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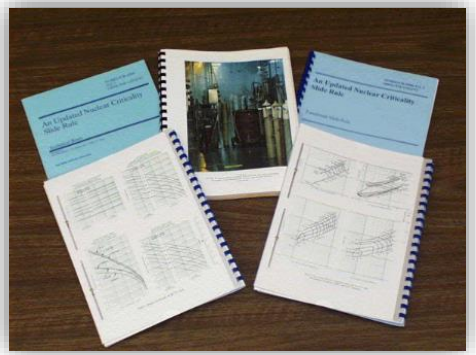
IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

STATUS OF THE SLIDE RULE UPDATE

2024 Annual NCSP Technical Program Review

Speaker: Sophie PIGNET
PoC: Johann HERTH

SlideRule



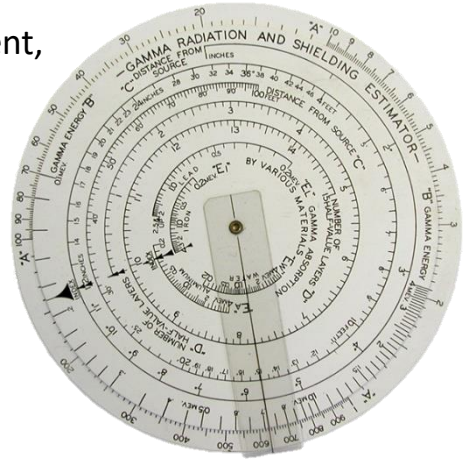
HISTORY AND PURPOSE

An Updated Nuclear Criticality Slide Rule dated of April 1997

- ORNL/TM-13322/V1 & V2: Technical Basis / Functional Slide Rule

The document gives an order of magnitude estimates of key parameters, useful for emergency response staff and public authorities for U systems only:

- The magnitude of the **number of fissions** based on personnel or field radiation measurements or various critical system parameter inputs,
- Prompt 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.



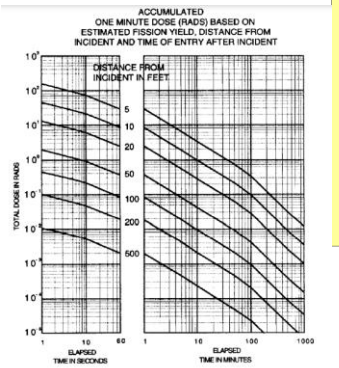
Slide-Rule

[LONG TERM DOE/NNSA NCSP – IRSN COLLABORATION

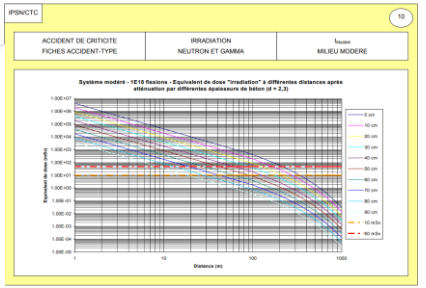
NCSP wants to develop and maintain modern Slide Rule

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"



US Slide-Rule



IRSN "Slide-Rule"

Proposal of a complete work, divided into several steps:

- **Step 1**: Estimation of the doses for uranium systems (including delayed gammas).
- **Step 2**: Introduce Pu systems.
- **Step 3**: Sensitivity studies for U systems.
- **Step 4**: Delayed fission-product gamma dose rates of Pu critical systems.
- **Step 5**: Estimation of the number of fissions.

https://ncsp.llnl.gov/analytical-methods/criticality-slide-rule

Slide-Rule

CONFIGURATION OVERVIEW

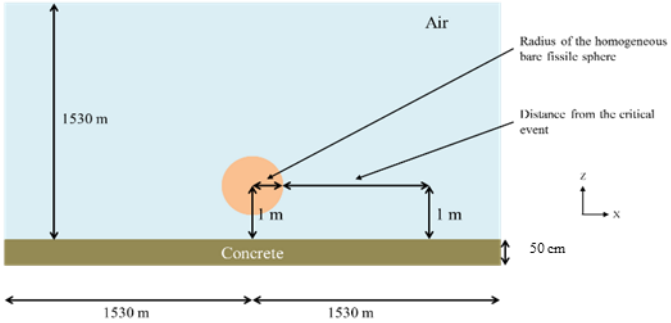
Geometry: one air (sky) layer above 50 cm concrete layer (ground)

