Overview of CEA activities in Nuclear Criticality Safety

Criticality Safety Expert Group of CEA

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1/ CEA – CSEG : 2025/2026 works and perspectives

2/ Focus on CIRCEE:
a tool for calculation of criticality accident consequences and CAAS placement validation

CEA – CSEG

- 25 years of existence
- Composed of 8 experts and engineers
- Provides NCS technical support to installations and projects of CEA (and more) : calculations, assessments, expertise, interface with authorities…
- Supports CEA activities regarding the criticality accident aspects (from studies to emergency preparedness)
- Involved in International organizations: ISO (WG8, 7753), AIEA (SSG27), NEA
- Participates to regulatory criticality trainings (CCE, QCE) or educations (master's degree)
- …

CEA – CSEG: works and perspectives (2025-2026)

- **Pursue the CEA participation to the Hands-on training sessions**
  3 participants in 2024, 4 participants in 2025
- **Propose to NEA/WPNCS a "practitioner" project**
  Sept 2024 meeting: International exercise on NCS evaluation → sub-group in 2025?
- **Make a few of our guidances and handbooks available**
  permissible values (0.97, 0.93), criticality accident guide, history of programs in CRAC and SILENE…
- **Pursue our participation to ISO/WG8**
  project in 2025: a standard related to mass control
- **Specify and formalize few of CEA experimental needs for the future**
  project in 2026
- **Fill the Learning from Experience (LfE) Database**
  IRSN meeting with licensees in oct 2024
- **Make our knowledge, experience and expertise a valuable support for any collaboration** *(improvement of safety has no frontier)*

CIRCEE

A tool for calculation of criticality accident consequences and CAAS placement validation

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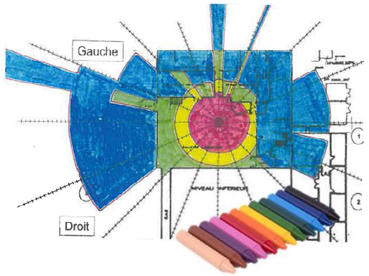
Context

Since the 1999 JCO accident, French regulators require production of isodoses maps for facilities where the criticality risk cannot be ruled out, in support to the safety report.

Moreover, since the 2011 Fukushima accident, estimation of consequences of a criticality accident as an aggravating factor, as well as provisions to limit its consequences are required for most facilities handling fissile material.

⇒ Many studies to be produced, for very different facilities and postulated states.



- **Establishing such maps without a dedicated software is long, tedious, and error prone.**

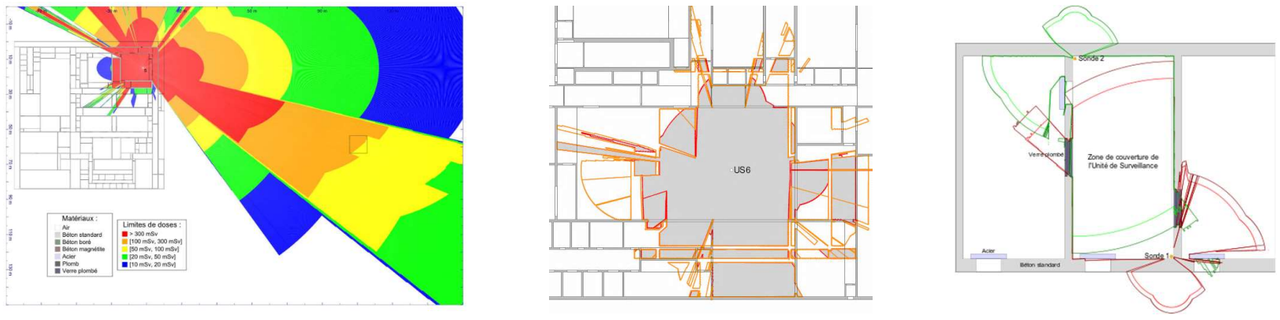
- **Use of state-of-the art transport codes is impractical (cost, time…)**

Development of CIRCEE began in 2006 as an answer to these problems.

