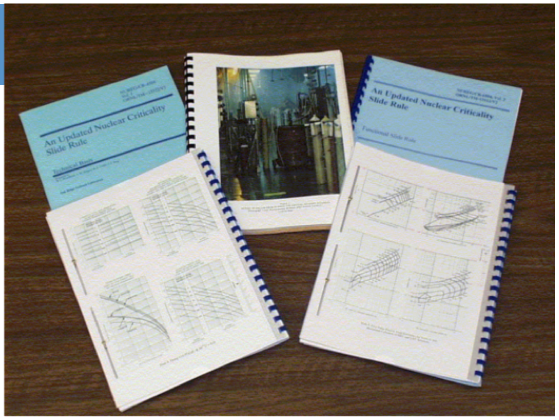
Enhancing nuclear safety

Nuclear Criticality Slide Rule – Introducing Plutonium Systems

Thomas MILLER, Cihangir CELIK, Calvin HOPPER, Matthieu DULUC, Dave HEINRICHS, Soon KIM, Alex BROWN, Richard JONES, Chris WILSON and Marc TROISNE

March 27, 2018
Oak Ridge, TN

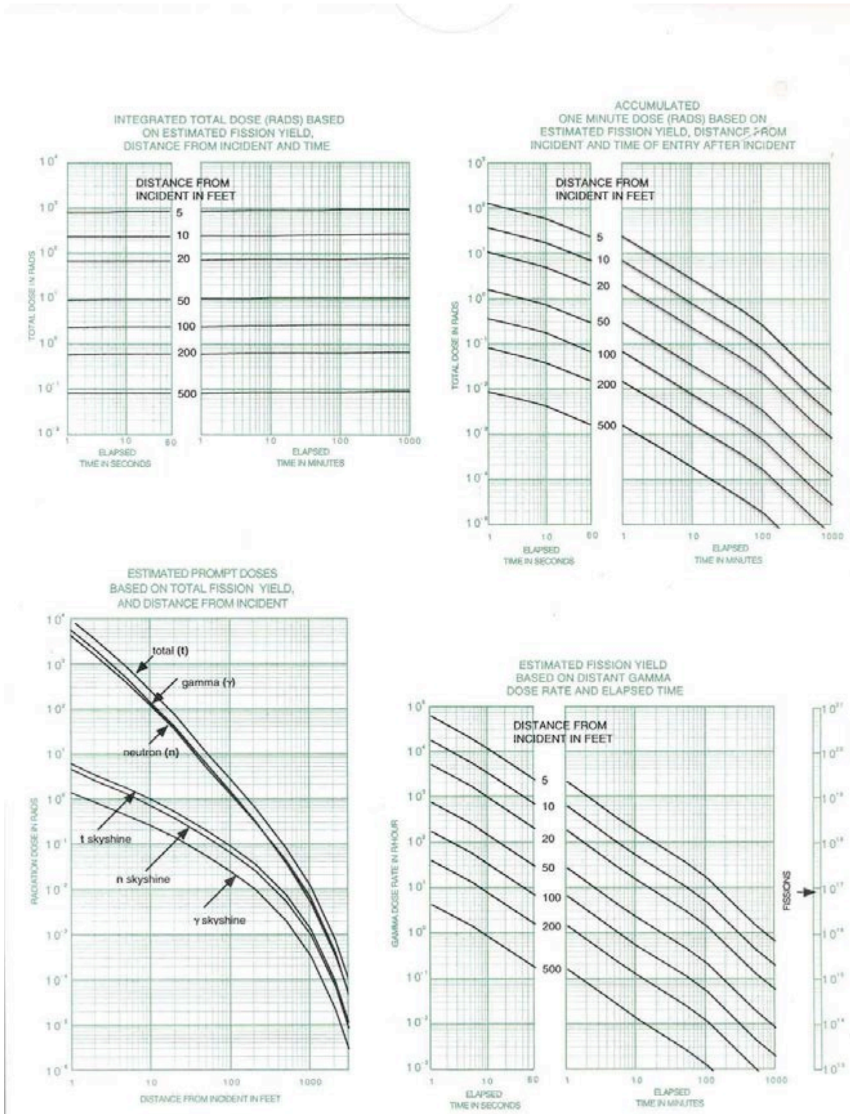
Slide Rule ?



- April 1997, An Updated Nuclear Criticality Slide Rule
  - ORNL/TM-13322/V1 & V2: Technical Basis / Functional Slide Rule

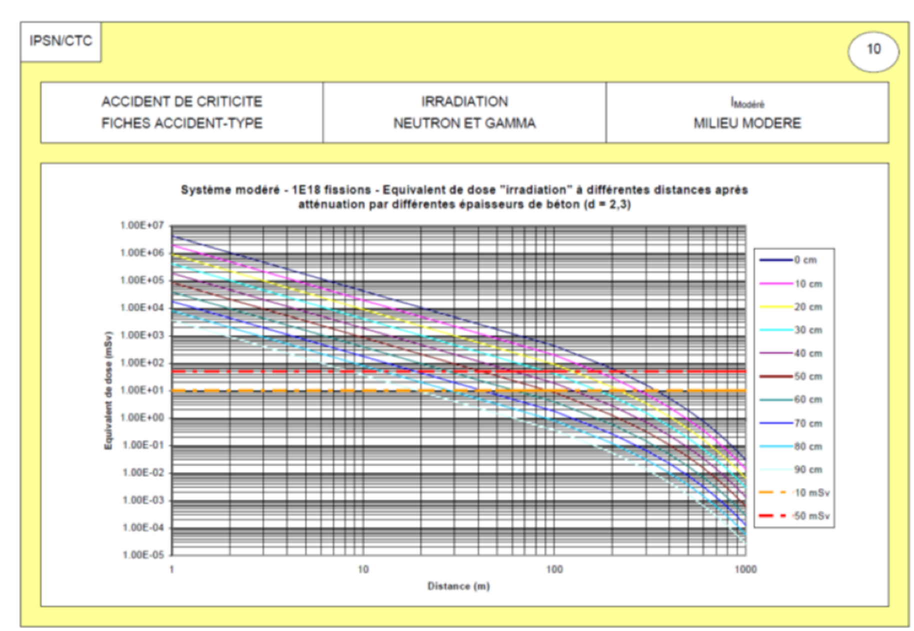
- This document gives order of magnitude estimates of key parameters, useful for emergency response teams and public authorities:
  - The magnitude of the number of fissions based on personnel or field radiation measurements or various critical system parameter inputs,
  - Neutron- and gamma-dose at variable unshielded distances from the accident,
  - The skyshine component of the dose,
  - Time-integrated radiation dose estimates,
  - One-minute decay-gamma radiation dose,
  - and dose-reduction factors for variable thicknesses of steel, concrete and water.