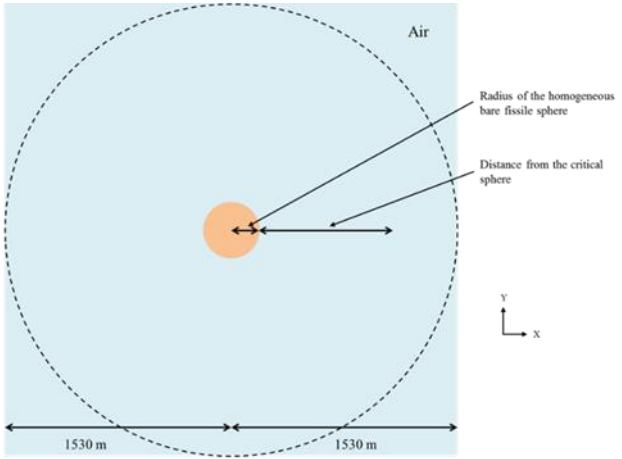
Source:

- 5 Uranium critical systems
  (uranyl fluoride, uranium dioxide, uranyl nitrate, uranium metal, uranium oxide)
- Bare sphere – 1 meter over the ground
- Fission burst yielding a total of 10^{17} fissions in 1 µs
- Prompt and several decay times after the event
  (T = 1 s, 5 s, 10 s, 1 min, 5 min, 10 min, 50 min, 100 min, 500 min and 1,000 min)

Dose detection:

- 30 cm to 1.2 km between source and dose detector





Slide-Rule: Phase 1

INITIAL CONFIGURATIONS – U SYSTEMS

Objectives: Redo with modern radiation transport tools, for the same configurations and assumptions, the calculations performed initially fo the 1997 estimation of the doses for uranium systems.

Methods and Codes Used:

- Codes : *MCNP, SCALE, COG*
- New dose conversion factors : *ICRU-57, ANSI/HPS N13.3*
- Updated cross-section data: *ENDF-B7.1*
- Use of advanced variance reduction techniques.

Prompt Dose Results: Analysis of prompt neutron and gamma doses.

- Comparison with 1997 Slide Rule results : good agreement with minor discrepancies attributed to model improvements.

Delayed Gamma Doses: evaluation of delayed gamma doses over time

- Discrepancies with 1997 data explored and analyzed (mainly due to nuclear data)

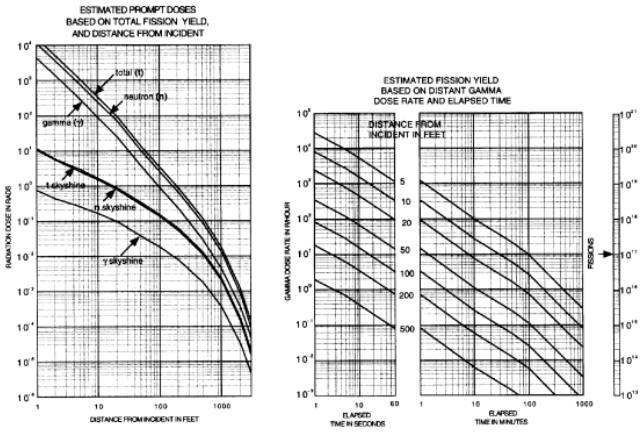
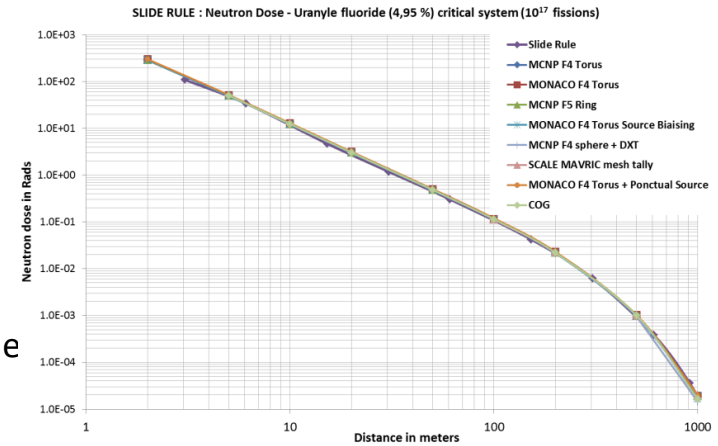


