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Enhancing nuclear safety

INTRODUCTION OF PLUTONIUM SYSTEMS TO THE NUCLEAR CRITICALITY SLIDE RULE

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millennium

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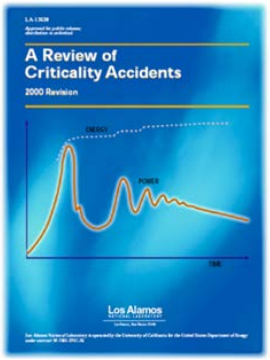
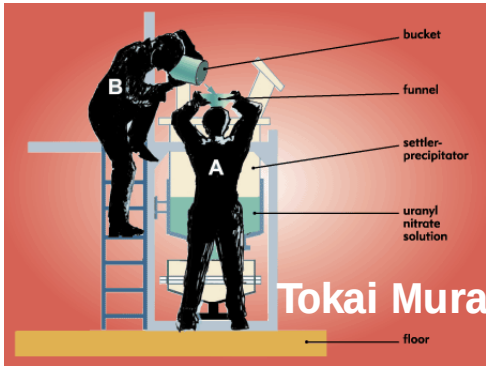
Nuclear Criticality Accident

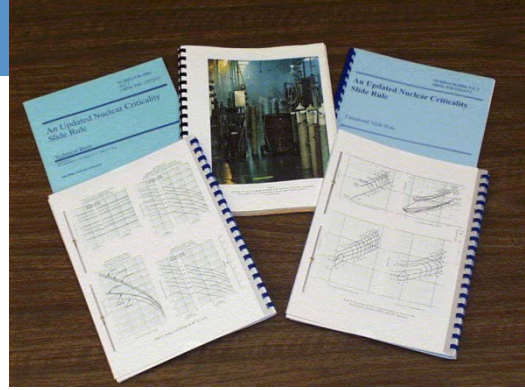
- The release of energy as the result of inadvertently producing a self-sustaining or divergent fission chain reaction
  - Intense production of neutrons and gamma radiations



- 60 reported criticality accidents in the world
- 21 deaths



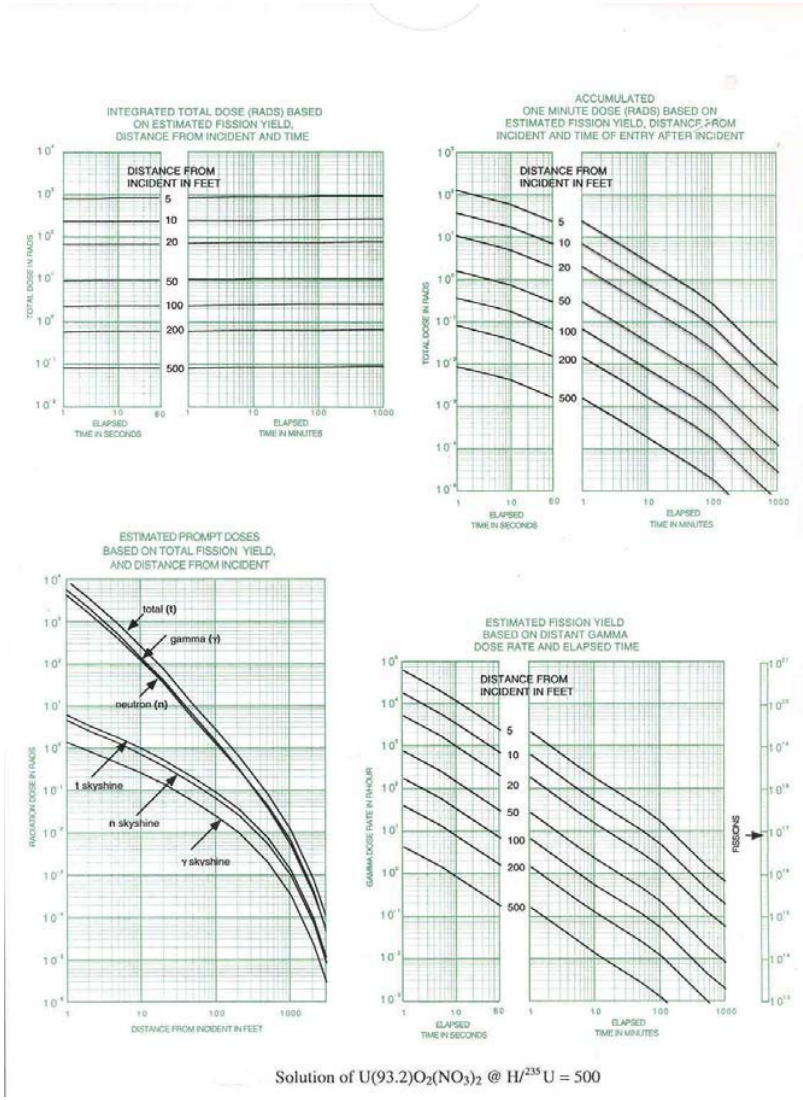
Slide rule?



