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IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

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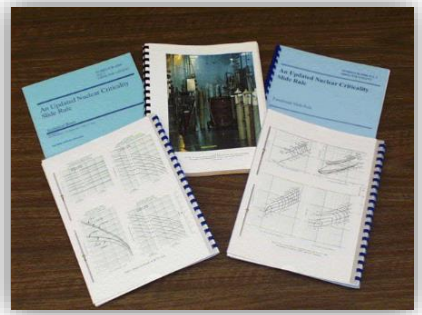
STATUS OF THE SLIDE RULE UPDATE

PHASE 4
PLUTONIUM CONFIGURATIONS – DELAYED GAMMA

MEMBRE DE ETSON

IRSN/FRM-296 ind. 06

Slide-Rule ?



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 teams and public authorities:

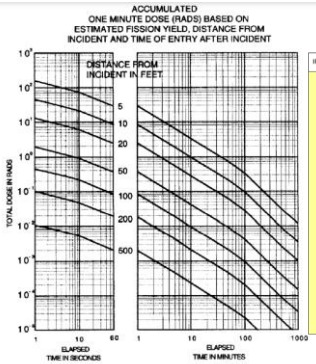
- The magnitude of the **number of fissions** based on personnel or field radiation measurements or various critical system parameter inputs,
- Neutron- and **gamma- dose** at variable unshielded distances from the accident,
- The **skyshine** component of the dose,
- Time-integrated radiation **dose** estimates,
- One-minute **decay-gamma** radiation dose,
- **Dose-reduction factors** for variable thicknesses of steel, concrete and water.

Long term DOE/NNSA NCSP – IRSN collaboration

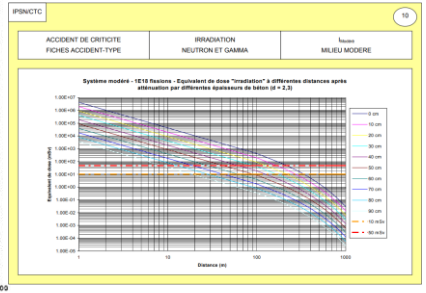
NCSP wants to develop and maintain modern Slide Rule

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**: Redo with modern radiation transport tools, for the same configurations and assumptions, the calculations performed initially for the 1997 estimation of the doses for uranium systems.
- **Step 2**: Introduce plutonium systems. Additional configurations/calculations that combine new source geometries and reflectors.
- **Step 3**: Dedicated to sensitivity studies for uranium systems (step 1).
  - Impact of shielding material,
  - Contribution of humidity on the unshielded configurations,
  - Effects of changing the ground composition from concrete to dry soil.
- **Step 4**: Delayed fission-product gamma dose rates of unreflected plutonium critical systems.

Configuration overview

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

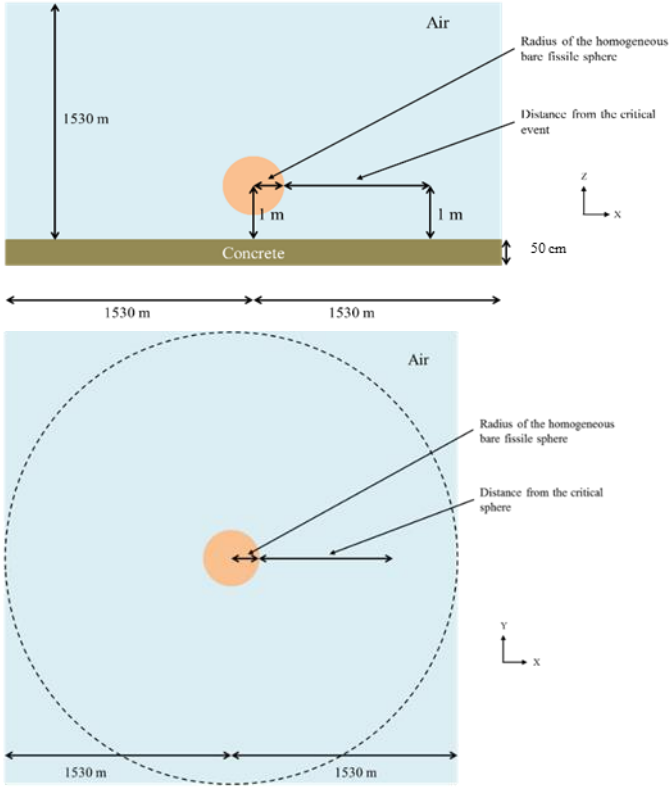
Source:

- Plutonium critical system
- Bare sphere – 1 meter over the ground
- ^{239}Pu metal homogeneously mixed with water: 5 moderation ratios (0, 10, 100, 900 and 2,000)
- Fission burst yielding a total of 10^{17} fissions in 1 µs
- 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 detection,
- 3 flux-to-dose conversion factors (Henderson, ICRU-57, ANSI/HPS N13.3).