Figure 13 Damp $U(93.2)_3O_8$ @ $H/^{235}U = 10$



Slide-Rule: Phase 2

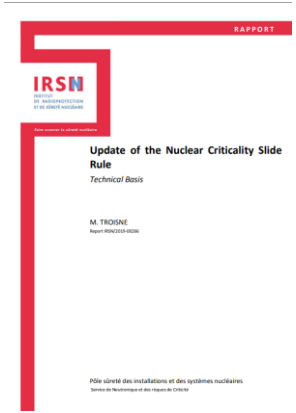
[PU SYSTEMS

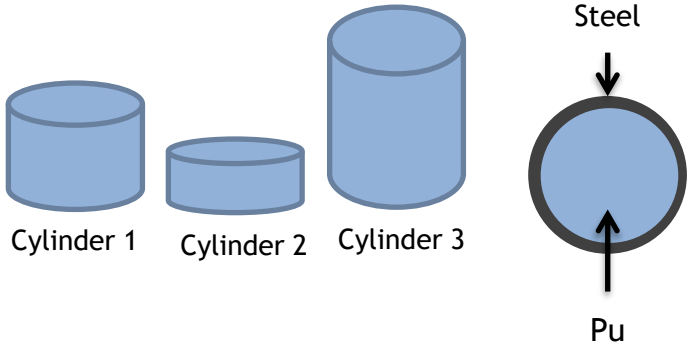
- **Introduce Pu systems** (bare sphere)
  - Prompt N/P dose
  - ^{239}Pu metal homogeneously mixed with water
    5 moderation ratios (H/Pu = 0, 10, 100, 900 and 2,000)

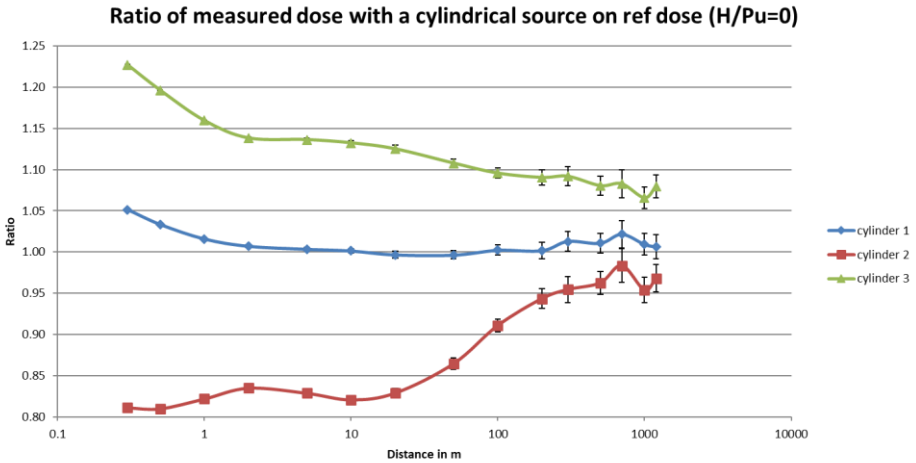
- **Additional configurations**:
  - New source geometries (bare cylinders)
  - Steel reflected sphere

- **Results:** Phase 1 & 2

Report:
IRSN (rev. A) 2019-00266.pdf







Slide-Rule: Phase 3

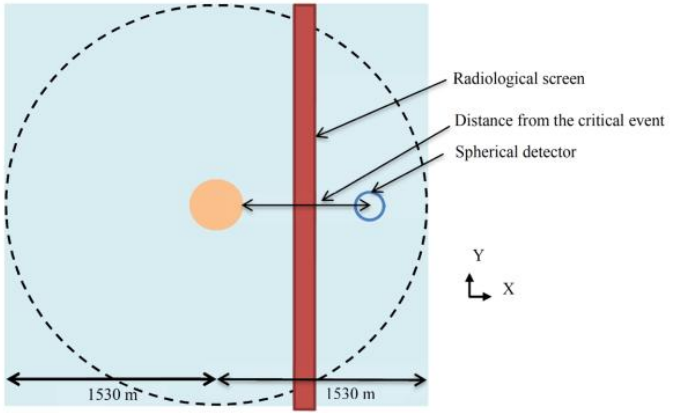
SENSITIVITY STUDIES – U SYSTEMS

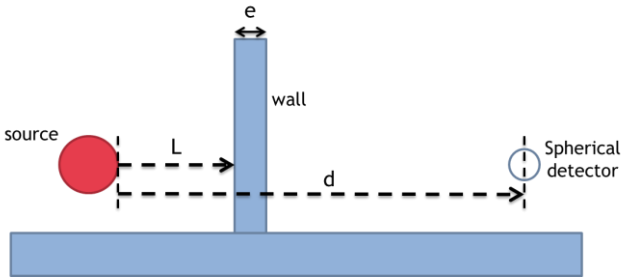
Key focus: quantify the impact of various shielding materials / thicknesses and sensitivity studies on radiation doses.