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

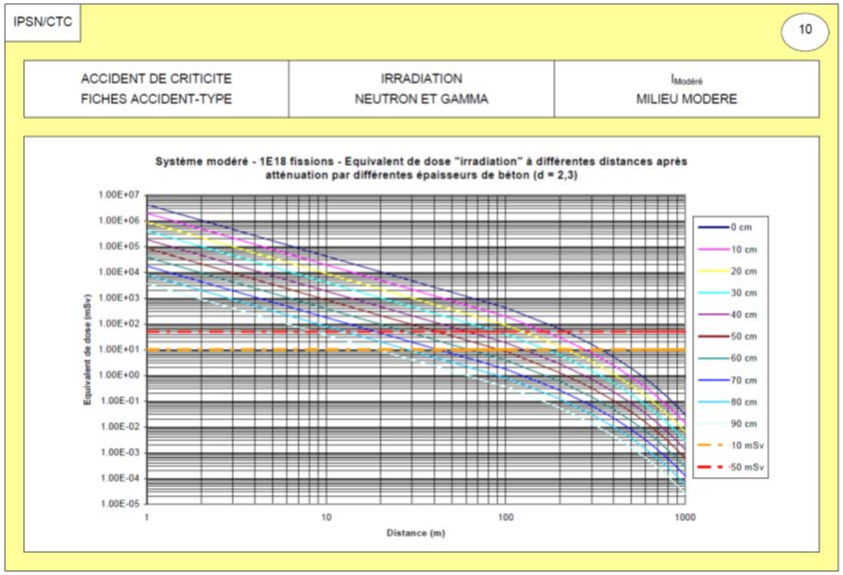
- This document gives order of magnitude estimates of key parameters, useful for emergency response teams and public authorities:
  - The magnitude of the number of fissions based on personnel or field radiation measurements or various critical system parameter inputs,
  - Neutron- and gamma-dose at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

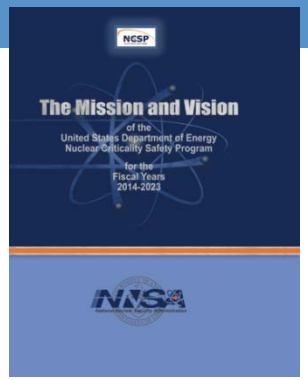
US Slide Rule



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

IRSN « Slide Rule »



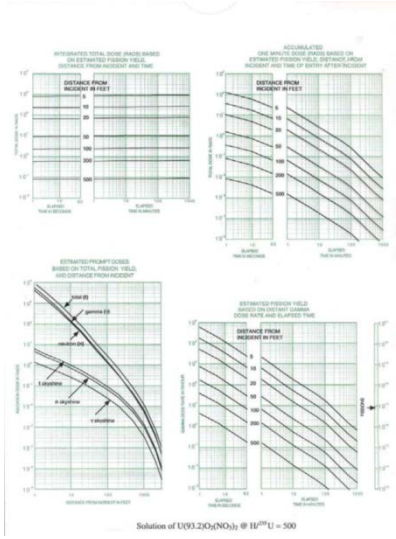


Long term DOE/NNSA NCSP – IRSN collaboration

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

Step 1: Slide Rule « Initial » Configuration

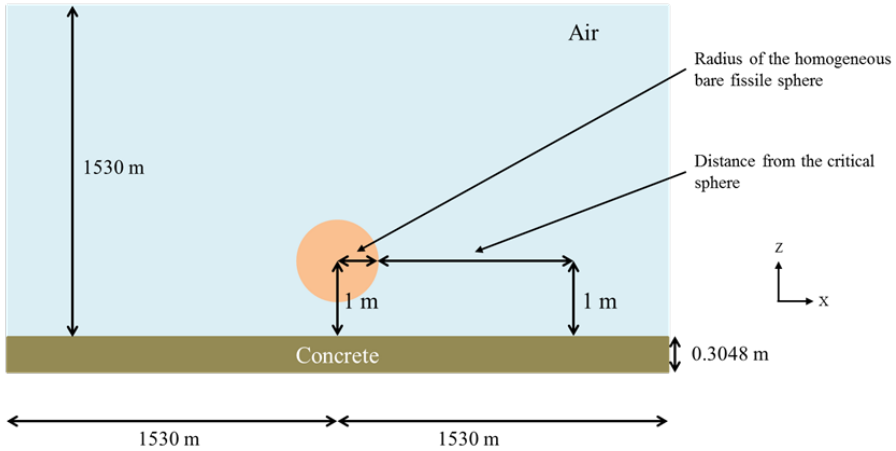
Geometry: One Air (sky) layer above a ~30 cm concrete layer (ground)

