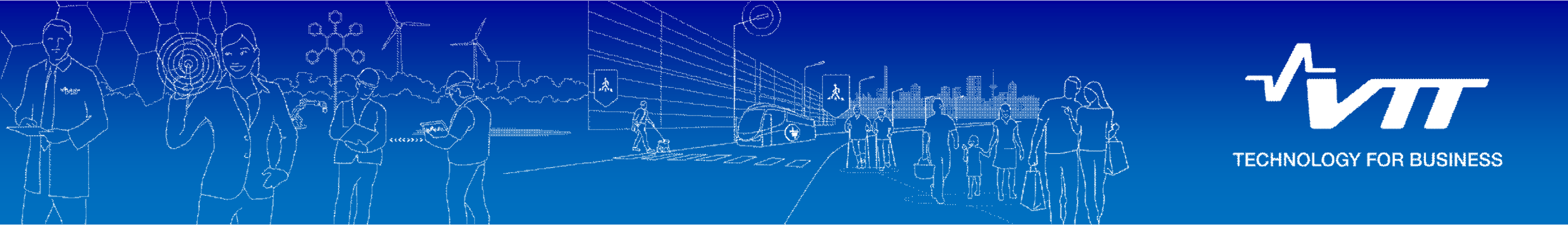

Nuclear criticality and safety analyses preparedness at VTT (KATVE)

Pauli Juutilainen • Eric Dorval • Risto Huhtanen • Silja Häkkinen • Toni Kaltiaisenaho • Petri Kotiluoto • Jaakko Leppänen • Juho Peltola • Karin Rantamäki • Antti Räty • Riku Tuominen • Ville Valtavirta • Tuomas Viitanen
VTT Technical Research Centre of Finland Ltd

Criticality safety

- The mission: ensure that the nuclear fuel remains subcritical in storage facilities, transport casks or wherever it is not allowed to go critical.
- When criticality safety analysis is performed, the systematic bias of the computing platform has to be known. It is determined with the help of a validation package, such as the one that has been under construction at VTT. The package is presented in Figure 1.

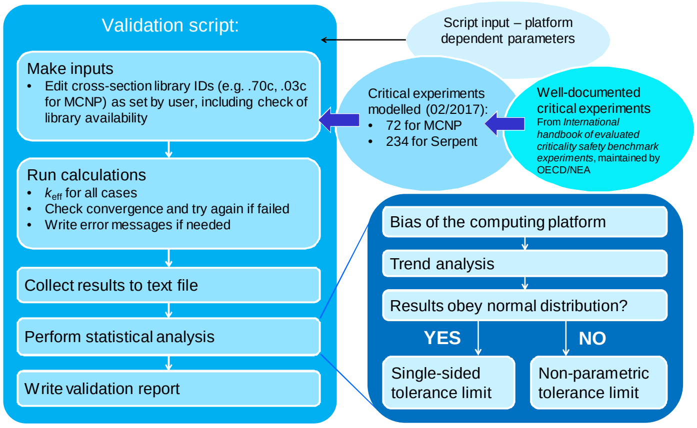

Figure 1. *Rough process scheme describing the criticality safety validation package.*

Radiation shielding

The scope of the Serpent code has been expanded from reactor physics to radiation shielding applications. An important step in this process has been the development of a *photon transport* mode, which includes detailed treatment of photon interactions in matter. The photon interaction physics has been compared against MCNP6 with good results.

Radioactive decay source mode has also been developed for generating decay gammas emitted by activated materials that can be obtained from a burnup or activation calculation.

Shielding calculations require efficient *variance reduction* techniques in order to estimate dose rates in well shielded regions. *Weight-window* based variance reduction method and a built-in *response matrix* based importance solver are under development.