Shielded configurations:
- Radiological screen (lead, steel , concrete, water)
- Thickness of the wall (e)
- Position from the source and the detector (L, d)

Sensitivities studies:
- Air humidity
- Ground composition and thickness
- Skyshine effect

Materials Studied: enriched uranyl fluoride and uranium metal





Paper: ANS RPSD 2018 – T. M. MILLER & al

Slide-Rule: Phase 4

[DELAYED FISSION GAMMA – PU SYSTEMS

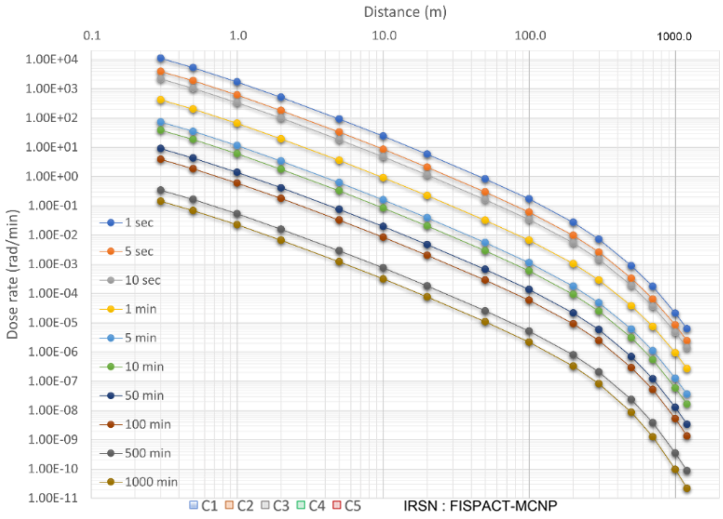
Objectives: Estimate fission product release dose (created by the accident)

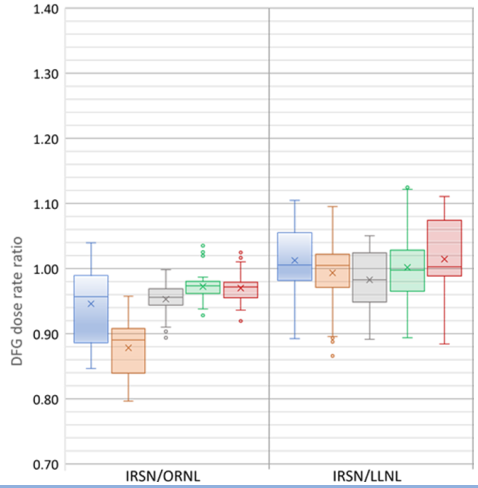
Computational methodology implemented:

- A calculation scheme for DFG dose rates and its application to five Pu case (bare sphere).
- Comparisons between radiation transport and depletion codes such as MCNP, SCALE, COG and FISPACT.
- 15 distances x 10 decay times x 5 cases x 3 conversion factors *(= 2,250 values)*

Conclusion: Overall, DFG dose rates calculated by each laboratory led to consistent results.

Paper: ANS NCSD 2022 – J. HERTH & al.





