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

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Global Nuclear Fuel
A Joint Venture of GE, Toshiba, & Hitachi

Overview

- Introduction
- Methodology
- Results and Discussion
- Conclusions

Introduction

Global Nuclear Fuel - Americas (GNF-A) fuel fabrication facility involves in production, processing, handling, and storage of uranium oxides enriched to $\leq$ 5 wt% ^{235}U.

Wilmington Site – 1650 acres (300 developed)

Introduction - Nature of the Fabrication Process

Gad Fabrication Process

U_nO_m powder + Gd_2O_3 powder → pellets → Rods

Introduction - Nature of the Process

- After Gd_2O_3 addition (2-10 wt.%), the mixture is stored and handled in less than a safe mass in 3-gallon favorable geometry cans.



- Fabrication processes are dry and under moderation control.

Introduction - Uniform Mixing

Uniform mixing of Gd_2O_3 powder with U_nO_m powder

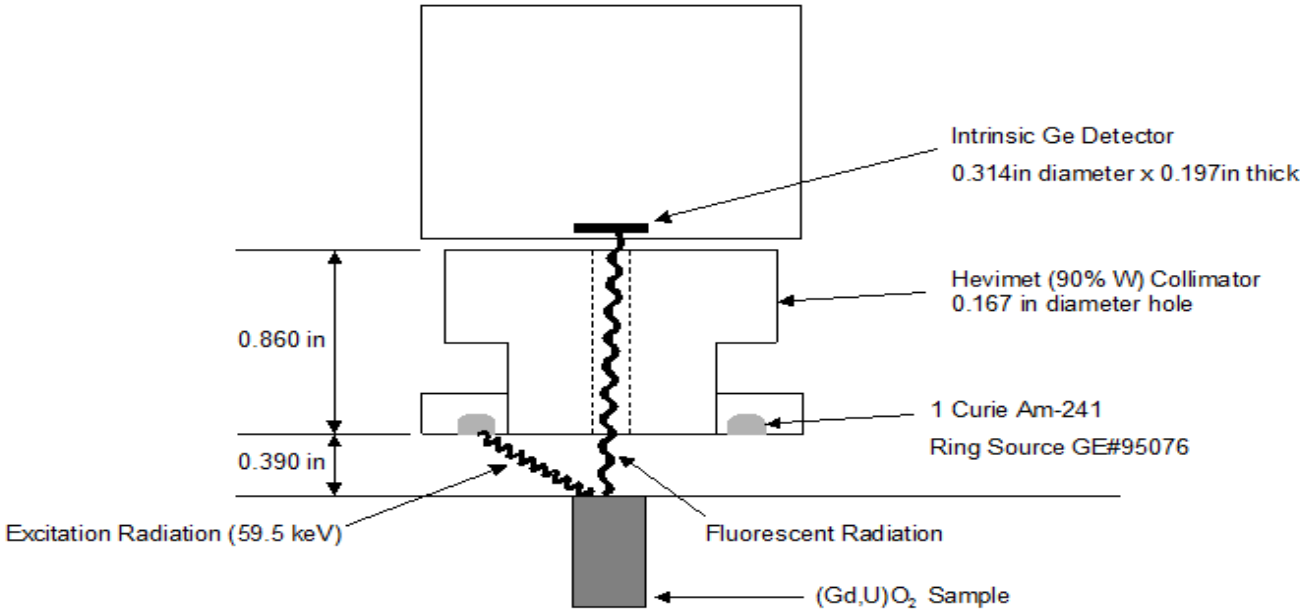
Vibromill

Introduction - Uniform Mixing

Vibromill (media)

Introduction - Uniform Mixing

- Multiple samples of $UO_2 + Gd_2O_3$ powder are analyzed for Gd uniformity and content before pellet production.
- Pellet samples are also analyzed at the furnace exit for Gd uniformity and content.



X Ray Fluorescence Diagram

Introduction - Current Safety Basis

- Gad fabrication processing relies on mass, geometry and moderation controls for criticality safety.
- No credit for Gd presence or the nature of the process.
- Nearly 90 IROFS against accidental criticality.
- Maintaining management measures for IROFS is costly.
- Potential for regulatory violations.
  - Powder spill in Gad Slugger Hood (2010)
  - Gad Press Feed Tube Overfill (2011)
  - Gad Press Feed Tube Overfill (2012)

Introduction - Gadolinium as Neutron Poison

- Small amount of Gd_2O_3 is sufficient to prevent a criticality accident in the event the fuel mixture is accidentally moderated.
- Gd_2O_3 is mixed well with uranium oxide powder.
- Gd_2O_3 does not separate from uranium during the fabrication process.
- Taking credit for Gd_2O_3 can significantly reduce the number of IROFS and regulatory violations.