15 distances x 10 decay times x 5 moderation ratios x 3 conversion factors *(= 2,250 values).*



Computational methodology

IRSN calculation approach

"Rigorous Two Steps" (R2S) method

Neutron and photon transport steps are done separately (as opposed to the Direct One Step (**D1S**) method):

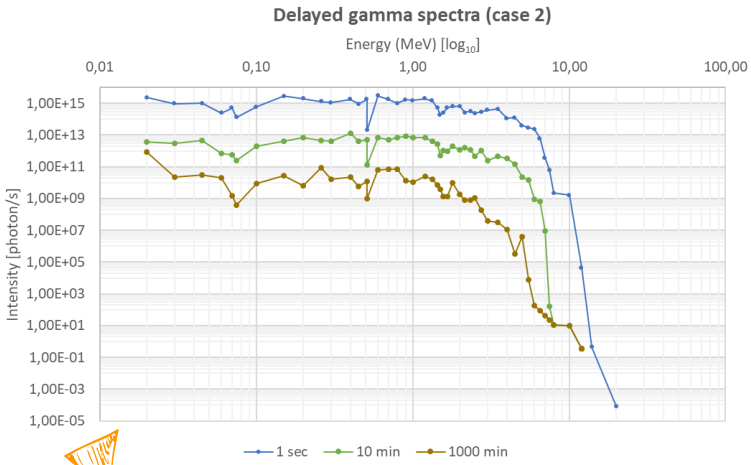
- Compute the decay photon source,
- Transport the decay photons and compute the dose rates.

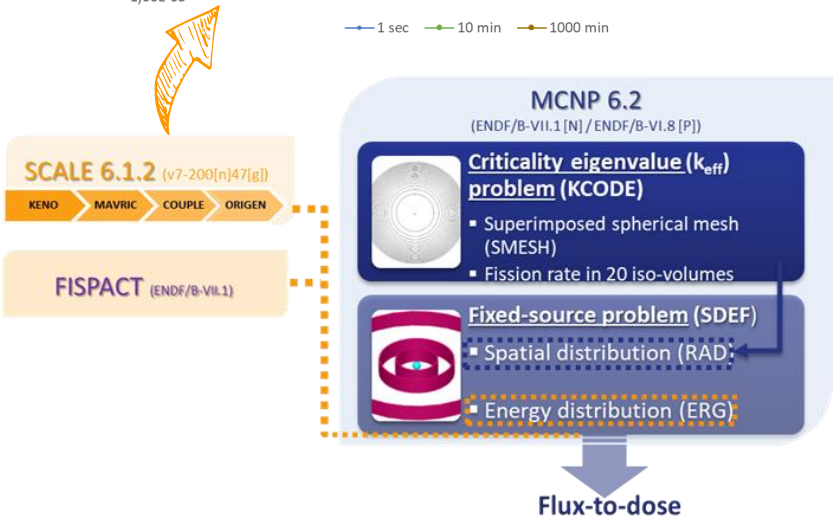
Delayed Fission Gamma (DFG) source term

- **SCALE** 6.1.2 (*KENO>MONACO>COUPLE>ORIGEN)*
  200 neutron/47 gamma structure (MG v7.1-200n47g),
- **FISPACT-II** 5.0 (CE ENDFB-7.1).

Transport: MCNP 6.2

1. **KCODE** simulation to generate spatial distribution of neutrons *(= spatial distribution of delayed gamma),*
2. **SDEF** simulation of DFG dose rates. Variance reduction technics (WW) used for long distances.





Computational methodology

ORNL calculation approach

SCALE 6.3 beta

- Two-step method:

1. **ORIGEN** for generation of activation sources.
   → *AMPX 1597-group structure (v7.1-1597n) based on ENDF/B-VII.1 cross-section library data (MG).*
2. **KENO-VI** simulation to generate energy and spatial distribution of neutrons. **MAVRIC** simulation of photon doses with neutron multiplication turn off.
   → *CE cross-section data based on ENDF/B-VII.1*

- Weight windows and source biasing provided by the MAVRIC sequence.