US Slide Rule

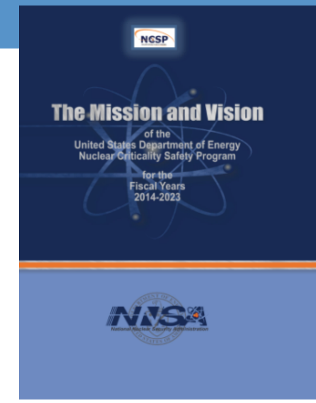


Solution of $U(93.2)O_2(NO_3)_2$ @ $H/^{235}U = 500$

IRSN « Slide Rule »



Long term DOE/NNSA NCSP – IRSN collaboration



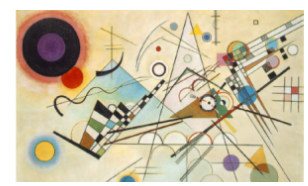
- NCSP wants to develop and maintain modern Slide Rule

Accident analysis:		Budget Priority / Technical Priority	
Field-deployable emergency response methods on portable, handheld platform	Develop and maintain modern, accident analysis capability (SlideRule)		

- IRSN wants to review and improve its "Slide Rule"

- Proposal of a complete work, divided into several steps:
  - Step 1: Redo with modern radiation transport tools, for the same configurations and assumptions, the calculations performed initially for the 1997 estimation of the doses

ICRS 13 RPSD 2016
October 3|6, 2016
Paris, France



  - Step 2: Perform additional configurations/calculations
    - New configurations (new geometry of the source, new fissile media <u>including plutonium systems</u>, etc.)
    - New flux-to-dose conversion factors

2017 NCSD Topical Meeting
September 10-15, 2017 | Carlsbad, NM | Pecos River Village Conference Center

Step 2: "Introduction Of Plutonium Systems"

Geometry: One Air (sky) layer above a 50 cm concrete layer (ground)

Source: Plutonium critical system – 1 meter over the ground

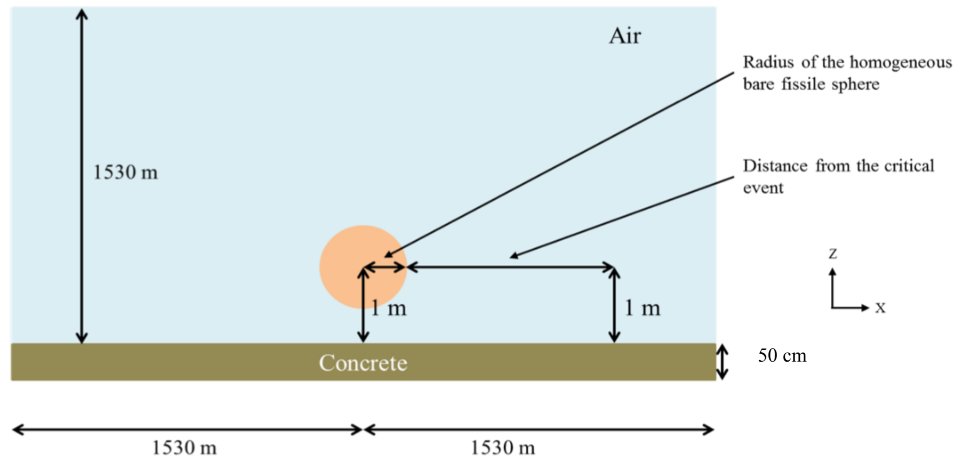
Composition: ^{239}Pu metal homogeneously mixed with water

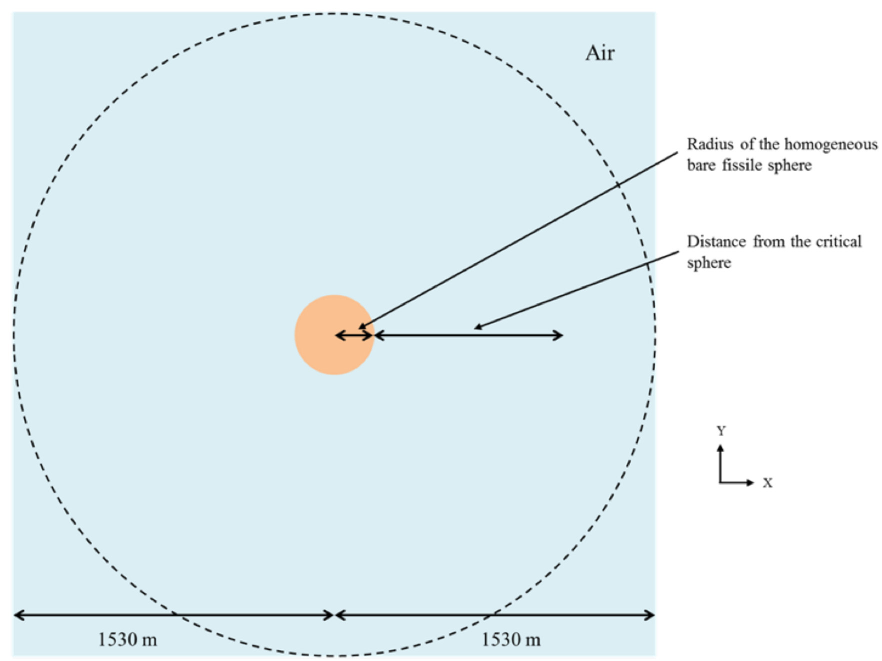
- 5 moderation ratios (H/^{239}Pu): 0 (=metal), 10, 100, 900 and 2000

Geometry: bare sphere, bare cylinder, steel reflected sphere

Dose Detection: 0.3 to 1200 meters between source and dose detection.

