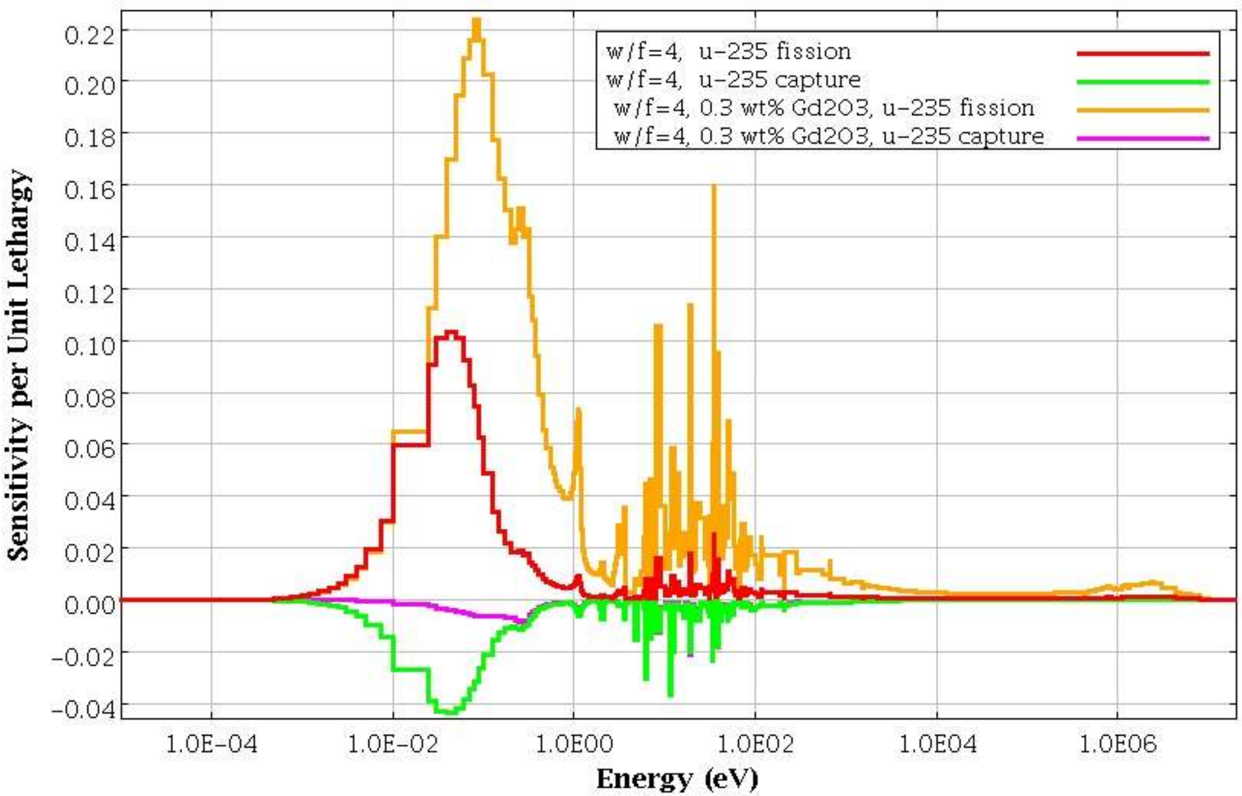
Results (cont)