LLNL calculation approach

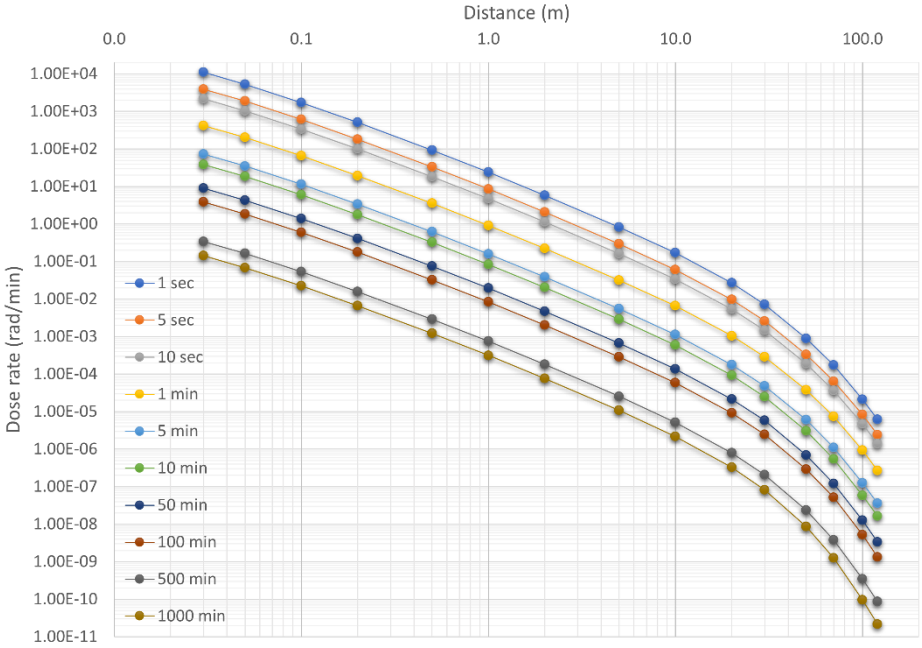
COG 11.2

- One-step method, *i.e.*, eigenvalue simulation with neutron and photon dose tallies.
- ENDF/B-VII.1 cross-section library data (CE).

DFG dose rates results

- Whatever the case, dose rates decrease by more than 9 orders of magnitude between 30 cm and 1,200 m from the external surface of the source, and by 5 orders of magnitude between 1 s and 1,000 min after the critical event.

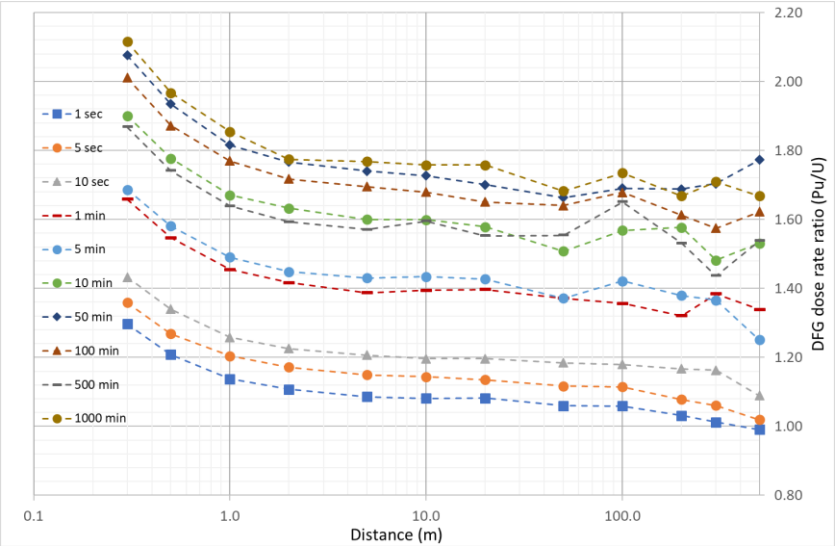
- The difference between the extreme cases goes from a factor 9.3 for short distances to a factor 3.4 for long distances. The lowest dose rate is obtained for the metal plutonium system whereas the highest dose rate is obtained for an intermediate moderation ratio (H/Pu=100 or 900).



IRSN (FISPACT-MCNP) results obtained with HPS N13.3 conversion factor

Comparison of DFG dose rates between Pu and U metal (step 1)

- Slight increase trend at short distances, which stabilizes as the distance increases.
- Plutonium metal configuration generates dose rates up to twice higher than the uranium metal configuration.
- Compared to uranium configurations, observed variations of the dose rates from the plutonium cases are driven by the differences in half-lives of the fission products.
- Shows the interest to update the original Slide Rule with plutonium systems to adapt the emergency response to a nuclear criticality accident.