Introduction - Minimum Required Gd_2O_3

How much Gd_2O_3 is needed to maintain an infinite system of uranium oxide subcritical under optimum moderation and refection?

- Need to analyze both Homogenous and Heterogeneous systems.
- Homogenous systems: Uranium oxide powder
- Heterogeneous systems: Uranium oxide swarf, pellets, rods.

Methodology

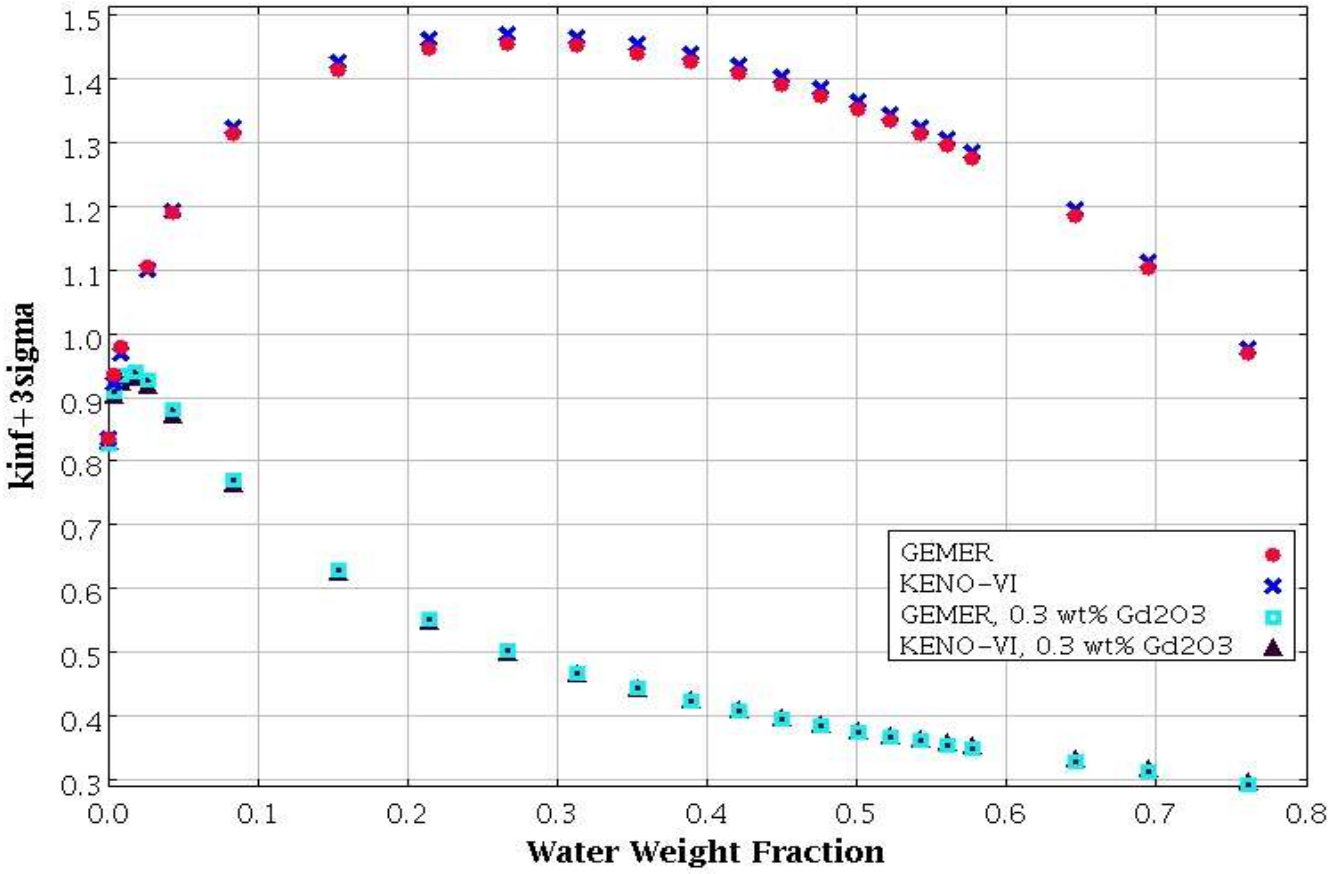
- Two Monte Carlo codes, GEMER1.2 and SCALE6.1/ KENO-VI, are used to calculate the minimum amount of Gd_2O_3 required to maintain subcriticality.
- GEMER is a GEH proprietary multi-group Monte Carlo code used at GNF-A. GEMER uses 190-group cross sections from ENDF/B-IV.
- SCALE6.1/KENO-VI has a dodecahedral array option that can be used for modeling of heterogeneous mixtures. SCALE uses 238-group/CE cross sections from ENDF/B-VII.0.