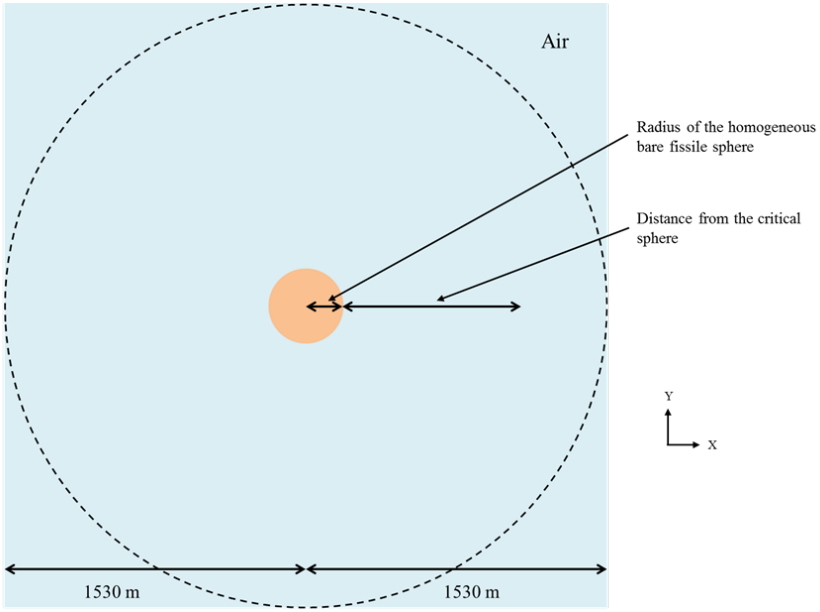
Source: Unreflected spherical uranium critical system – 1 meter over the ground

- $U(4.95)O_2F_2$ – ($H/^{235}U$ = 410)
- $U(5)O_2$ – ($H/^{235}U$ = 200)
- $U(93.2)O_2(NO3)_2$ – ($H/^{235}U$ = 500)
- U(93.2) metal
- $U(93.2)_3O_8$ – ($H/^{235}U$ = 10)

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

Originally, Slide Rule results from DORT (2-D deterministic code) with the Henderson flux-to-dose conversion factor





Step 1: Slide Rule « Initial » Configuration

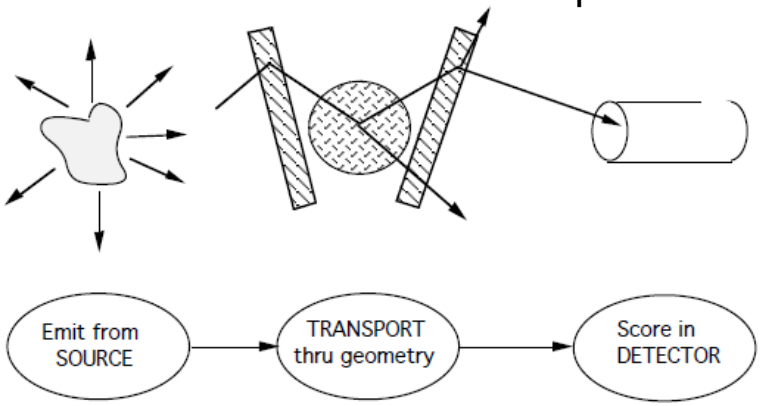
Codes used:

- MCNP 6.1
- SCALE 6.2
- COG 11.1

Various methods used:

- 1 step / 2 steps methods
- Size and shape of the detector
- Variance Reduction technics (WWG, CADIS, etc.)

Monte Carlo Particle Transport



COG User's Manual

But one:

- Cross-section library data: ENDF/B-VII.1 (CE)
- Flux-to-dose conversion factor: Henderson (1959)

Results presented at the ICRS13-RPSD2016 conference (2016)

"Update of the Nuclear Criticality Slide Rule for the Emergency Response to a Nuclear Criticality Accident"

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

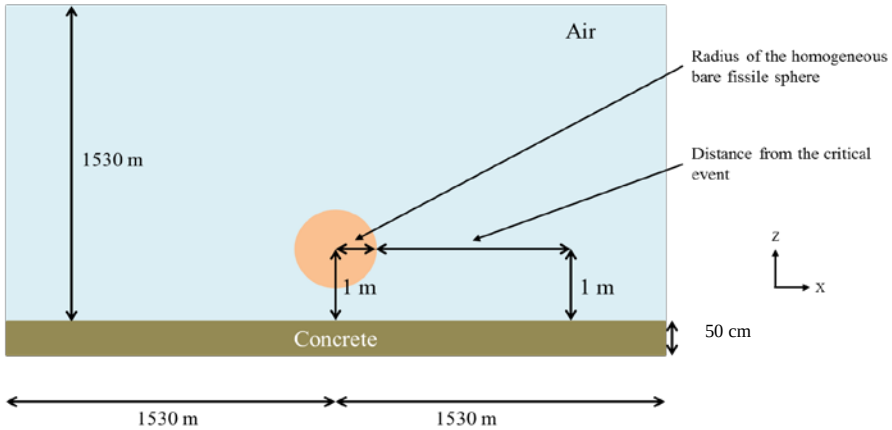
Composition: ^{239}Pu metal homogeneously mixed with water

