Business from technology

# Criticality Safety Calculation Package for Fuel Transport and Storage Systems

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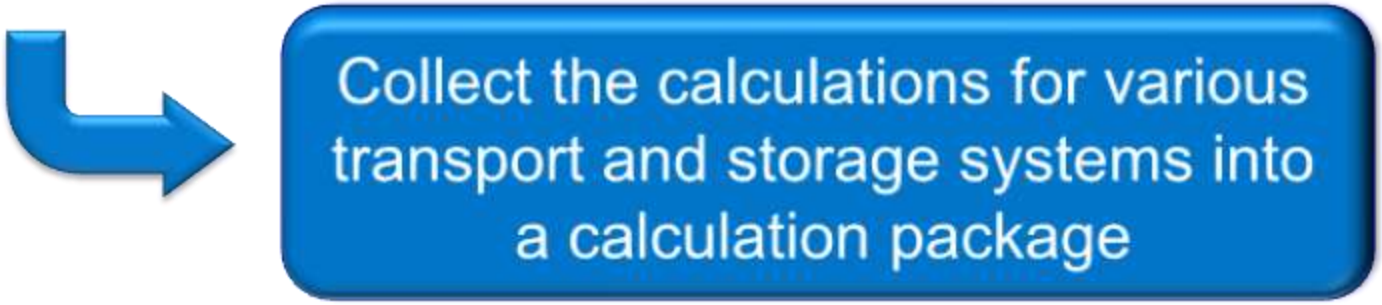
# Motivation

- Criticality safety assessments require sensitivity analyses
  - Large number of separate calculations with only small modifications
  - Tedious work if performed manually
- Possibility to reduce manual work
  - Saves time (releases time for other duties)
  - Reduces risk of human errors
- A need to document the work and transfer knowledge to next generation
  - No new storage systems in near future
  - Calculations for Loviisa NPP not done very often



# Outline

- Data transfer and analysis program
- Pool models for storage and transport systems

- Demonstrate the use of package
  - Effect of moderator density on $k_{eff}$ of single assembly
  - Design of spent fuel storage rack
- Summary and future work

# Definitions

- Pool = storage or transport system
  - Transfer cask, spent fuel pool, etc.
- Pool model = a skeletal MCNP input for the pool
  - Template for actual MCNP input
  - Contains “keywords” replaced by an appropriate number before actual MCNP calculation