Flux-to-dose conversion factors: ANSI/HPS N13.3 standard

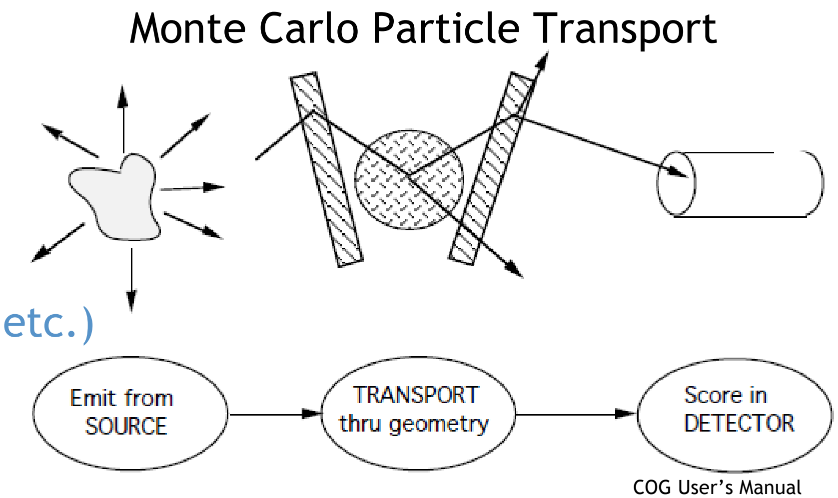




Step 2: "Introduction Of Plutonium Systems"

Codes used:

- MCNP 6.1
- SCALE 6.2.1
- COG 11.2



Various methods used:

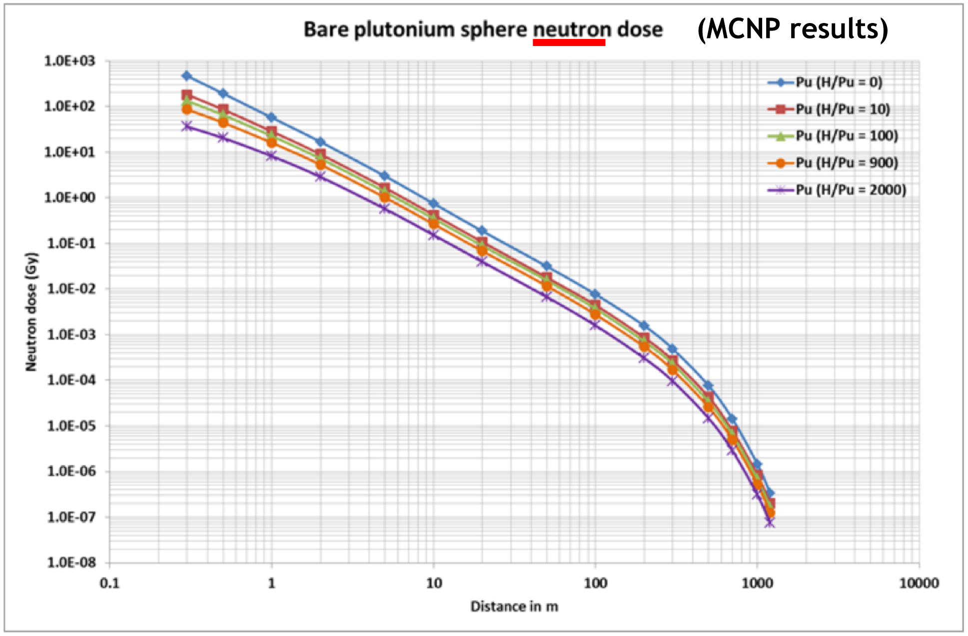
- 1 step / 2 steps methods
- Variance Reduction technics (ADVANTG, CADIS, etc.)

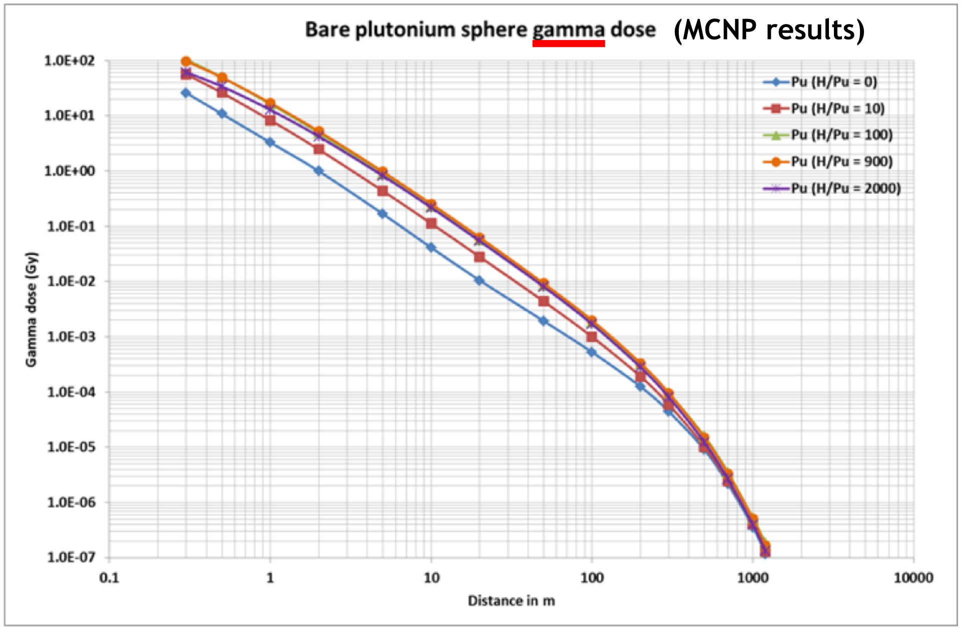
But one:

- Cross-section library data: ENDF/B-VII.1 (CE)
- Flux-to-dose conversion factor: ANSI/HPS N13.3 standard ("Dosimetry for Criticality Accidents", 2013)
- Kind of detector: a cylindrical shell with a square cross-section of 5 cm x 5 cm