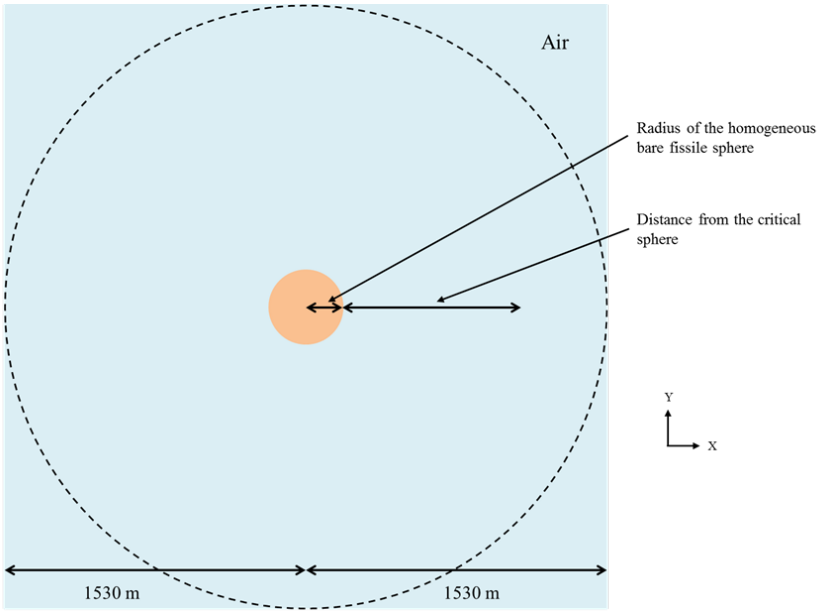
- 5 moderation ratios (H/^{239}Pu): 0 (=metal), 10, 100, 900 and 2000

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



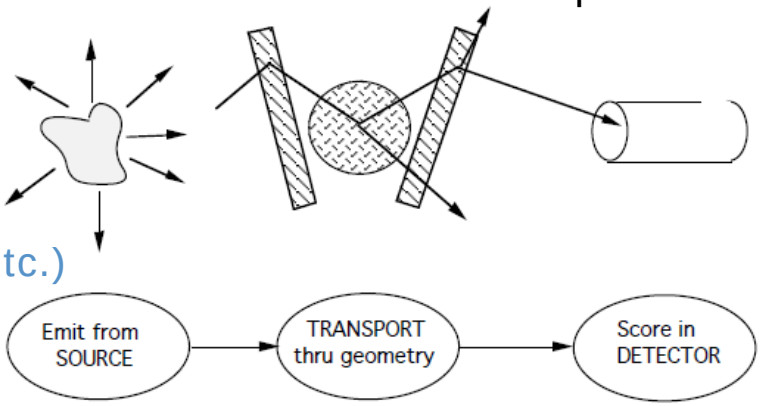


Step 2: "Introduction Of Plutonium Systems"

Codes used:

- MCNP 6.1
- SCALE 6.2.1
- COG 11.2

Monte Carlo Particle Transport



COG User's Manual

Various methods used:

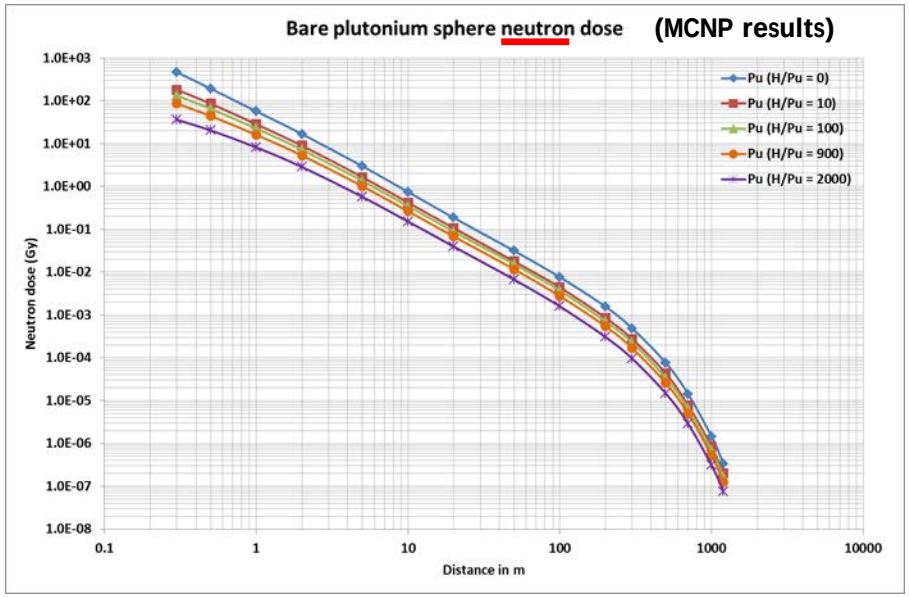
- 1 step / 2 steps methods
- Variance Reduction technics (ADVANTG, CADIS, etc.)