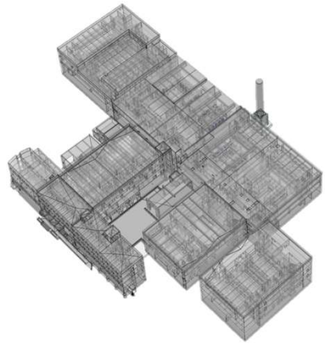
Objectives & principles

- **A fast, industrial code aimed at criticality accident related studies**
  - ⇒ Isodose maps calculations
  - ⇒ CAAS probes positioning validation

- From preliminary safety studies to crisis management
  - ⇒ A few minutes to calculate the isodose map of a full facility + surroundings;
  - ⇒ No need for a dedicated cluster, runs on standard computers
  - ⇒ Allows to perform parametric, sizing, validation… studies

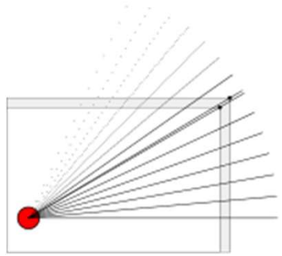


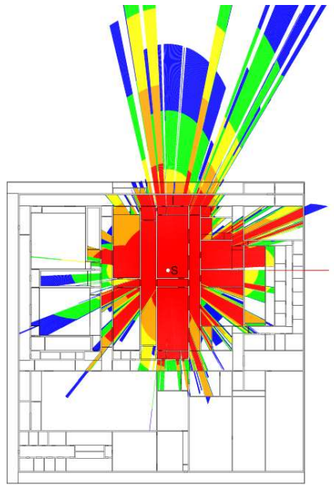
Characteristics



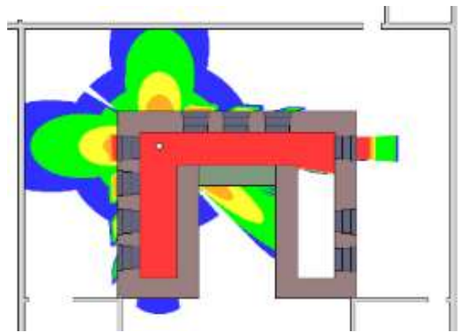
- ⇒ Written in C++11 (~24k lines), Windows and Linux – command line only
- ⇒ Full 3D calculation
- ⇒ CAD imported geometric models
  - ⇒ Using STEP exchange format + SALOME platform

- ⇒ Straight line attenuation
  - ⇒ With pre-calculated attenuation coefficients
  - ⇒ With correction for diffusion/reflection





- ⇒ Space discretization (spherical centered on source)
- ⇒ Tabulated source terms and attenuation factors



Input data and library

- 1D calculations with CEA's SN1D (deterministic 1D coupled n-γ transport)

- Coupled library based on ENDF/B-VI (175n+36γ)
- Attenuation factors pre-calculated for:
  - ⇒ Source particle (fission neutrons, fission γ, secondary γ)
  - ⇒ Dose, Kerma
  - ⇒ Selected source composition and dimensions
  - ⇒ Selected shields compositions, widths
  - ⇒ …

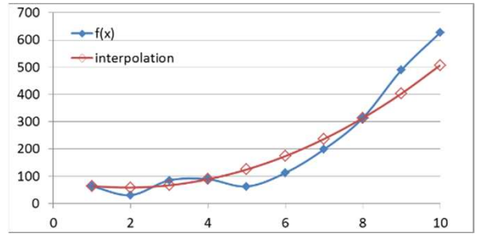
10^5 - 10^6 dose values stored as 7000 interpolation coefficients

Materials library:

- 5 types, up to 2m thickness:
  - ⇒ Ordinary concrete d=2.287
  - ⇒ Borated concrete d=2.401
  - ⇒ Heavy concrete (magnetite) d=3.3
  - ⇒ Steel d=7.89
  - ⇒ Lead d= 10.9
- + 8 pairs (concrete+metal, ordinary concrete + special concrete)

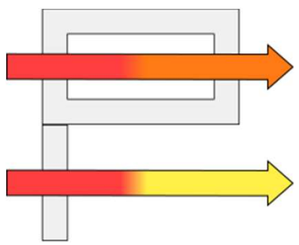
Overview of library content

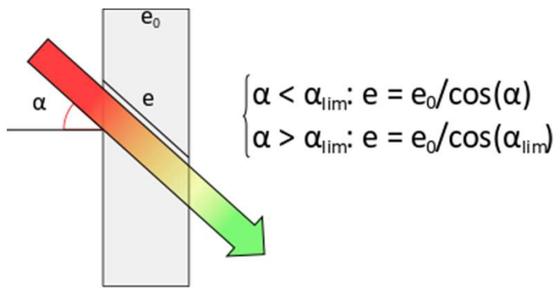
- **Attenuation factors:**
  - For a given source and a given shield composition and width and…
  - Ratio unshielded/shielded dose
  - At a fixed arbitrary distance from the source
  - Stored as Lagrange polynomial interpolations
    2 (source volume and shield thickness) or 3 dimensions (+second shield width)

