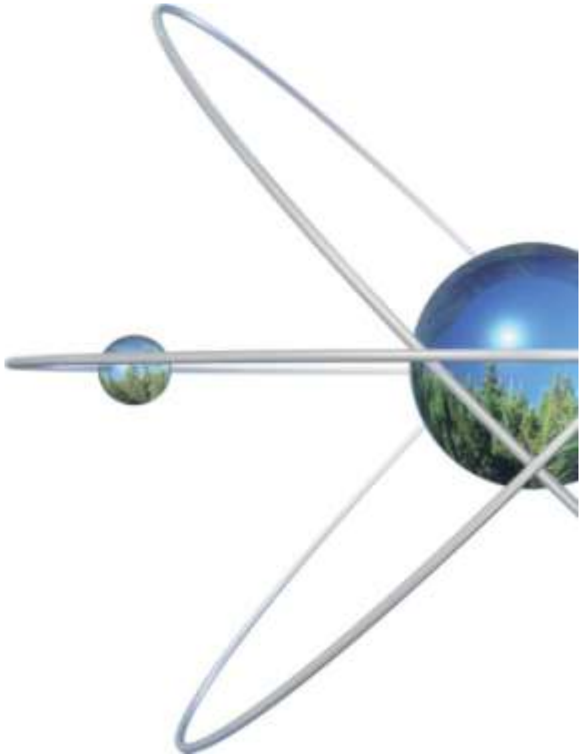
GE Hitachi Nuclear Energy

Criticality Accident Alarm System Detector Placement Methodology at the GNF-A Fuel Manufacturing Operations Facilities

Chris Geiser
Qi Ao

NCSD 2013 Topical Meeting
Wilmington, North Carolina
October 2, 2013



Overview

- Background
- Methodology
- Regulations and Guidance
- Source Term Development
- Shielding Model
- Detector Response
- Conclusions

HITACHI

Background: Historical Overview

1970's : Original detector placement analysis for FMO/FMOX buildings using point-kernel/build-up factor method

1997: Detectors added to cover Dry Conversion Process (DCP) building

2012-2013: Replacement design for new CIDAS® detector system

Mk X Detector

GE HITACHI

Background: Historical Technical Basis

- SNM-1097 License: Detectors placed in accordance with (IAW) ANSI/ANS-8.3-1997 (2003)

- Minimum source based on source normalization form both neutron and gamma.

- Detector response contributed by gamma rays from point sources

- Simple transport calculations:
  - Point-kernel method
  - Build-up factor approximation

- Radius of detector coverage determined using the alarm set-point of **10 mR/hr** gamma dose rate in **air**

HITACHI

Method

Assumptions:

- Low enriched uranium (LEU) materials ($\leq$5 wt% ^{235}U)
- Gamma detection with the alarm set point of 100 mR/hr
- Primary gamma transport only (neutron induced gammas ignored) outside fissile sources

1. Develop a set of facility-credible critical sources.
2. Characterize gamma source terms (energy and intensity) from fission gamma and fission neutron induced gamma from fissile materials with MCNP KCODE.
3. Determine the least detectable source as a bounding source term for the given set of facility-credible source terms.
4. Map gamma dose distributions for all credible source locations in facility models using MCNP mesh tally for the bounding source term.
5. Select coarse detector locations based on gamma dose maps
6. Calculate gamma dose rate at each selected detector location using MCNP point detector.
7. Optimize the detector coverage through fine placement calculations.

GE HITACHI

Regulations and Guidance

Appendix A of ANSI/ANS 8.3 states:

- Criticality accident source term - "**minimum accident of concern**"
- Absorbed dose rate in free air of 0.2 Gy/min (20 rad/min) at 2 meters from the reacting material is used in ANSI/ANS-8.3-1997 as a suggested value for situations in which there is only nominal shielding.

NRC Regulatory Guide 3.71

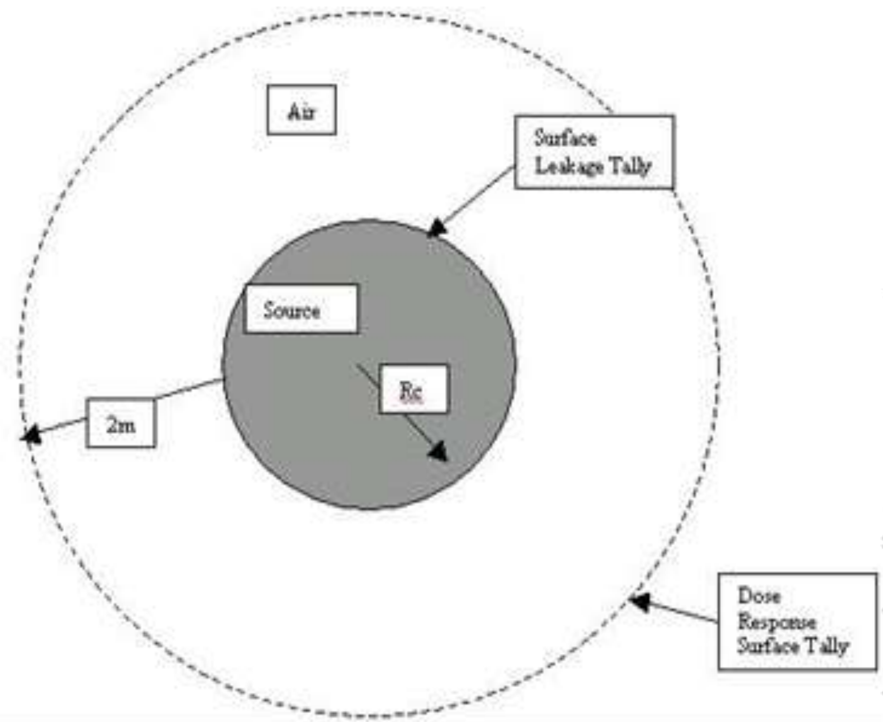
- Generally accepts the above definition of "minimum accident of concern", but requires an absorbed dose in soft tissue instead of in free air.