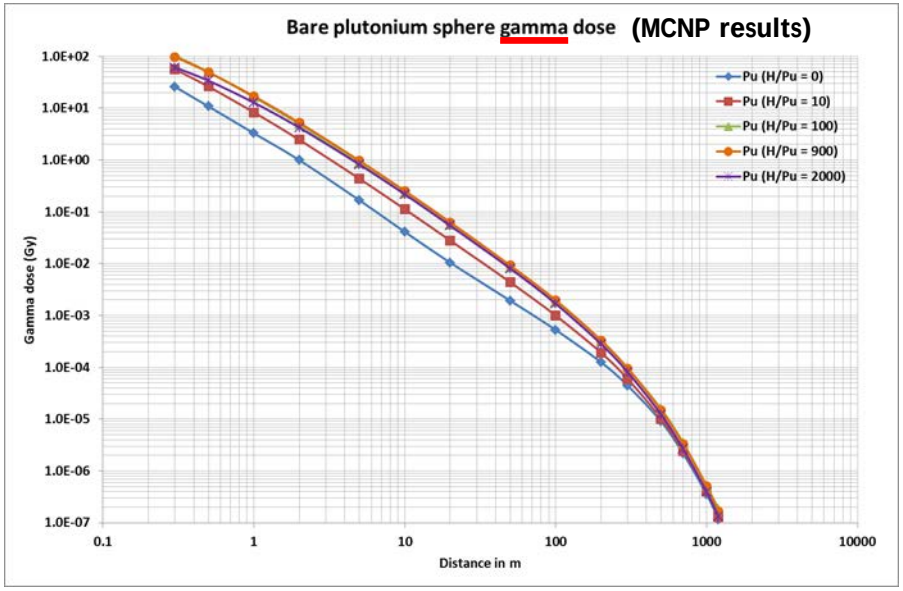
But one:

- 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

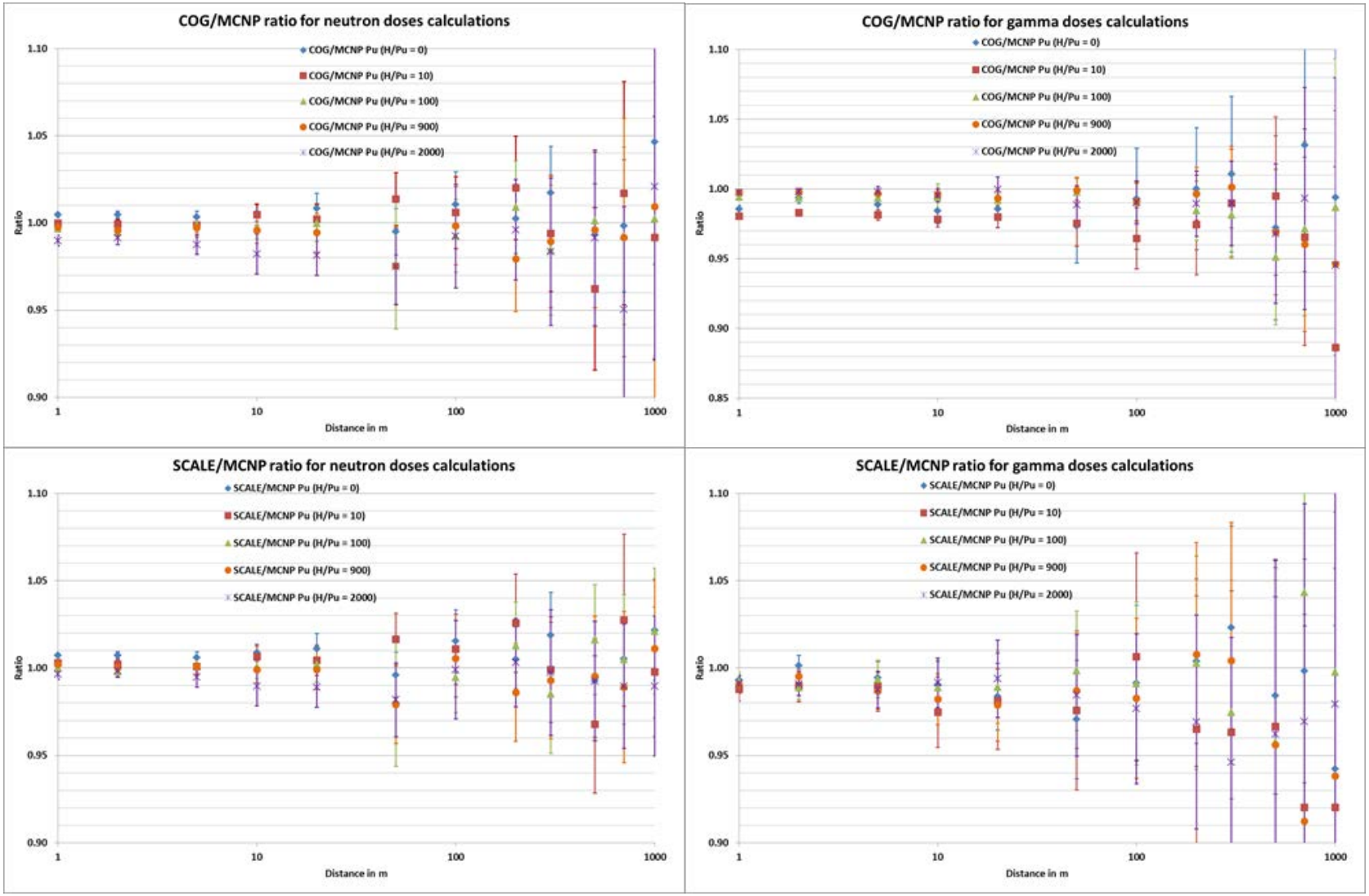
Examples of prompt dose results shown for accidents that generate 10^{17} fissions

Bare sphere (prompt dose results)