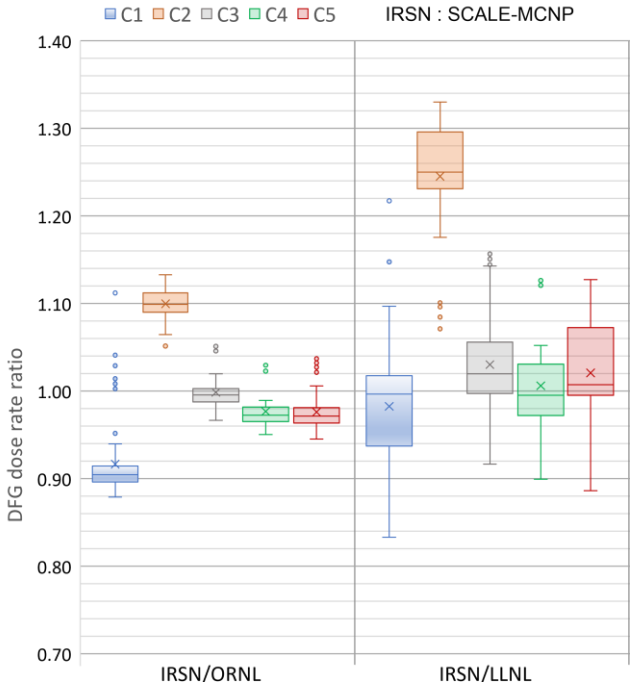
239-Pu metal (case 1) and 93.2% 235-U metal calculated with Henderson conversion factor

Code-to-code comparison (1/4)

IRSN (SCALE-MCNP) vs. ORNL & LLNL

- **IRSN/ORNL**: for cases 3, 4 and 5 results are in reasonably good agreement.
  IRSN tends to underestimate ORNL results by approximately 10 % for case 1 and conversely overestimate by 10 % for case 2.

- **IRSN/LLNL**: except for case 2, a relatively good agreement is observed, although ratios variance is slightly higher.
  For case 2, IRSN overestimates LLNL results by 20 % to more than 30 %.

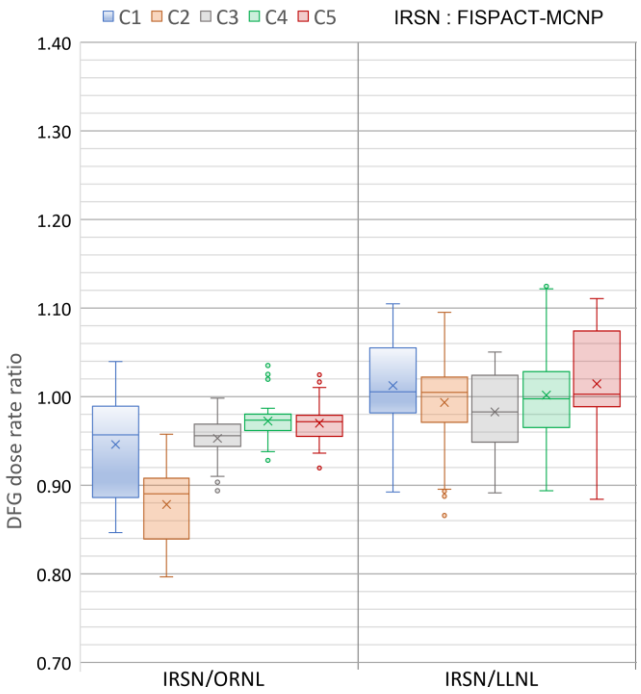


Code-to-code comparison (2/4)

IRSN (FISPACT-MCNP) vs. ORNL & LLNL

- **IRSN/ORNL**: a relatively good agreement is observed for cases 3, 4 and 5 with a squeezed distribution.
  For cases 1 and 2, the distribution is stretched with a trend for IRSN results to underestimate the dose rates calculated by ORNL, with a more pronounced effect for case 2.