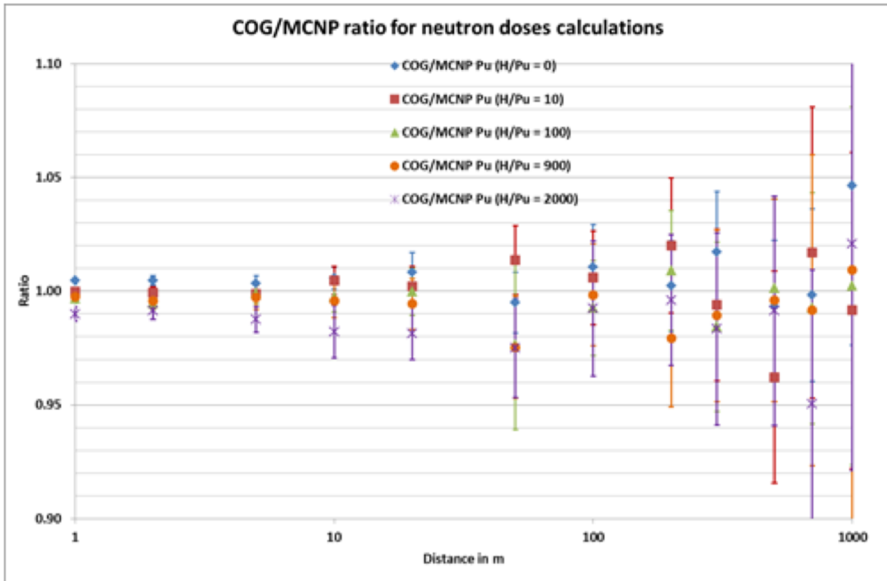
Examples of prompt dose results shown for accidents that generate 10^{17} fissions

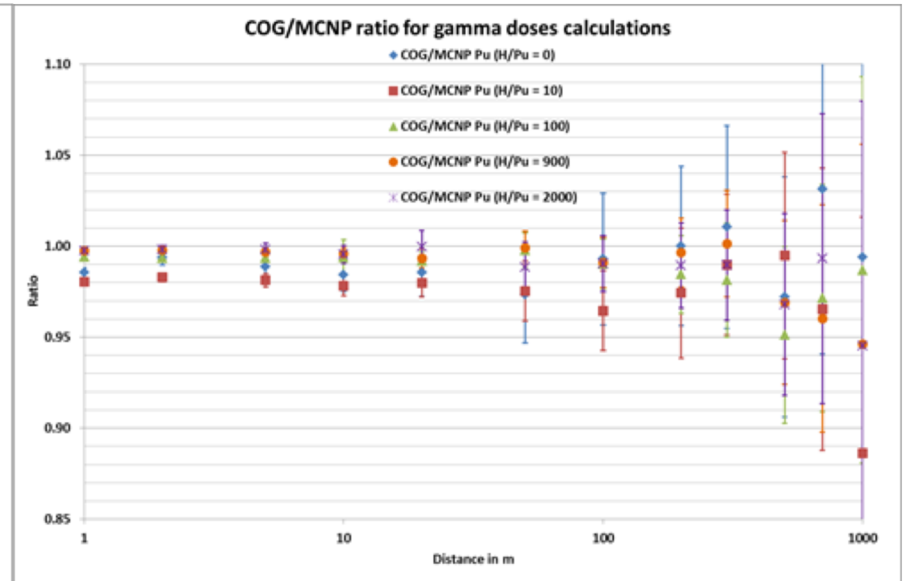
Bare sphere (prompt dose results)

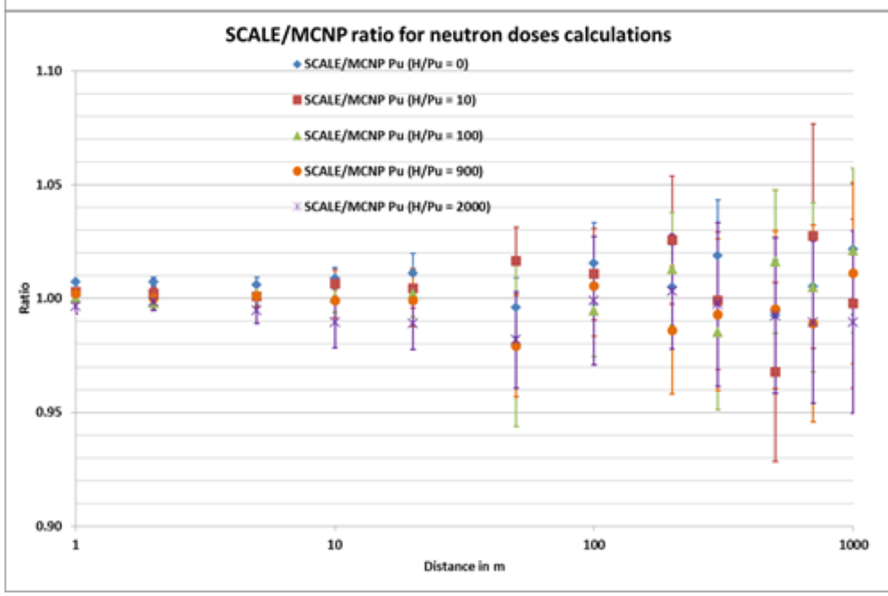


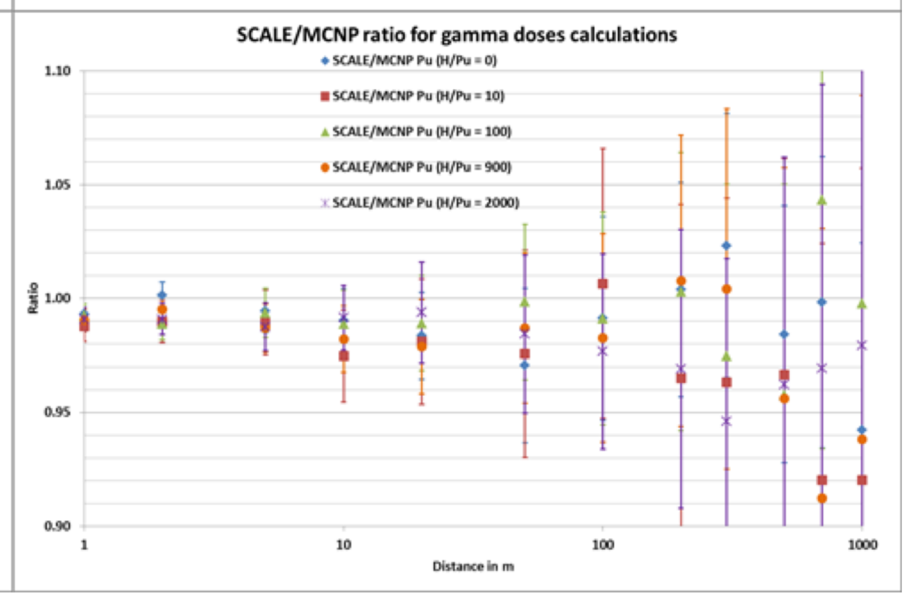


Bare sphere (comparison between codes)