Methodology - Heterogeneous System Modeling

- **GEMER: Virtual Fill Option (VFO)**
  - It allows easy creation of heterogeneous models.
  - Triangular-pitched arrays are easily created using geometry constructs (INTERS, SPINTERS, TRITERS).
  - Results in faster run time.
- **SCALE6.1: Dodecahedral array**

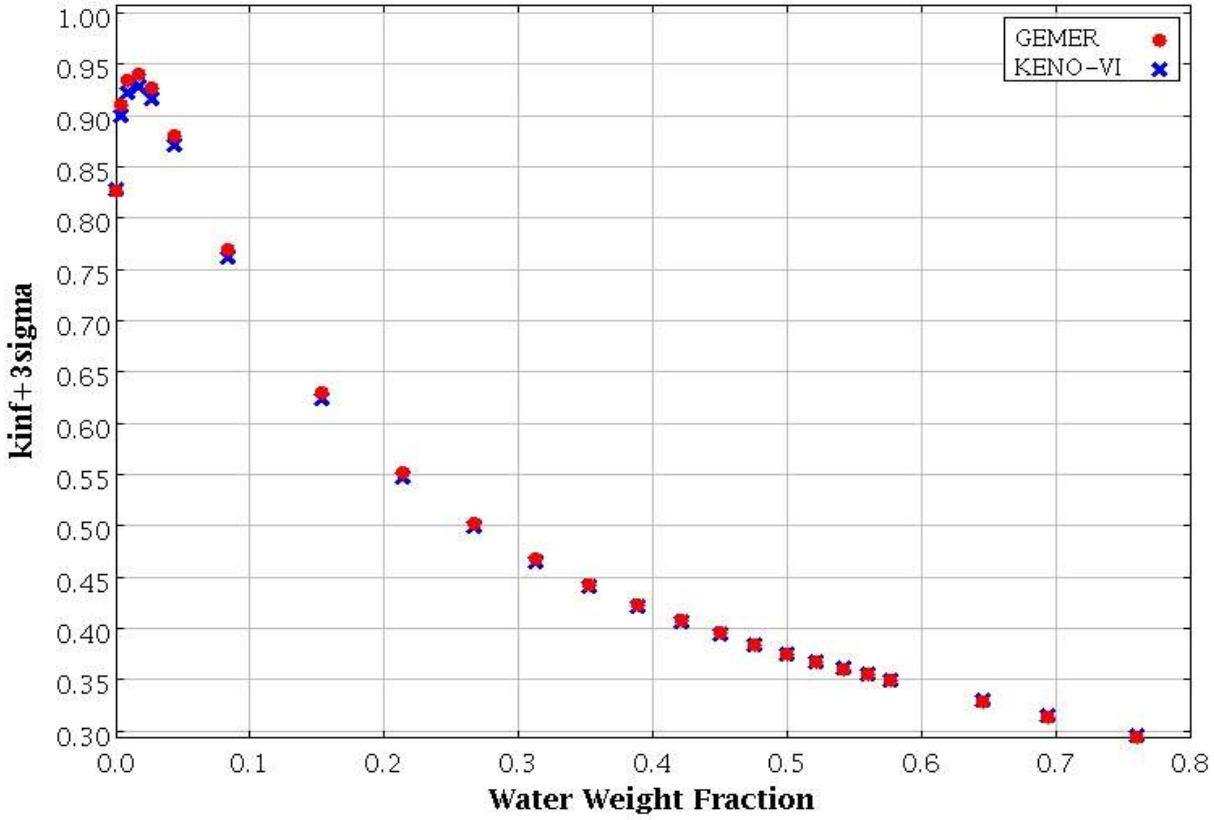
Results and Discussion

Infinite Homogeneous System of UO_2 and water



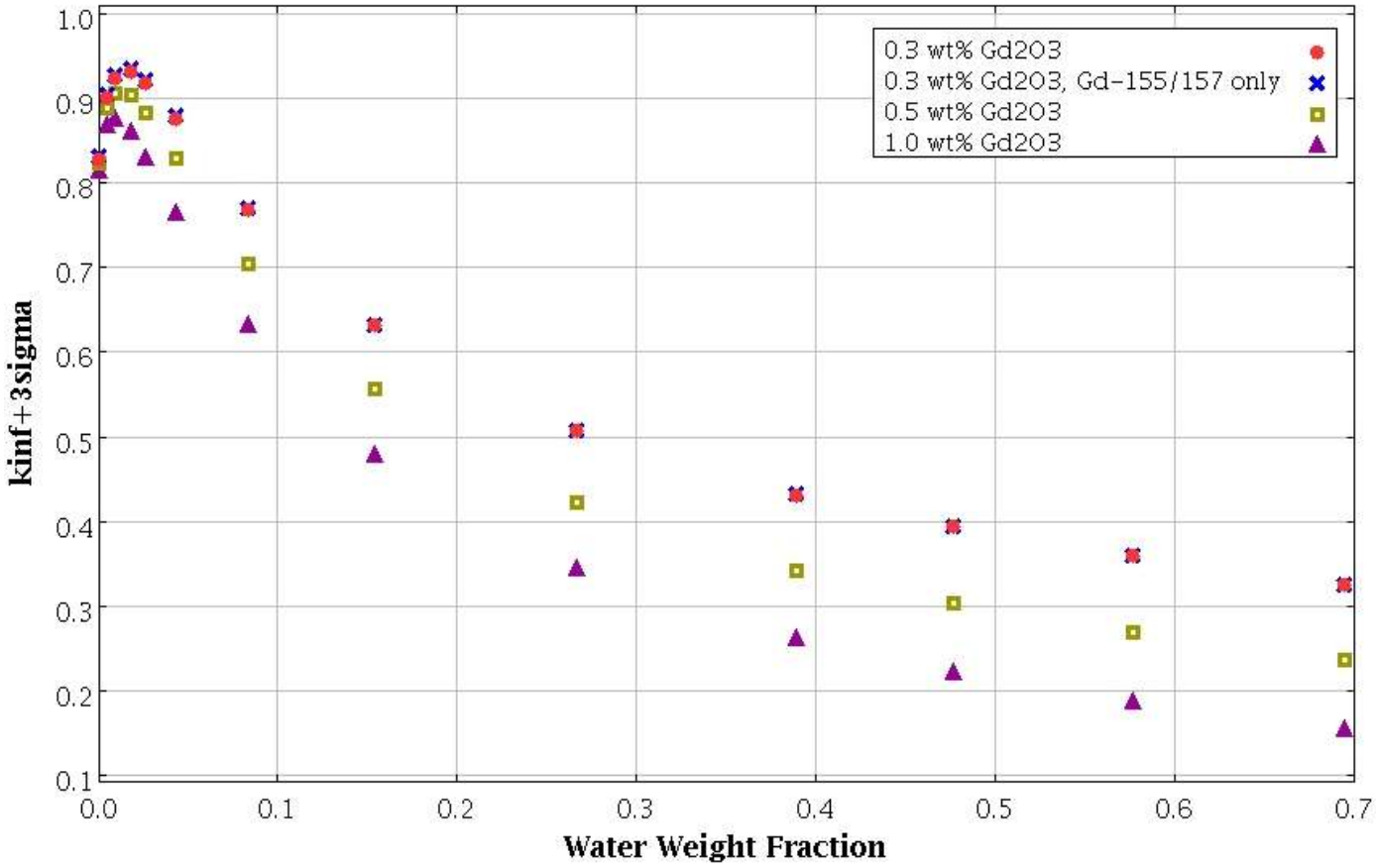
Results and Discussion

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