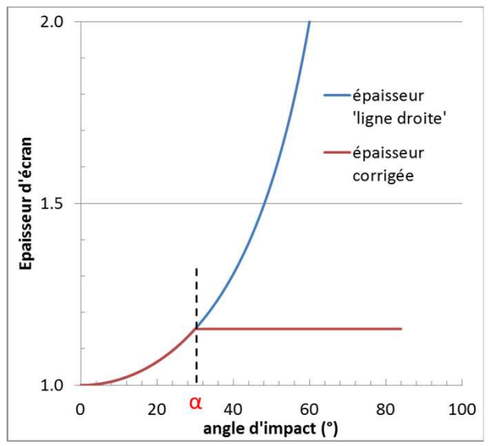


$$\mathrm{FA}(e,V)=\frac{(e2-e)}{(e2-e1)}\frac{(e3-e)}{(e3-e1)}\mathrm{f}(e1,V)+\frac{(e1-e)}{(e1-e2)}\frac{(e3-e)}{(e3-e2)}\mathrm{f}(e2,V)+\frac{(e1-e)}{(e2-e3)}\frac{(e2-e)}{(e2-e3)}\mathrm{f}(e3,V)$$

- **To compensate for 1D limitations: corrections calculated with TRIPOLI-4**
  - Diffusion correction inside rooms/buildings: reflection factor
  - Diffusion correction through shields: limit angle





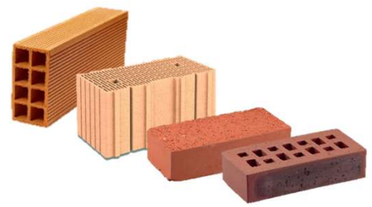


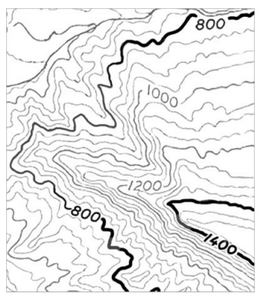
Improvements to the material library

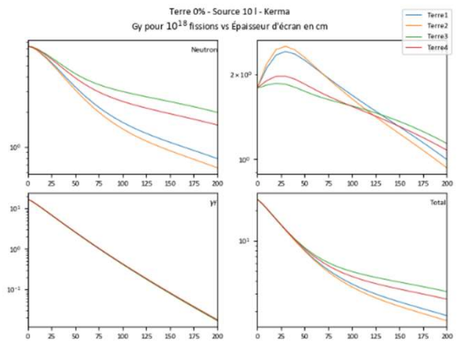
- **Addition of new materials is tedious: large number of calculations required.**
  - ⇒ Solution chosen: equivalence to already calculated materials (ordinary concrete)

- **Example: Lead glass for hot cells windows**
  - γ, equivalent to ordinary concrete (overestimation of secondary γ)
  - Neutrons, equivalent to air (underestimation of attenuation)

- **Example: Soil and bricks**
  - Large variety of possible compositions, density, water fraction… (bibliographic study)
  - Parametric calculation of attenuation factors => equivalent width of concrete
  - Creation of material families : “brick”, “dry hollow brick”, “wet full brick”…
    - ➔Isodoses: min attenuation; CAAS: max attenuation
  - Example orders of magnitude of concrete width:
    - Dry hollow brick: 1/8
    - Dry full brick: 2/5
    - Dry soil: 1/4



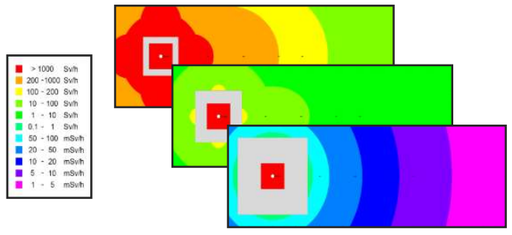




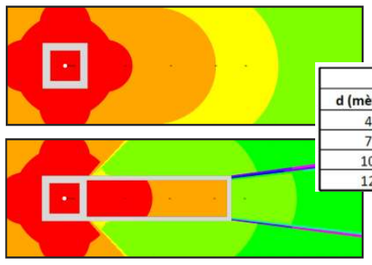
⇒ **Modelling of facilities where wall features are unclear**
⇒ **Testing use of topographical data for more realistic long range dose estimations**

Validation

- Still in progress
- Polynomials vs SN1D: OK (±5 %)
- CIRCEE validation vs TRIPOLI-4© on simplified models
  - ICNC 2015 paper
  - TRIPOLI-4 reference values issued in 2021
- Validation of TRIPOLI-4© for criticality accidents: ICSBEP (ALARM-TRAN-*-SHIELD-001)