To comply with the national standard and regulatory guidance

- 20 rad absorbed dose in soft tissue in one minute at a distance of 2 meters from the surface of the reacting material will be used as the criteria for the source normalization.

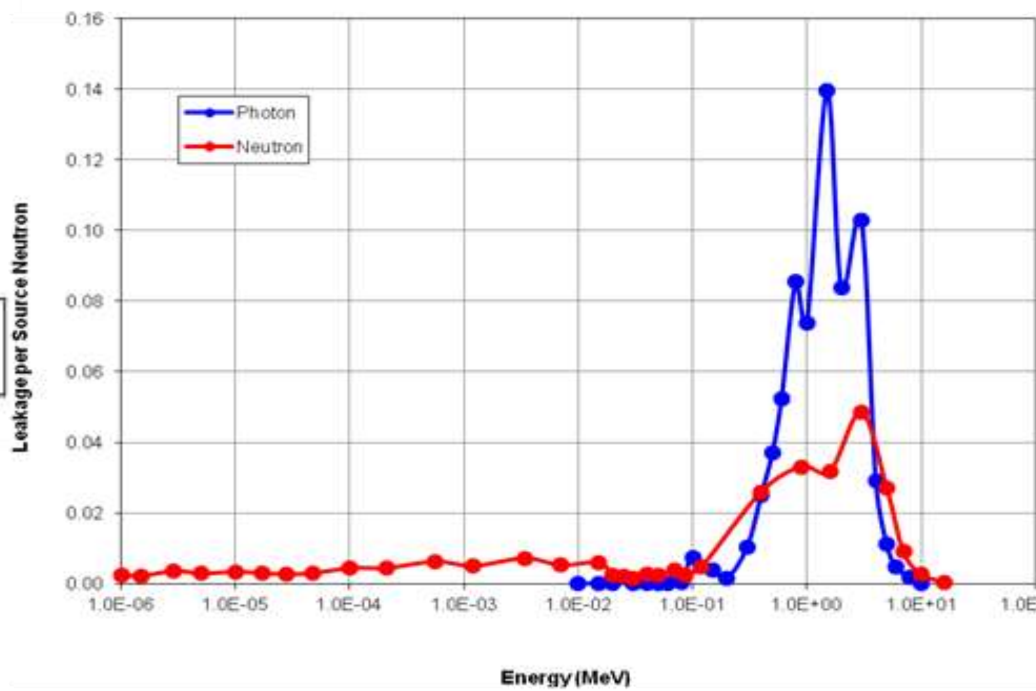
HITACHI

Source Term Development



Spherical Source

- Calculate radiation leakage spectra
- Normalize to "Minimum Accident of Concern" at 2 m ANSI/ANS-8.3-1997)
- Use bounding source term for detector response calculation



Radiation Leakage Spectra

HITACHI

Source Term Development (con't)

A basic consideration in the design of a criticality accident alarm system is the definition of the lower magnitude of the event size to be detected, termed the "minimum accident of concern." The resulting accident (one which will result in a dose to free air of 0.2 Gy (20 rad) in the first minute at a distance of 2 m from the reacting material) is used in ANSI/ANS-8.3-1997 as a suggested value for situations in which there is only nominal shielding.*

Type 1: "Prompt Burst"

All 20 Rad absorbed dose received in very short time duration (~0.001 sec). Essentially zero absorbed dose in remaining 59.999 sec.

Effective dose rate of ~ 7E+07 Rad/hr.

Yields source term ~ 1.0E17-1.0E18 per sec.

Non-conservative source term for CAAS detector placement analysis – Overestimates detector response

Type 2: "Slow Cooker"

All 20 Rad absorbed dose received in longer period averaged over 1 minute.

Effective dose rate of 1200 Rad/hr.

Yields source term ~ 1.0E+14 -1.0e+15 per sec.