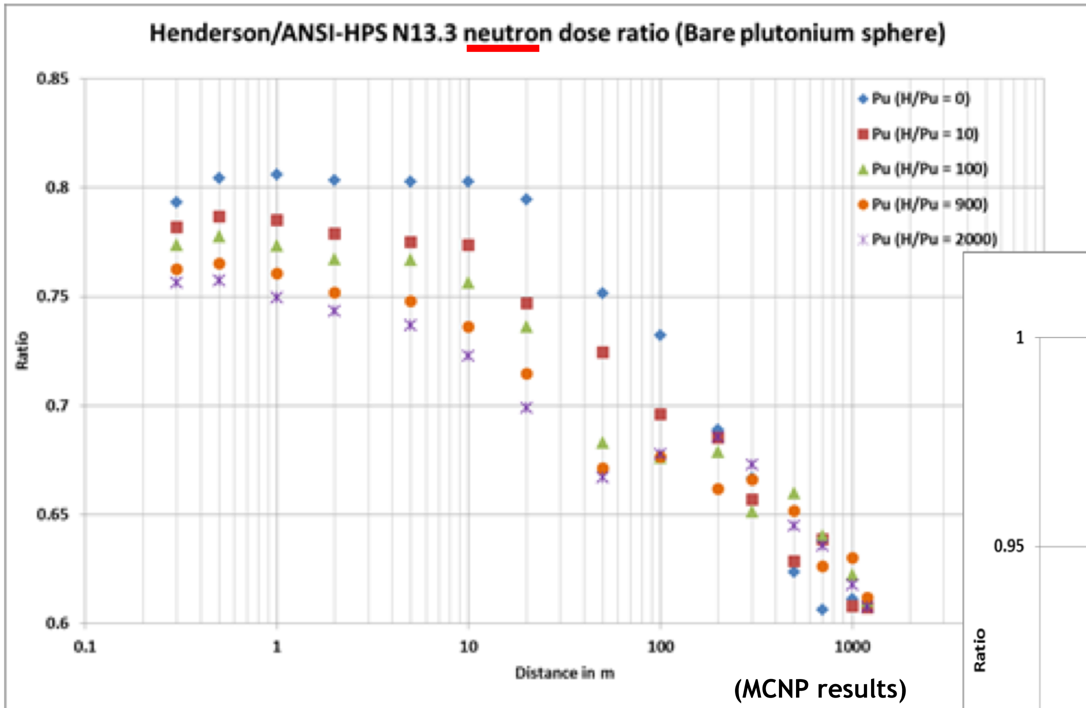


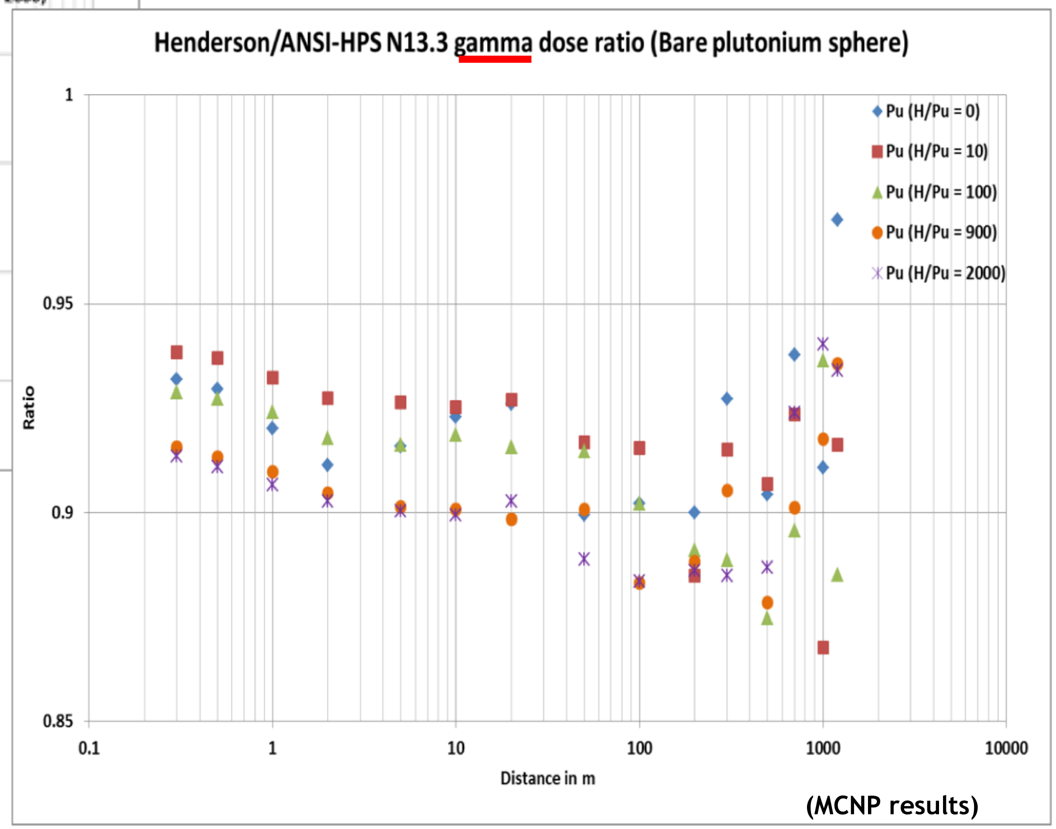




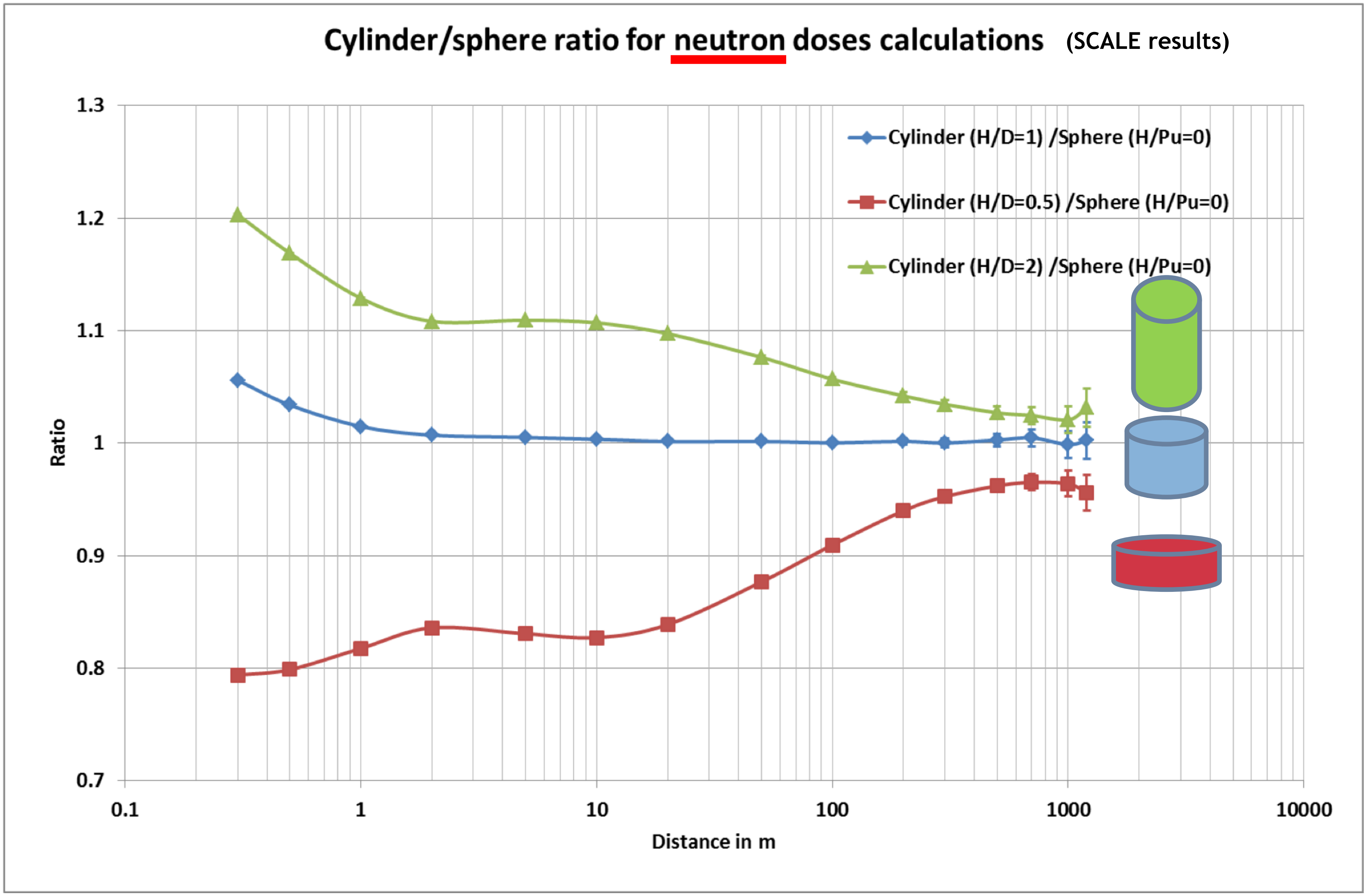


Bare sphere (comparison between conversion factors)