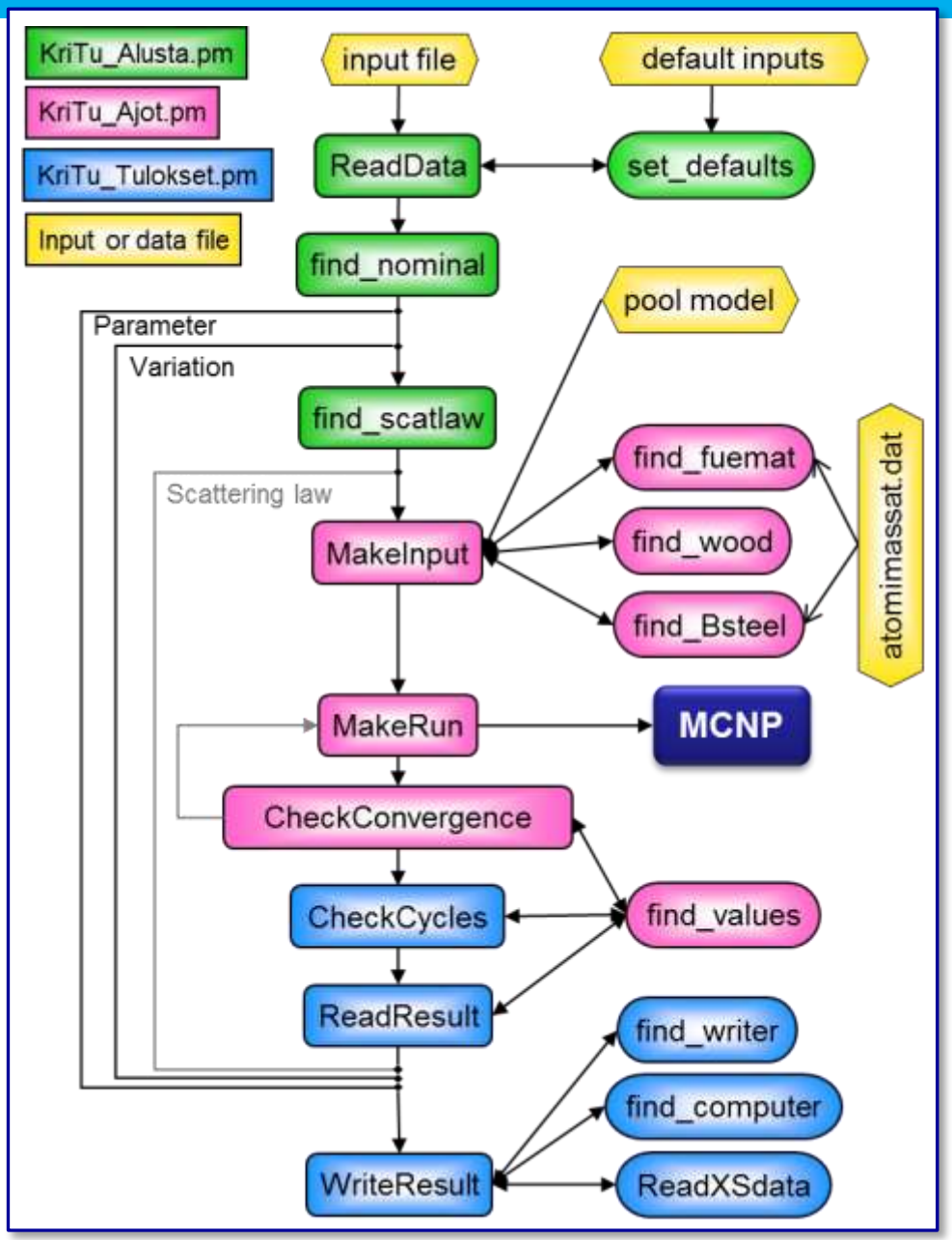
# Input of the package

- Defines pool to be calculated
  - Chosen from pool library
- Gives parameters to be varied and their values
  - First value always nominal case
  - Additional values variations
- Several parameters may be given to be varied
  - Variations done for a single parameter at a time
  - All other nominal values
- Default parameter file and cross section library

```
# VVER assembly with water density varied
# Pool to be calculated
POOL     asse2.in
DEFPAR   defaults.in
# XSDIR /home/projle/xsdata/sss_jeff311u.xsdir

# kcode data: number of neutrons, skipped
# cycles and total number of cycles
KCODE 50000 300 1000

# Fuel enrichment and U234 portion of U235
ENRI      4.4
F4OSUUS   0

# Assembly pitch, water layer outside shroud
# tube, moderator density
NPITCH  22.5
OUTEDGE 0.01
MODDENS  -0.9591 -0.0 -0.2 -0.4 -0.6 -0.8 -1.0
```

# Data Transfer and Analysis Program

- Built around MCNP
- Written in Perl
- Prepares MCNP inputs from pool models
- Performs the MCNP runs
- Makes a few crude tests
  - User needs to verify e.g. convergence
- Collects the data into a report
  - pdfLaTeX



# Pool Models

- Skeletal inputs for MCNP
- Contain all details for the pools
- Keywords for parameters to be varied
  - Replaced by actual value given in input
- Keywords cover
  - All geometry parameters
  - All material densities
  - Uranium enrichment => fuel
  - B concentration of boron steel
  - Water content of wood