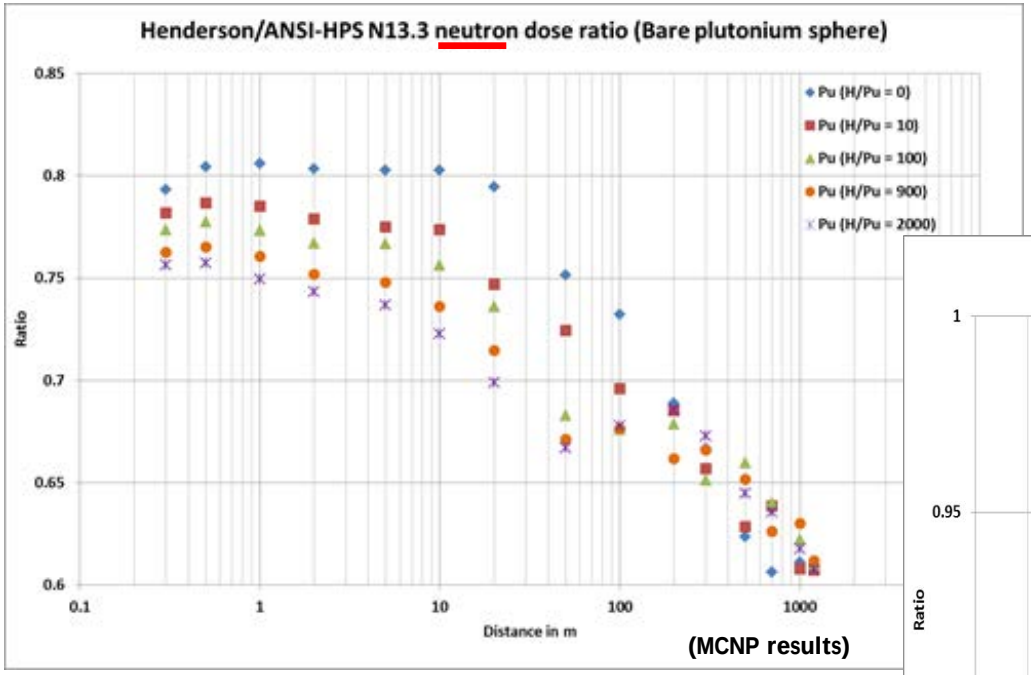


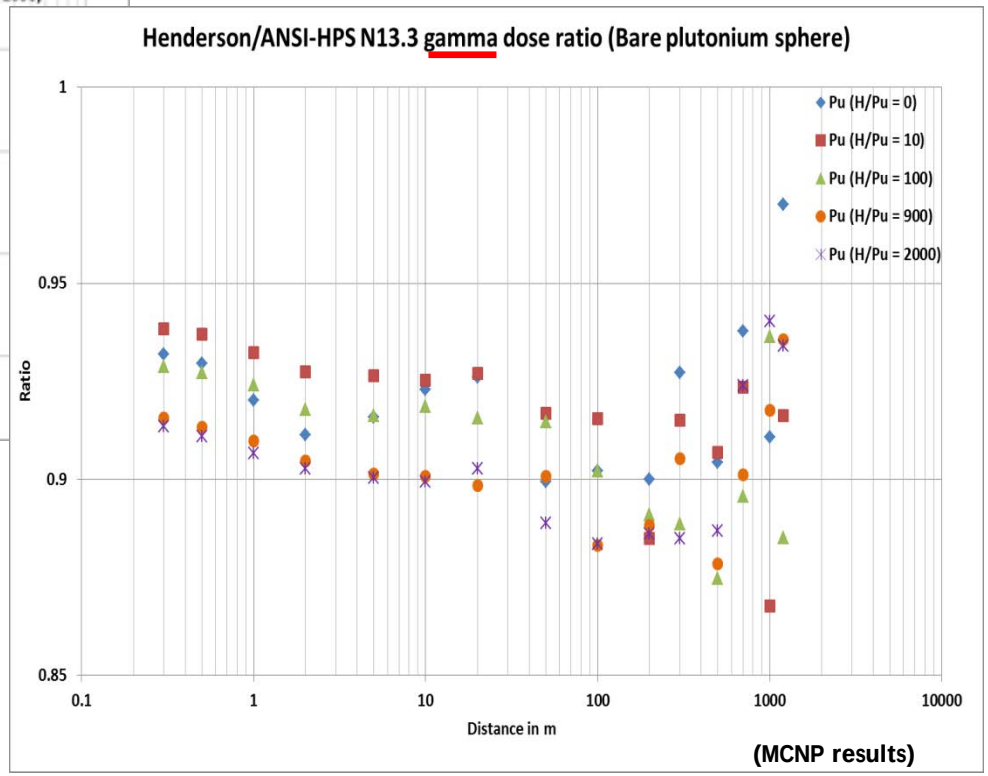


Bare sphere (comparison between codes)