Infinite Homogeneous System of UO_2 + Gd_2O_3(0.3 wt%) and water



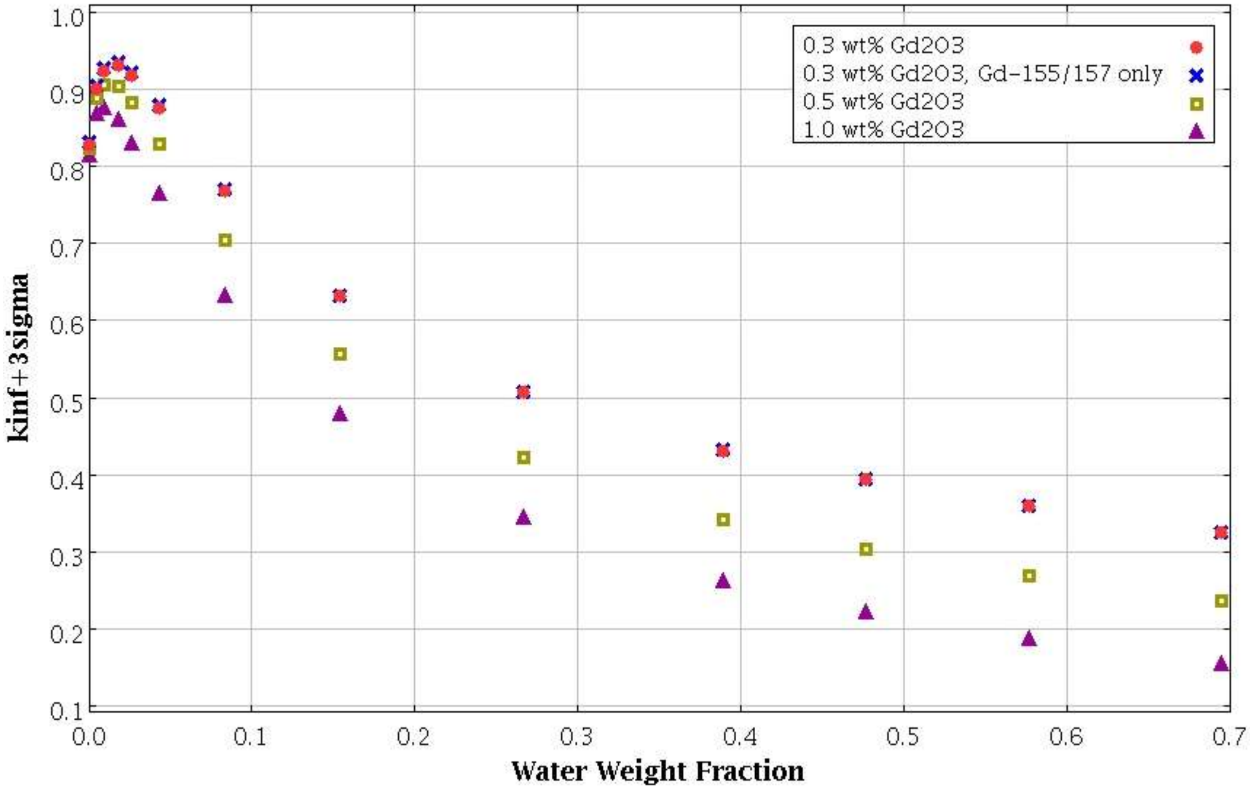
Results (cont)

Infinite Homogeneous System of UO_2 and water



Results (cont)