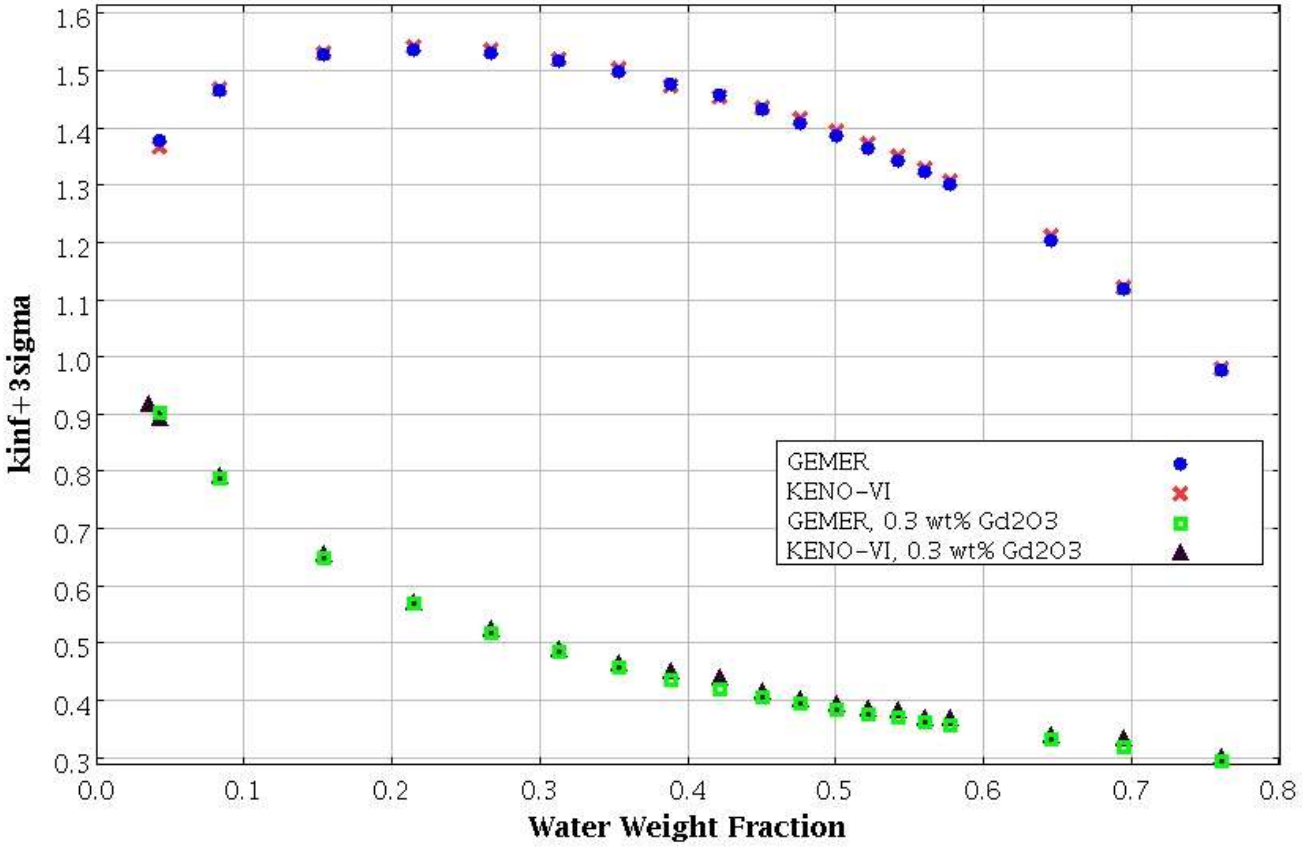
Results and Discussion

Infinite Homogeneous System of UO_2+$Gd_2O_3$and water



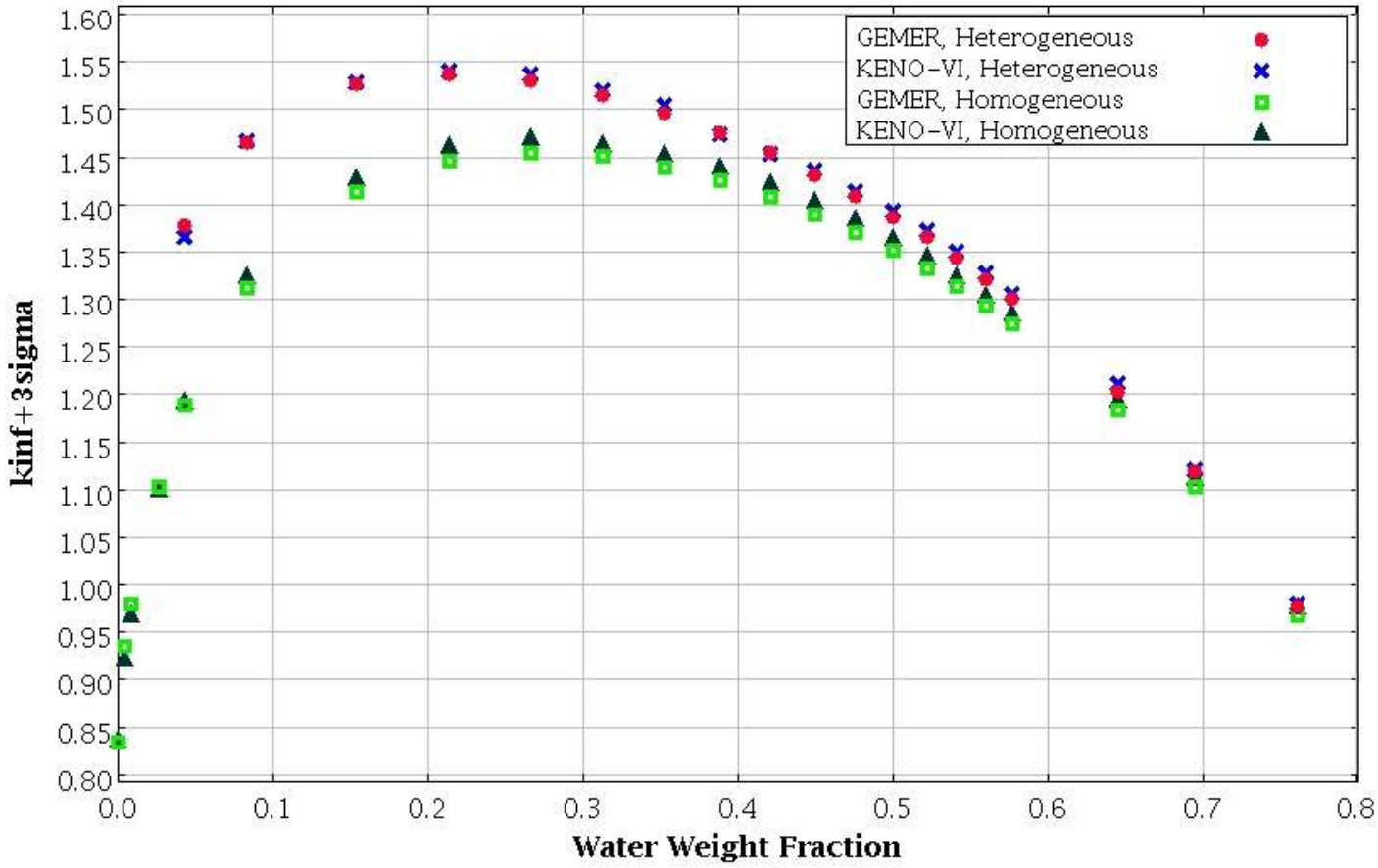
Results and Discussion

Infinite Heterogeneous System of UO_2 and water



Results and Discussion

Comparison of Homogeneous & heterogeneous Systems of UO_2 and water



Results and Discussion

- Gadolinium is an excellent burnable poison that is used for controlling long-term reactivity in thermal reactors.
- Between 2-10 wt% of Gd_2O_3 powder is mixed with the uranium oxide powder to make fuel rods containing gadolinium.
- The majority of rods contain 6 - 8 wt% Gd_2O_3.
- The results show that 0.5 wt% Gd_2O_3 is enough to maintain either homogenous or heterogeneous system subcritical.

Results and Discussion

- Benchmarks used for bias determination – ~ 5 wt.% enriched fuel rods moderated by water containing dissolved gadolinium nitrate.
  - THERM-005
  - THERM-028
  - THERM-052
- TSUNAMI-IP used to determine penalty.

Conclusions - Key Controls

Gadolinium can be credited for criticality safety without compromising 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 - Key Controls

- 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 uranium oxide. Calculations show 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 - Nature of the Process

Favorable Factors in Gad Fabrication Process:

- Fuel is stored and handled in less than a safe mass in safe geometry containers.
- Fabrication processes are dry and the area is under moderation control.
- Uranium oxides and Gd_2O_3 are insoluble in water.
- There are no reactions in the fabrication processes that could preferentially separate Gd_2O_3 from uranium oxide.