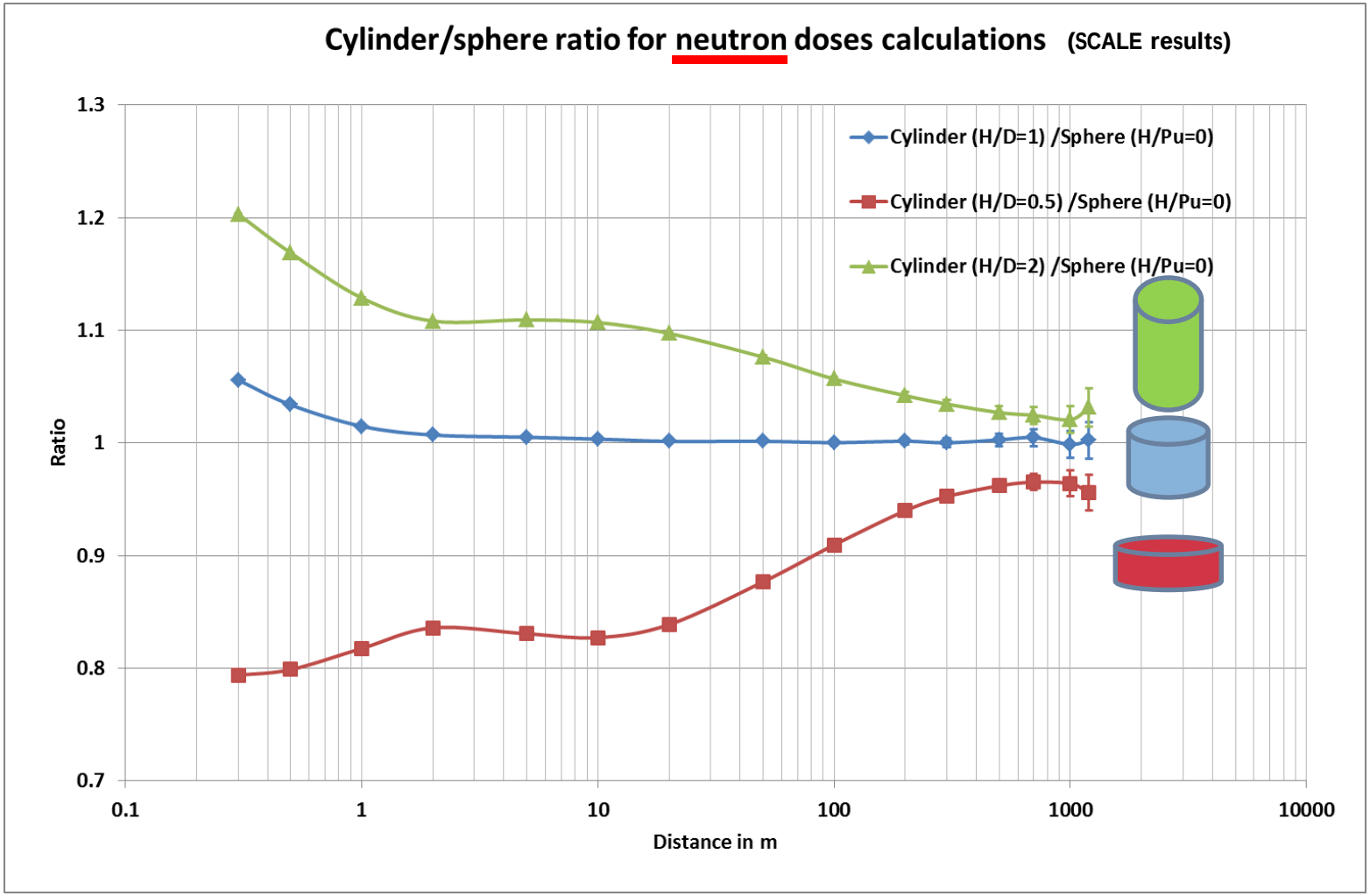


Bare sphere (comparison between conversion factors)