Slide-Rule: Phase 5

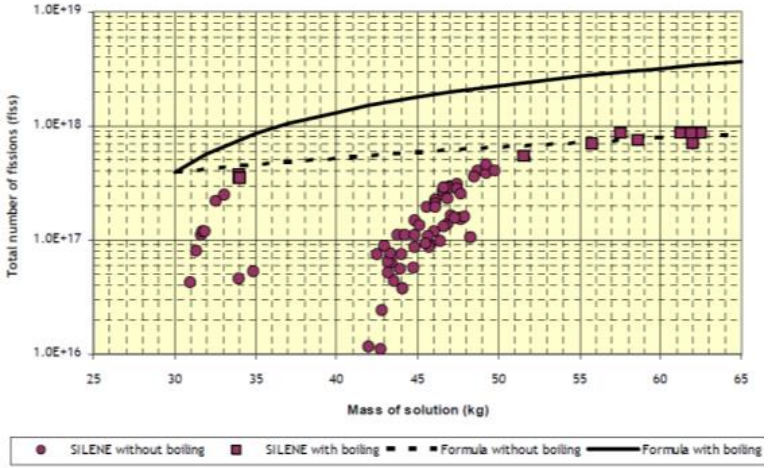
REVIEW OF THE ESTIMATION OF THE NUMBER OF FISSIONS

Objectives:

- Estimate the total number of fissions for the entire criticality accident duration (including boiling for system with water)
- Require limited information, compatible with an emergency context
- Expand the kind of system (solution, powder or rods in water, metal)
- Provide bounding deterministic approach

Formulae based on the “heat energy formula”:

- Parameters and assumptions are adapted to consider the various systems (solution, powder or rods in water, metal) and the heat loss (for solution systems only)
- Comparison performed with experiments and past criticality accidents (see article and associated references)



Update of the Nuclear Criticality Slide Rule:
Review of the estimation of the number of fissions

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ABSTRACT

IRSN (France), LLNL (USA) and ORNL (USA) began a long-term collaboration effort in 2015 to update the nuclear criticality Slide Rule (https://scsp.hpc.inl.gov/analytical-methods/criticality-slide-rule) for the emergency response to a nuclear criticality accident. The Slide Rule presents the estimation of neutron and gamma dose rates and integrated doses based upon estimated fission yields, as a function of distance from the fission source, and time after criticality accidents for different critical systems. This paper presents the review of the section “estimation of the number of fissions”, named “fission yield” in the Slide Rule document. This estimation is important because the other information provided by the Slide Rule is directly proportional to the number of fissions. The previous models, based on Hansen and Barley formulae, will be presented with their associated assumptions and limitations. Then, new proposals will be presented with a comparison to past criticality accidents and experimental data. The new formulae, based on the heat energy equation, cover many types of criticality accidents (solution, dry or low-moderated powder, rods assemblies in water and dry metal) and require limited information in an emergency situation.

Key Words: Criticality accident, Slide Rule, number of fissions

1 INTRODUCTION

In 1997 Oak Ridge National Laboratory published the report “An Updated Nuclear Criticality Slide Rule” [1-2] as a tool for emergency response to a nuclear criticality accident. A similar document was produced by the Institut de Radioprotection et de Sûreté Nucléaire in 2000 [3]. According to [3], this kind of document “permits continued updating of information during the evolution of emergency response, including exposure information about accident victims, estimates of potential exposures to emergency response re-entry personnel, estimates of future radiation field magnitudes, and number of fissions (fission yield) estimate” without precisely knowing the initial conditions leading to the criticality accident. This document gives order of magnitude estimates of key parameters, useful for emergency response teams and public authorities.

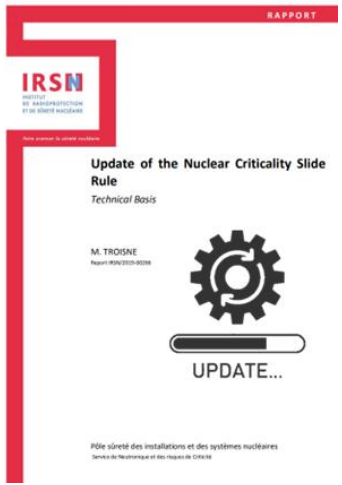
Paper: ANS NCSD 2022 – M. DULUC & al.

Slide Rule

[STATUS UPDATE

Work in progress:

- Update IRSN report (**rev. B**) integrate step [1-5] with consolidated results



Perspectives:

- Perform sensitivity studies for plutonium systems, replicating the sensitivity calculations done for uranium systems.
- Complete existing Slide Rule by adding a section regarding actions to stop an on-going criticality accident (for example, standards with neutron poison)
- Write a comprehensive operational document, integrating all advancements since 2015.
- Create a user-friendly emergency response application for handheld devices (e.g., smartphone or tablet PC)
- Develop an NCSET (*training & education*) module on the use of criticality safety accident Slide Rule to support emergency response.

NCSP FY25 Call For Proposals