Infinite Homogeneous System of UO_2+Gd_2O_3 and water



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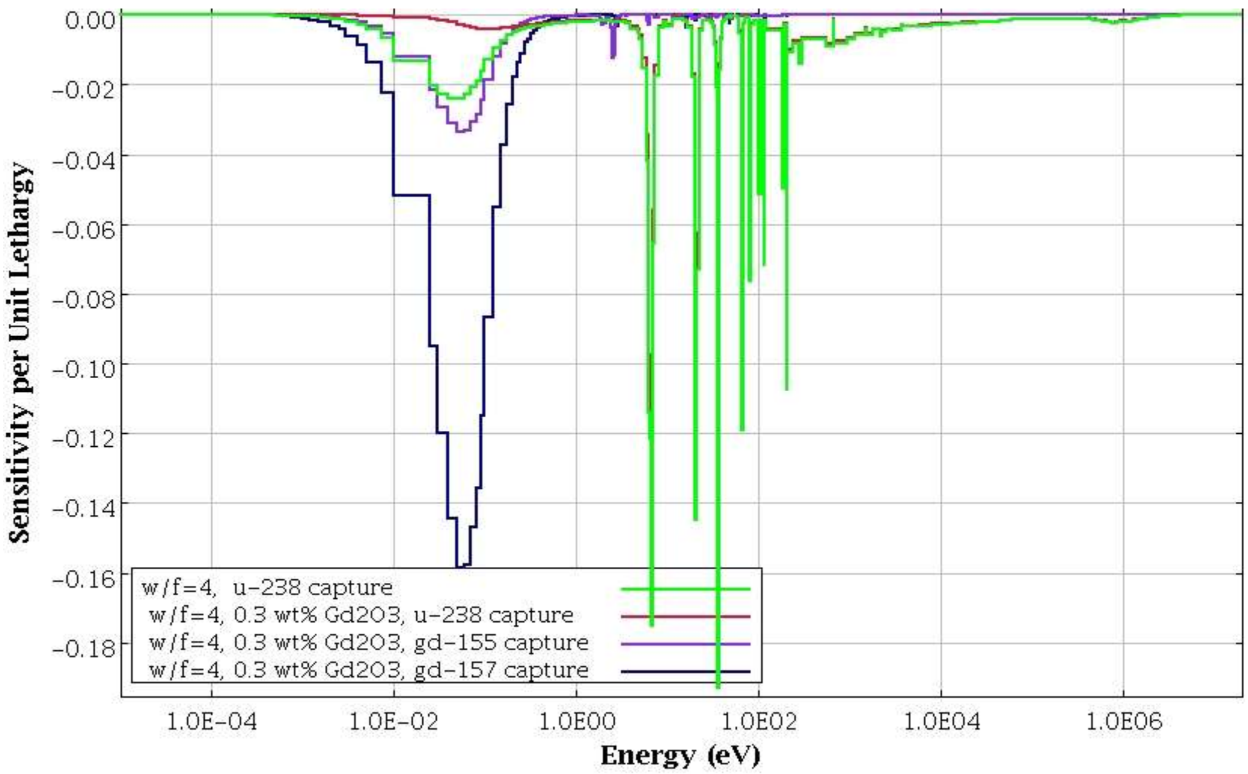
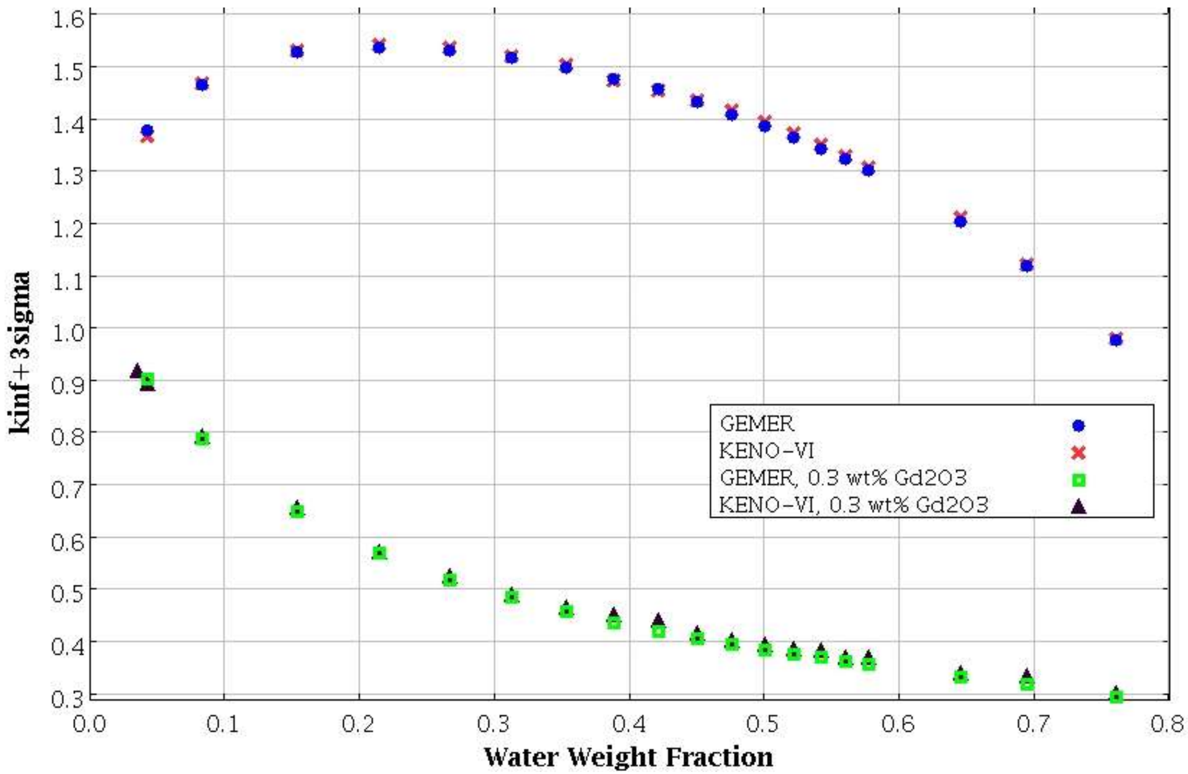
Results (cont)

Infinite Homogeneous System of UO_2 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_2O_3 powder procurement.
- The procured Gd_2O_3 powder shall be sampled at the site laboratory to verify its isotopic weight percent.
- Augmented administrative controls ensure the correct amount of Gd_2O_3 (2-10 wt%) is mixed with UO_2 powder. Calculations demonstrates 0.5 wt% Gd_2O_3 is needed for criticality safety.
- Multiple samples of UO_2/Gd_2O_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.
- UO_2 and Gd_2O_3 are insoluble in water.
- There are no reactions in the fabrication processes that could preferentially separate Gd_2O_3 from UO_2.