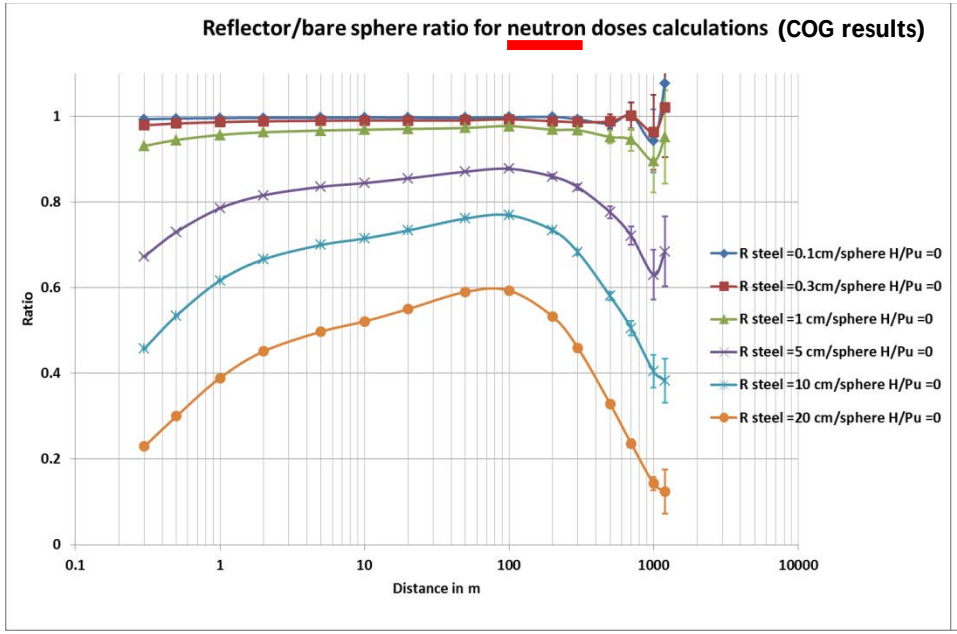


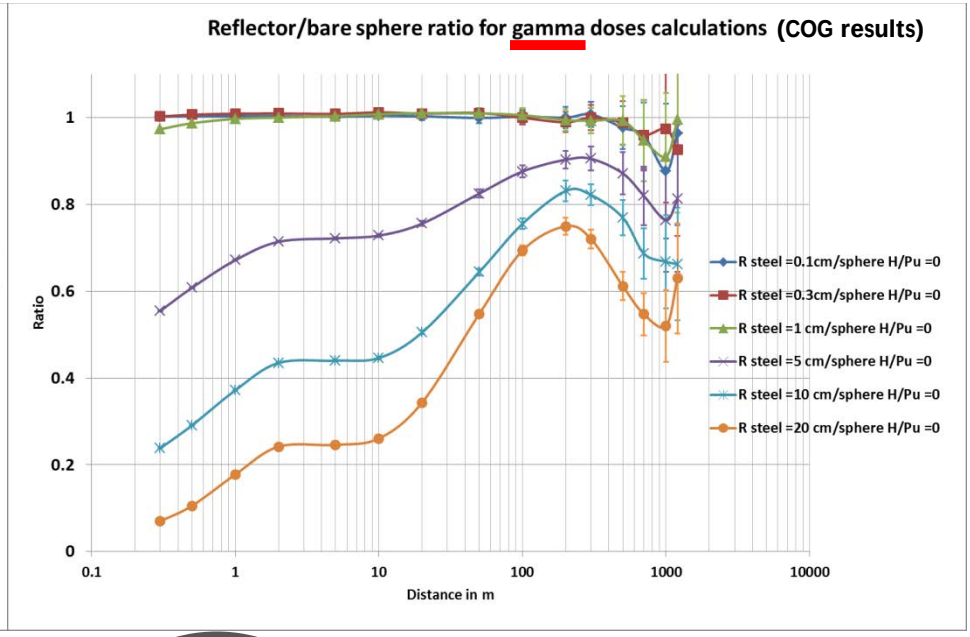


Bare cylinder (prompt dose results for Pu metal (H/Pu=0))

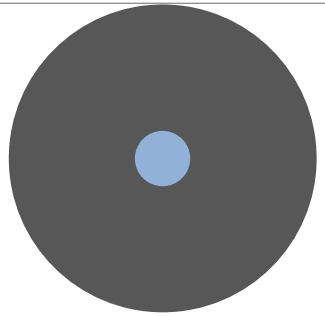


Sphere surrounded by a steel reflector
(prompt dose results for Pu metal (H/Pu=0))





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

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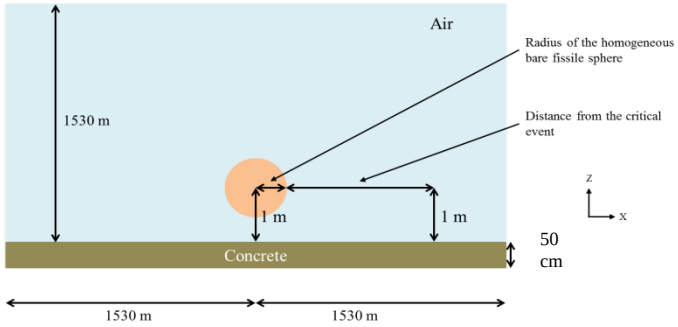
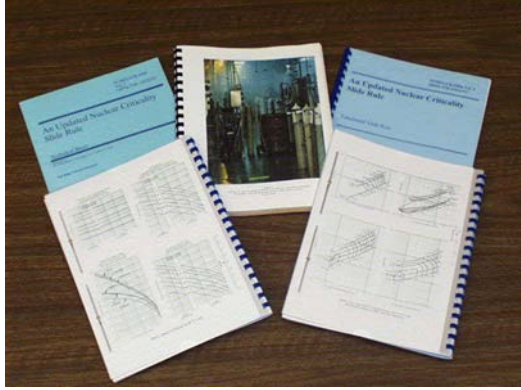
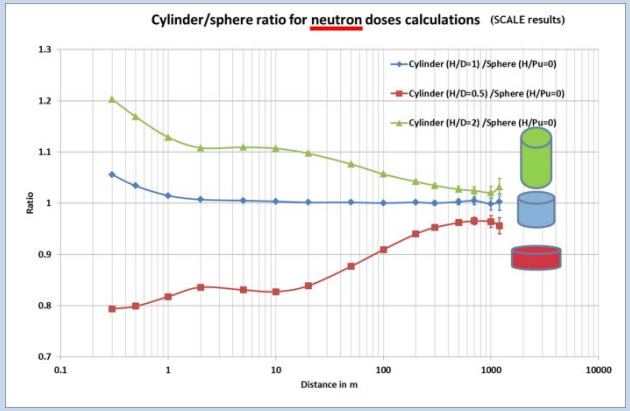




Thank you for your attention



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