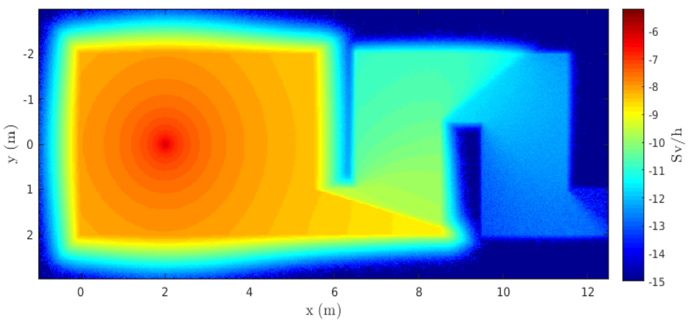

Figure 2. *Photon dose rate from a 400 kBq Cobalt-60 point source in a concrete maze calculated with Serpent.*

Dosimetry and activation analysis

The materials located inside the reactor core as well as the interior of the pressure vessel are exposed to high levels of fast neutron irradiation, which results in radiation-induced damage affecting the mechanical properties. The neutron dose of these components are estimated by the means of *neutron dosimetry,* in which the measured data is combined with computational results.

Recent activities to improve the dosimetry and activation analysis capabilities at VTT include:

- The MAVRIC code has been introduced to replace the outdated codes TORT and DORT and test calculations have been performed against measured data from Loviisa-1 NPP, see Fig. 3. The same case has also been computed with Serpent.
- The documentation of the neutron adjustment LSL-M2 code has been improved and an auxiliary Matlab script to calculate covariances among activities has been created.

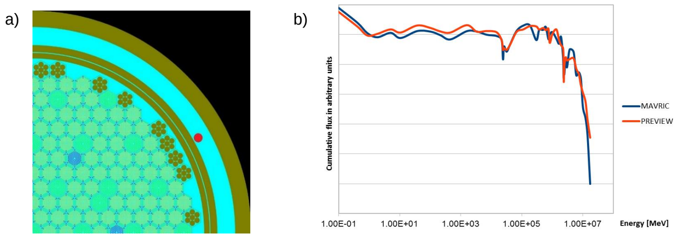

Figure 3. *a) Location of the modelled surveillance chain in the core of Loviisa-1 b) Qualitative comparison of results obtained with the MAVRIC and PREVIEW codes.*

Heat transfer in dry storage casks

Concept: air-cooled dry storage facility is an option to store spent nuclear fuel between discharge from reactor and final disposal.

Motivation for dry storage: no active cooling is required.

The studied pre-requisite: the temperature of the fuel pin remains below the assumed limit of 400°C above which it could be damaged.

The calculations: source term, or spent fuel composition by Serpent, heat transfer analysis through CFD (computational fluid dynamics) calculations with OpenFOAM to determine the peak cladding temperature of the fuel pins stored in a Castor-V/21 cask. Samples of results are depicted in Figures 4 – 6.

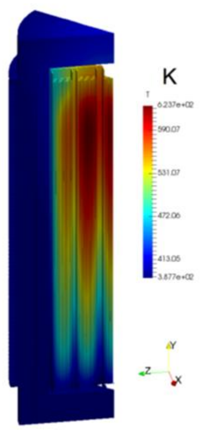

Figure 4. *Temperature distribution at 4 years after discharge.*

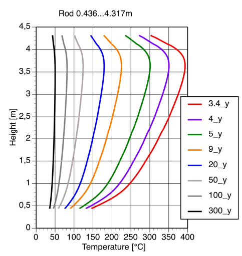

Figure 5. *Axial cladding temperature profiles in the most heated zone of the cask at various cooling times.*

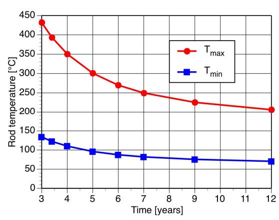

Figure 6. *Highest and lowest cladding temperature over the first years in storage cask. The 400°C limit is fulfilled by fuel discharged more than ~3.4 years earlier.*