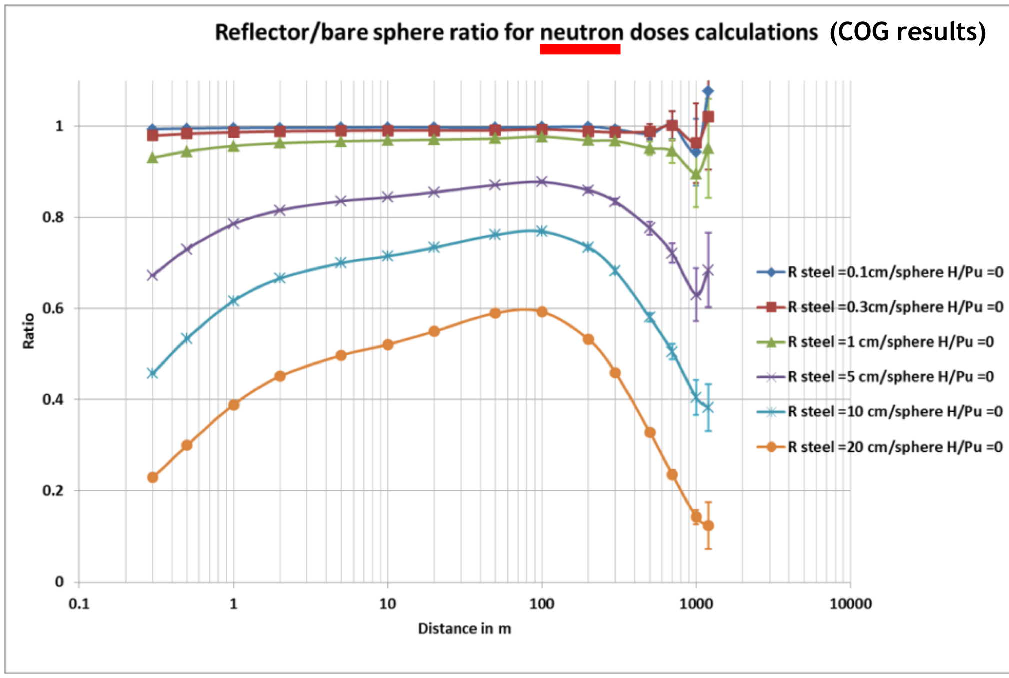


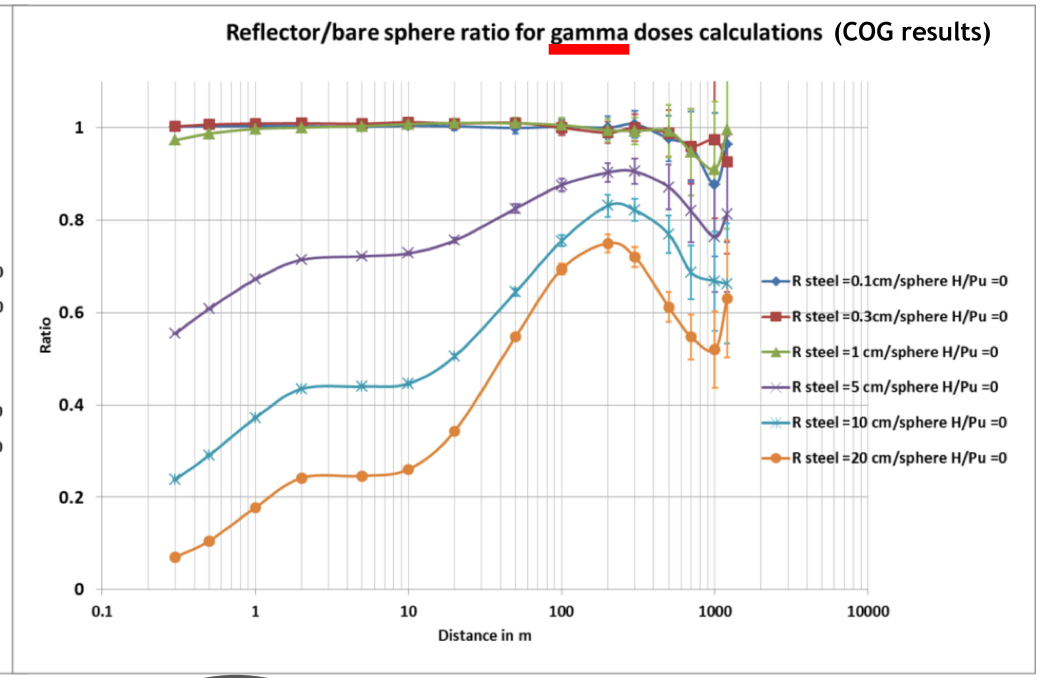
Bare cylinder (prompt dose results for Pu metal (H/Pu=0))

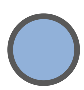


Sphere surrounded by a steel reflector

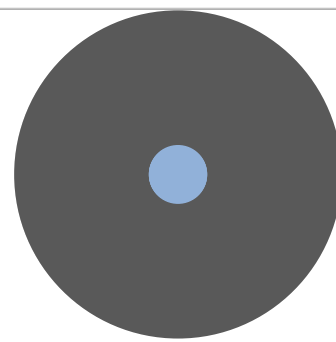
(prompt dose results for Pu metal (H/Pu=0))







R steel = 0.1 cm



R steel = 20 cm

Conclusions and perspectives

Conclusions:

- Introduction of plutonium systems and new flux to dose conversion factors (more penalizing than the previous one)

- Prompt doses: consistency between modern codes with small discrepancies on prompt gamma due to the different codes gamma transport treatment of bremsstrahlung

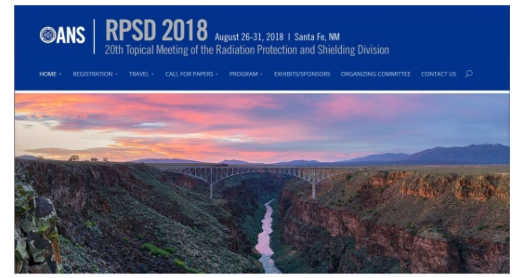
- Bare cylinders: up to 30% compared to the bare sphere but approach, more or less quickly, to the sphere dose for long distances

- Steel reflector: deeply modifies doses and the effect depends on several parameters (distance, moderation ratio, type of radiation)