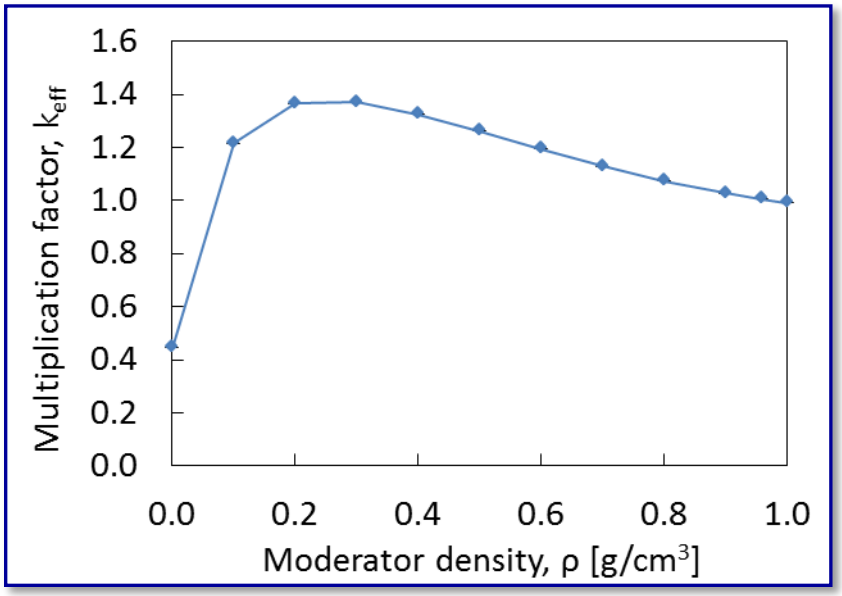
| Pool | Model | |
|---|---|---|
| Fuel assembly | asse2.in | Movable, reflecting boundary |
| Fuel pool | pool0.in | No positions plugged |
| | poolX3m.in | Modified X3 plugging of positions |
| | poolX4.in | X4 plugging of positions |
| Spent fuel storage rack | kpa.in | Boron steel plates |
| | kpa2.in | Boron steel casing |
| Fresh fuel transfer cask | fresh5x5.in | 5x5 containers, 2N for accident conditions |
| | fresh8x8.in | 8x8 containers, 5N for normal conditions |
| Transfer basket | bask.in | |
| Shipping cask | trans.in | |
| Transfer cask | cask.in | |
| Final disposal canister | kapseli.in | |

# Demonstration of the use of package

- Effect of moderator density on $k_{eff}$ of single assembly
- Design of spent fuel storage rack

# Moderator density effect

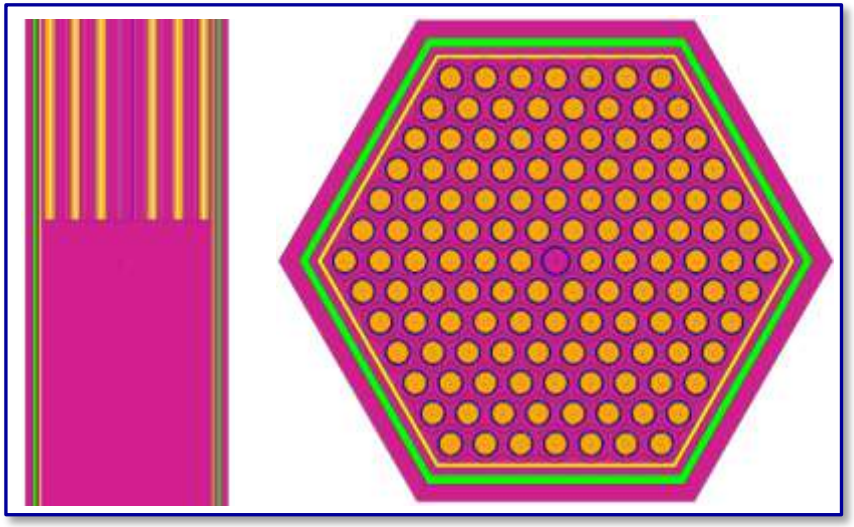
- Single VVER-440 assembly
  - Storage position, infinite lattice
  - Reflecting boundaries
  - 4.4 % enriched uranium
- Water density varied from 0 to 1
  - Nominal value 0.9591 g/cm$^3$
- These 11 runs took about 13 h of wall clock time on an 8 node Linux cluster
  - No manual interference needed




```
# VVER assembly with water density varied
POOL      asse2.in
DEFPAR    defaults.in

KCODE 50000 300 1000
MODDENS  -0.9591 -0.0 -0.1 -0.2 -0.3 -0.4
-0.5 -0.6 -0.7 -0.8 -0.9 -1.0
```