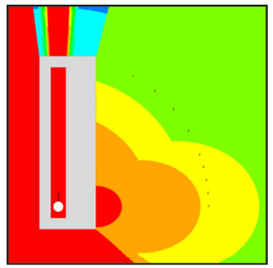
Concrete attenuation: -20% to +50% for total dose

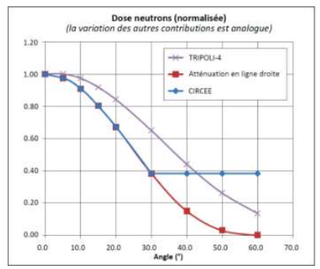


Circée / TRIPOLI-4 - H*(10) - écran présent

d (mètres)	n	γ(n,γ)	γfiss	γtot	total
4	0.8	0.9	1.4	0.9	0.8
7	0.8	0.9	1.4	1.0	0.8
10	0.8	0.9	1.4	1.0	0.8
12	0.7	0.9	1.3	1.0	0.8

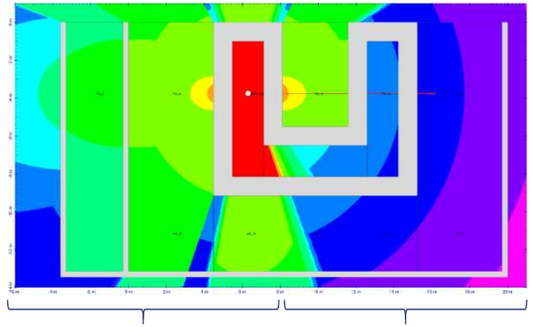
Shield vs no shield: 70 to 100% of reflection effect





Limit angle: mainly over-compensation (>70% vs TRIPOLI-4©)

Lacunar geometry (U-shaped hot cell)



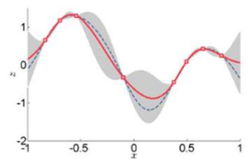
-10 to +80%

Large underestimation

Possible future improvements

- Revise the geometry processing
  ⇒ For now, only boxes
  ⇒ More complex shapes desirable; harmonization or use of other CEA codes processors?

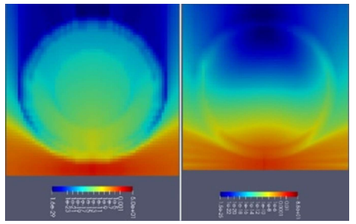
- Improve/ease additions to the material library:
  ⇒ Remove approximations due to interpolations (ie, kriging…)
  ⇒ Going further: flux attenuations per groups + conversion coefficients?
  (would allow to infer spectrum changes due to shields combinations and strongly restrict the number of calculations)



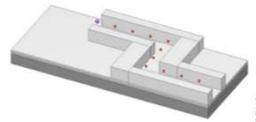
- Account for diffusion:
  ⇒ Alternative approach, a new code?
  ⇒ Performance/precision compromise
  ⇒ MC+CADIS? 3D deterministic? Albedo?

- Integration into the CEA OPERA platform?

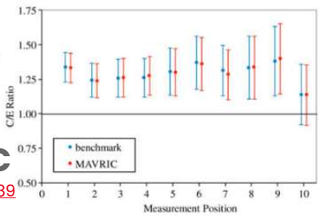
TRIPOLI-4+IDT

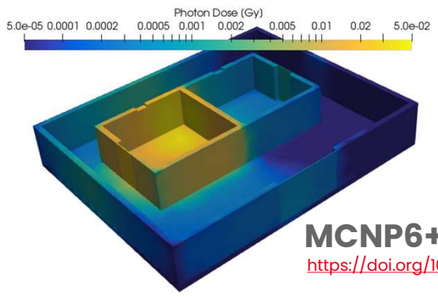


Overview of the TRIPOLI-4 Monte Carlo code, version 12
https://doi.org/10.1051/epjn/2024018



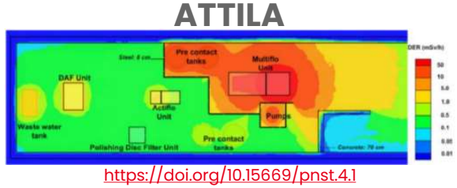
SCALE/MAVRIC
https://doi.org/10.13182/NT174-289





MCNP6+ATTILA
https://doi.org/10.2172/1565798

ATTILA



https://doi.org/10.15669/pnst.4.1