  - *difficulties to attribute one reduction factor value to a given thickness of steel*

Conclusions and perspectives

Perspectives:

- Finalization of Step 2 for prompt doses
- Calculation of delayed gamma doses for the Step 2
- Calculation of additional configurations (impact of multiple layers of shielding, of the thickness and the composition of the surrounding environment (ground, humidity of the air, etc.))



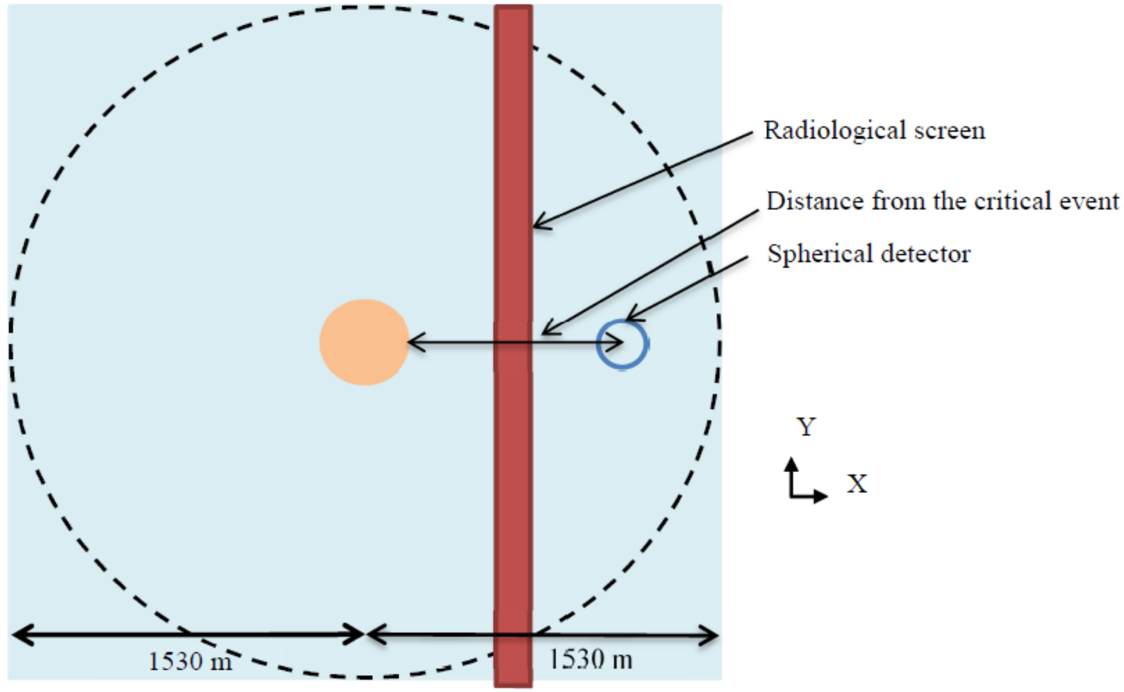
- Opportunity to create "computer benchmarks":
  - test and validate the various variance reduction methods
  - establish best practices for this kind of problems (e.g. fission source calculation)
- Opportunity to suggest new experiments for the validation of the tool (benchmarking effort)

- Then… beginning of the next Steps:
  - Step 3: review of the section regarding the estimation of the number of fissions
  - Step 4: addition of others sections (like actions to stop an on-going criticality accident)
  - Step 5: development of a Slide Rule "application" for a handheld device