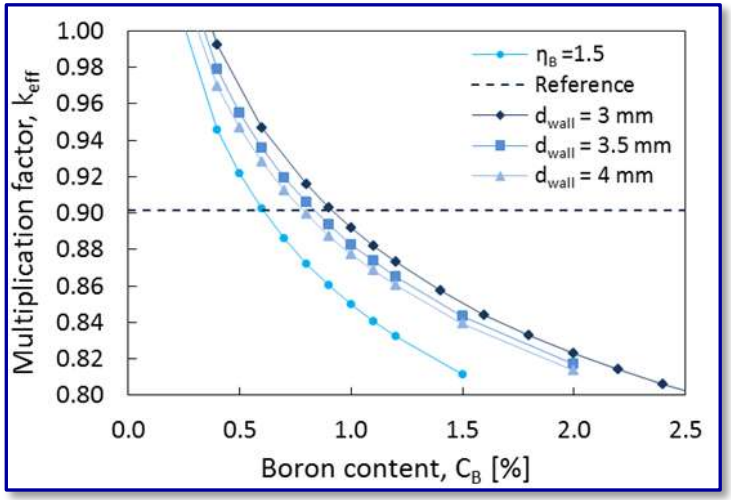
# Design of spent fuel storage rack

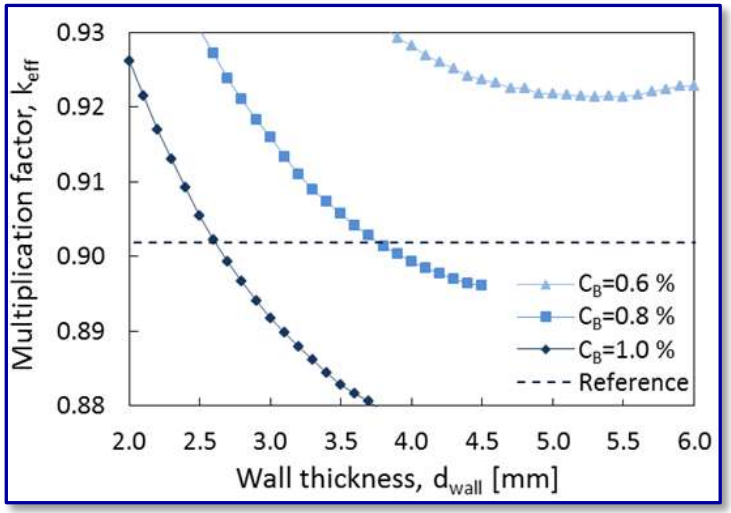
- Rack made of boron doped stainless steel
- Reflecting boundary conditions
  - 30 cm water below and above fuel



# Results for spent fuel rack

- Task was to
  1. Find boron content for fixed wall thickness
  2. Find wall thickness for given boron contents
- Reference value from older rack (recalculated with current model)




```
# Laskettava allas
POOL      kpa2.in
DEFPAR    defaults.in
KCODE 50000 300 1000
LWTR lwtr.12t
# Boron content, wall thickness [cm]
BCONS 0 0.2 0.4 0.6 0.8 0.9 1.0 1.1 1.2 1.4 1.6 1.8 2.0
STWALL 0.3
```

# Report by package

- Name of the analysed pool
- Name of user and date of calculations
- Computer and platform
- Directories for back tracing
  - Input
  - Run directory
  - Cross section directory
- Tables with data
  - Nominal values
  - Cross section data
  - Results