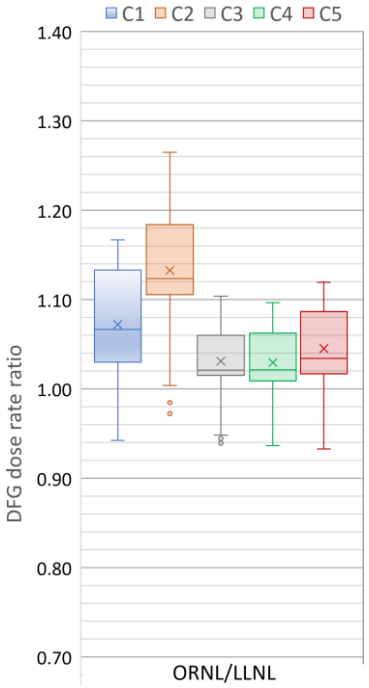
- **IRSN/LLNL**: for all five cases, a good agreement is observed with discrepancies generally lower than 10 % and ratios are symmetrically distributed around one.



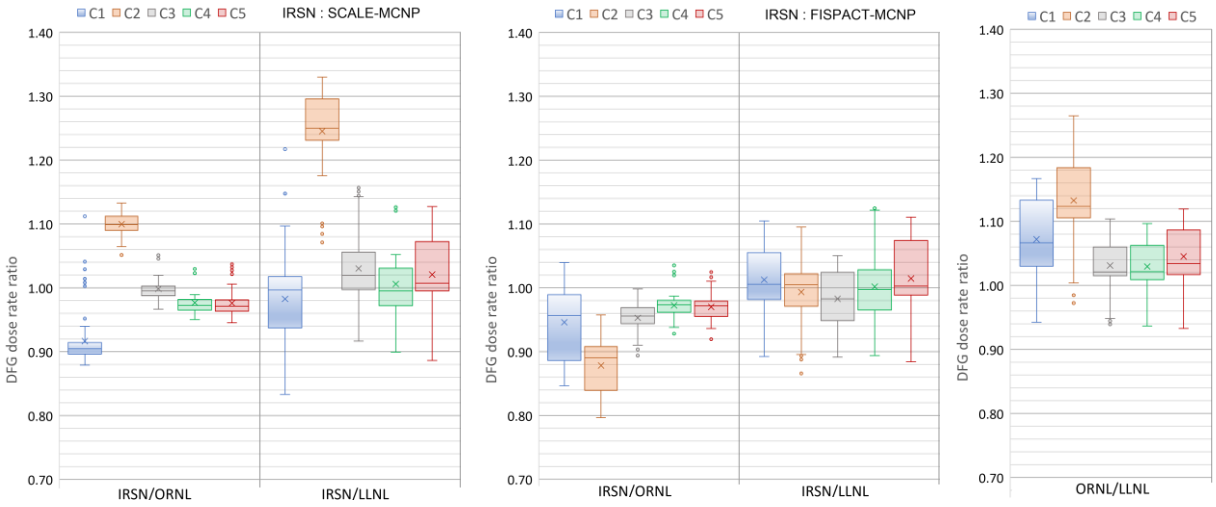
Code-to-code comparison (3/4)

ORNL vs. LLNL

- A relatively good agreement is observed for cases 3, 4 and 5. For cases 1 and 2, ORNL tends to overestimate LLNL dose rates with a pronounced tendency for case 2.



Code-to-code comparison (4/4)



For **case 2**:

- The coarse mesh of the multi-group library (v7.1-200n47g) used by IRSN in SCALE/ORIGEN to perform the depletion and decay may lack of accuracy in the intermediate energy region where the 239-Pu fission cross section is sensitive.
- The new very-fine AMPX 1597-group structure (v7.1-1597n) used by ORNL in SCALE-6.3/ORIGEN allows to reduce the gap for this case.
- The use of FISPACT give consistent results, close to those obtained by LLNL with COG.

CONCLUSIONS

- This fourth phase of Slide-Rule update gives:
  - a calculation scheme for DFG doses and its application to five plutonium material,
  - comparisons between radiation transport and depletion codes such as MCNP, SCALE, COG and FISPACT.
- Overall, DFG dose rates calculated by each laboratory led to consistent results.
  Extra effort is under way to identify the cause of the remaining differences, especially for case 2, by comparing precisely the gamma source, and particularly nuclides inventories.
- Results will be part of a NCSD 2022 paper.
  For more info: **ncsp.llnl.gov** > Analytical Methods > Criticality Slide-Rule.

PERSPECTIVES

- Sensitivity studies in the same way as those made for uranium systems (step 3).
- 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 results.
- Creation of a future new operational document.

ACKNOWLEDGMENTS

- IRSN and NCSP collaboration has been very fruitful. Regular basis meeting with LLNL and ORNL.
- Many thanks to US colleagues for their availability! We are looking forward to continuing our collaboration on the Slide-Rule project.

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THANK YOU FOR YOUR ATTENTION!

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