Current FY 2018 Work

Continuation of Step 2 – Studies with common shielding materials

- Various thicknesses of concrete, lead, stainless steel 304, and water
- Sources: HEU metal and LEU uranyl fluoride solution
- Shield always positioned halfway between the source and detector
- Also evaluate the effect of humidity and ground composition on dose



NCSP website: Analytical Methods

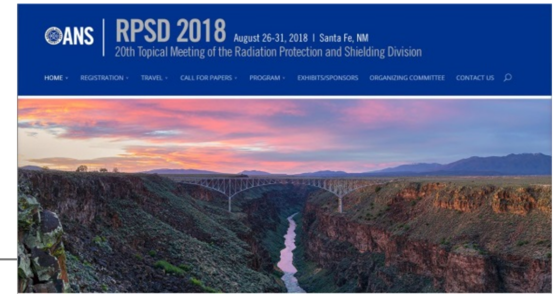
https://ncsp.llnl.gov/am_criticality_sliderule.php

About the Nuclear Criticality Slide Rule Project

AWE (UK), IRSN (France), LLNL (USA) and ORNL (USA) began a long-term collaboration effort in 2015 to update the Nuclear Criticality Slide Rule for emergency response to a nuclear criticality accident to modernize and expand the technical content of the previous (1998 version) last updated by ORNL.

The detailed plans and accomplishments of the project are provided in the task specifications and summary papers provided below. For additional information on this project, please contact the project coordinator, Matthieu Duluc (IRSN) at matthieu.duluc@irsn.fr.

Phase	Document Type	Title	Date
3	Task Specification	Update of the Nuclear Criticality Slide Rule Calculations – Sensitivity Studies	2017 Sep 12
2	Summary Paper	Introduction of Plutonium Systems to the Nuclear Criticality Slide Rule ANS NCSD Topical, Carlsbad, NM, USA	2017 Sep 14
	Task Specification	Update of the Nuclear Criticality Slide Rule Calculations – Plutonium Configurations	2017 Mar 24
1	Summary Paper	Update of the Nuclear Criticality Slide Rule for the Emergency Response to a Nuclear Criticality Accident, EPJ Web of Conferences 153, 05015 (2017) ICRS2016 – RPSD2013, Paris, France	2016 Oct 5
	Task Specification	Update of the Nuclear Criticality Slide Rule Calculations – Initial Configurations	2015 Dec 10



ANS RPSD 2018 - 20th Topical Meeting of the Radiation Protection & Shielding Division of ANS
Santa Fe, NM, August 26 – 31, 2018, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2018)

Update of the Nuclear Criticality Slide Rule Calculations – Studies with Common Shielding Materials

T. M. Miller[1], C. Celik[1], C. Hopper[1], M. Duluc[2], D. Heinrichs[3], S. Kim[3], A. Brown[4], C. Wilson[4], and M. Troisne[5]

[1]*Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN, 37831, USA* millertm@ornl.gov
[2]*Institut de Radioprotection et de Sûreté Nucléaire, B.P. 17, 92262 Fontenay-aux-Roses Cedex, France*
[3]*Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA, 94551, USA*
[4]*Atomic Weapons Establishment, Aldermaston, Reading, RG7 4PR, United Kingdom*
[5]*Millennium, 16 avenue du Québec – SILIC 628, 91945 Courtabœuf, France*

Introduction

In January 1974, a report entitled "A Slide Rule for Estimating Nuclear Criticality Information" was written by C. M. Hopper for the Oak Ridge Y-12 Plant as a tool for emergency response to nuclear criticality accidents[1]. In 1997, this report was updated by the Oak Ridge National Laboratory (ORNL)[2,3], and in 2000, the Institut de Radioprotection et de Sûreté Nucléaire (IRSN) produced a similar report[4]. In 2016 ORNL, IRSN, Lawrence Livermore National Laboratory (LLNL), and the Atomic Weapons Establishment (AWE) began an effort to update the nuclear criticality slide rule again by using modern radiation transport codes and nuclear data and introducing plutonium systems. This revision of the nuclear criticality slide rule will provide the same capabilities for continued updates to accident information during the evolution of emergency response. These updates will include the same information as that included in previous slide rules, namely victim exposure information, potential exposures to emergency re-entry personnel, estimates of future radiation fields, and fission-yield estimates.

Description of Work

This paper presents preliminary results from the third phase of the current update to the nuclear criticality slide rule. The first phase[5] repeated the simulations in Refs. 2 and 3 with modern radiation transport codes and nuclear data, and the second phase[6] introduced plutonium systems. MCNP[7], MAVRIC/Monaco[8], and COG[9] have simulated the dose from critical spheres of 4.95% enriched uranyl fluoride solution and 93.2% enriched uranium metal with various thicknesses of lead, steel, concrete, and water shielding included. This phase also evaluated the effects of humidity on the unshielded configurations in the first phase and changing the ground composition used in the analysis from concrete to dry soil.

Results

Figure 1 presents prompt fission neutron dose results as a function of distance from a critical sphere of uranyl fluoride that experienced 10^{17} fissions. There is a 20 cm thick concrete shield halfway between the critical sphere and each detector location. The detector is a simple sphere of air. These dose results are in units of Gy, and there is good agreement between MCNP, MAVRIC/Monaco, and COG at all distances. The error bars represent 2-sigma uncertainty.

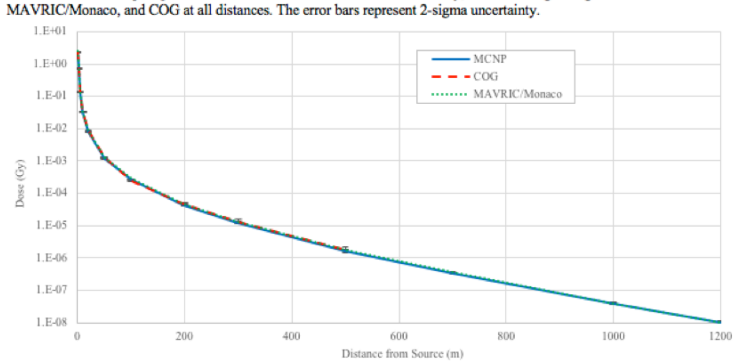


Figure 1. Prompt fission neutron doses as a function of distance from a critical uranyl fluoride sphere.

Thank you for your attention