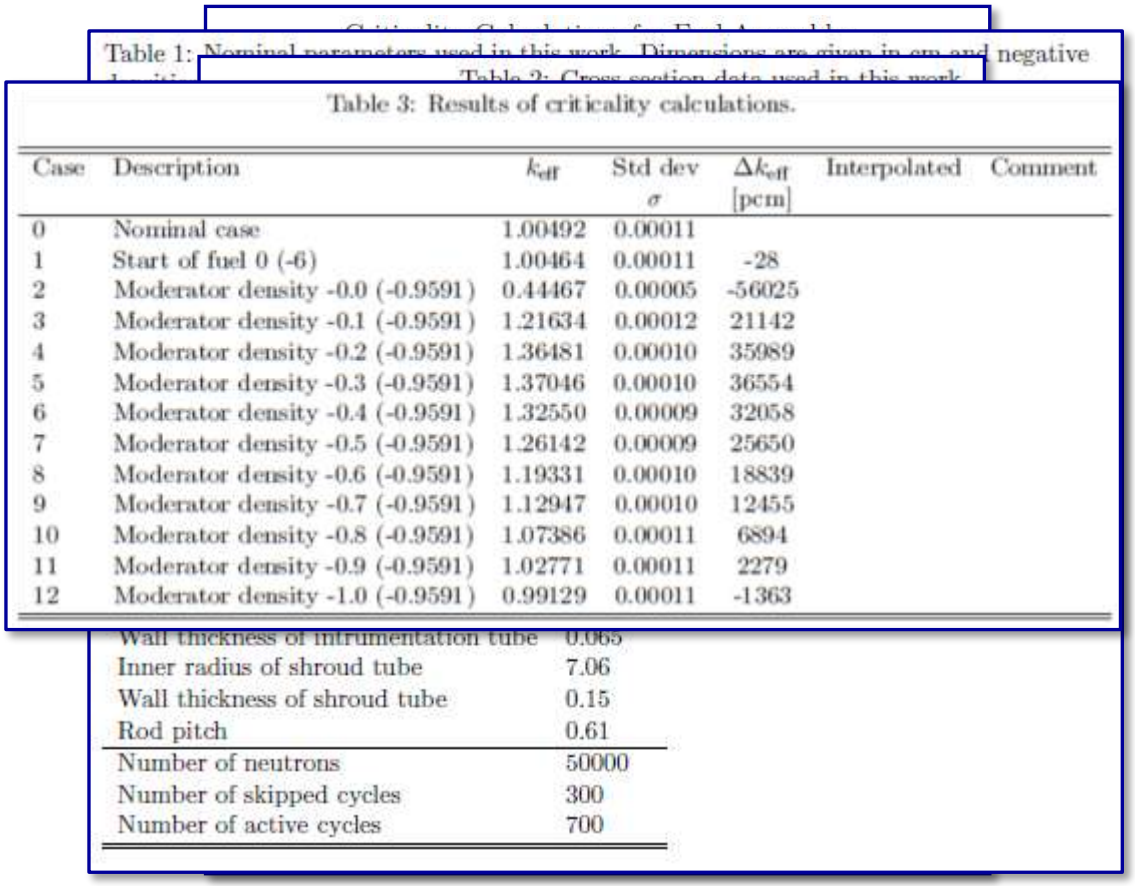


Table 1: Nominal parameters used in this work. Dimensions are given in cm and negative

Table 3: Results of criticality calculations.

| Case | Description | $k_{\text{eff}}$ | Std dev $\sigma$ | $\Delta k_{\text{eff}}$ [pcm] | Interpolated | Comment |
|---|---|---|---|---|---|---|
| 0 | Nominal case | 1.00492 | 0.00011 | | | |
| 1 | Start of fuel 0 (-6) | 1.00464 | 0.00011 | -28 | | |
| 2 | Moderator density -0.0 (-0.9591) | 0.44467 | 0.00005 | -56025 | | |
| 3 | Moderator density -0.1 (-0.9591) | 1.21634 | 0.00012 | 21142 | | |
| 4 | Moderator density -0.2 (-0.9591) | 1.36481 | 0.00010 | 35989 | | |
| 5 | Moderator density -0.3 (-0.9591) | 1.37046 | 0.00010 | 36554 | | |
| 6 | Moderator density -0.4 (-0.9591) | 1.32550 | 0.00009 | 32058 | | |
| 7 | Moderator density -0.5 (-0.9591) | 1.26142 | 0.00009 | 25650 | | |
| 8 | Moderator density -0.6 (-0.9591) | 1.19331 | 0.00010 | 18839 | | |
| 9 | Moderator density -0.7 (-0.9591) | 1.12947 | 0.00010 | 12455 | | |
| 10 | Moderator density -0.8 (-0.9591) | 1.07386 | 0.00011 | 6894 | | |
| 11 | Moderator density -0.9 (-0.9591) | 1.02771 | 0.00011 | 2279 | | |
| 12 | Moderator density -1.0 (-0.9591) | 0.99129 | 0.00011 | -1363 | | |

| | |
|---|---|
| Wall thickness of intrumentation tube | 0.065 |
| Inner radius of shroud tube | 7.06 |
| Wall thickness of shroud tube | 0.15 |
| Rod pitch | 0.61 |
| Number of neutrons | 50000 |
| Number of skipped cycles | 300 |
| Number of active cycles | 700 |

# Summary and development

- A calculation package facilitating sensitivity studies and reducing manual work has been set up
  - Built around MCNP
  - Consists of code preparing inputs for and running MCNP, and set of pool models
- Already proven useful in design work
- Further development
  - Plots of source entropy in report helps checking of convergence
  - Plots of results in the report
  - Variation of other material compositions
  - Linking to a burnup code

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