Conservative source term for CAAS detector placement analysis – Underestimates detector response

HITACHI

***NRC Reg. Guide 3.71 specifies dose in tissue**

Source Term Development (con't)

Uniform Homogeneous Source Types	• UO_2 + H_2O at wtfr. H_2O of 0.014, 0.025, 0.05, 0.1, 0.2, 0.4
Non-Uniform Homogeneous Source Types	• Inner Sphere: UO_2 + H2O at wtfr. H_2O of 0.05, 0.1, 0.2 0.4, 0.6 • Outer Sphere: UO_2 + H2O at wtfr. H_2O of 0.014
Heterogeneous Source Types	• UO_2 + H_2O at W/F ratio of 1.0, 2.0, 3.0, 4.0 • Particle Sizes 0.01, 0.1, 0.15, 0.25, 0.50 cm
Uranium Solution Source Types	• UO_2F_2 and UNH (168, 198 g U/l)

HITACHI

Source Dose Rate Mapping

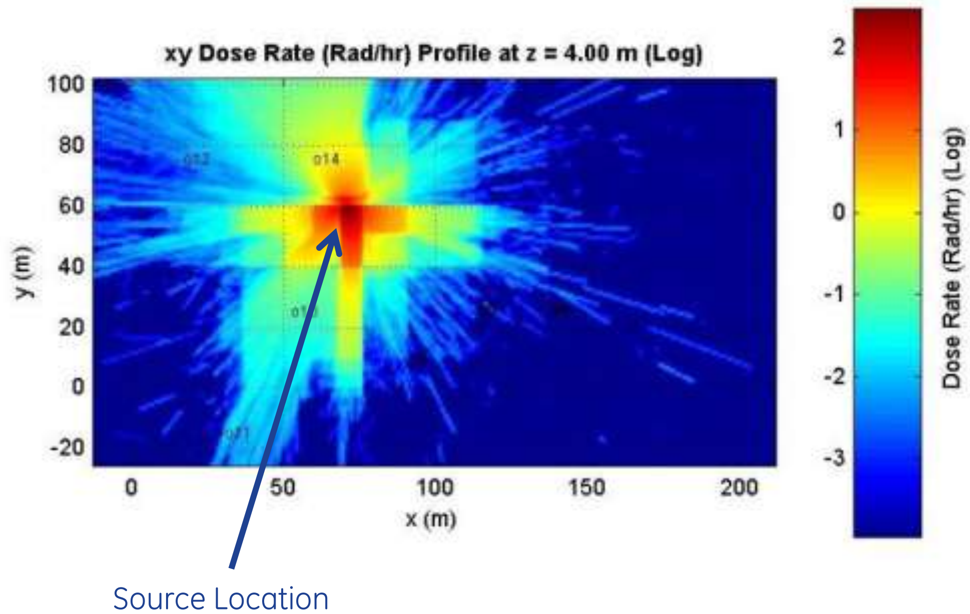
Bounding Source Determination:

- One inch 304SS shell (r=50.0 cm), Eight inch concrete shell (r=300.0 cm)
- Evaluate gamma response from all source types
- $UO_2 + 0.40H_2O$ source produces lowest gamma response

Simulated Source Locations:

- 25 - FMO/FMOX/Mezzanine
- 20 -DCP
- 5 -Shipping warehouse

.



Dose Rate Mapping:

- Rectangular spatial mesh
- Serve as guide for detector placement
- Construct a gamma dose map for each credible source location in a facility model using MCNP mesh tally for fixed source problems

HITACHI

Shielding Model

- Eliminate doors, window, fine structures, and equipment
- Use 1 inch stainless steel for structural components
- Model concrete cinder block walls as ‘equivalently’ solid concrete
  - Normal concrete 2.3 g/cc block, modeled as 1.45 g/cc sold block
  - At least 10% higher shielding power

Detector Response and Placement

Detector Response

- Point detectors
- No contributions from fission neutron induced gammas everywhere except for fissile materials
- No contributions from delayed fission gammas
- Alarm set-point: 100 mR/hr in-tissue

HITACHI

Detector Response and Placement (con't)

Elevation

- Accessibility for source check
- Line of sight
- Travel paths

Cost of Construction and Optimization Benefit

- Detector cost versus conduit

Environment

- Water holding area disruption
- Hurricane rating
- Ability to construct

HITACHI

Conclusions

- The CAAS detector placement methodology developed is based on the state-of-art Monte Carlo particle transport method – MCNP5 with ENDF/B-VII.0.
- The CAAS detector placement analysis used the conservative models by accounting for uncertainties in the excursion dynamics, source type and location, and shielding.
- The methodology is able to provide more cost effective and reliable coverage for process areas for fissile material on the GNF-A site.

Questions?

Christopher.Geiser@ge.com
Qi.Ao@ge.com

References:
1. ANSI/ANS 8.3-1997 (reaffirmed in 2003), "Criticality Accident Alarm System", (1997).
2. NRC Regulatory Guide 3.71, "Nuclear Criticality Safety Standards for Fuel and material Facilities", Rev. 2 (2010).