Scaling Factor Formation of FiR1 decommissioning waste

Finnish nuclear symposium, 1-2.2022

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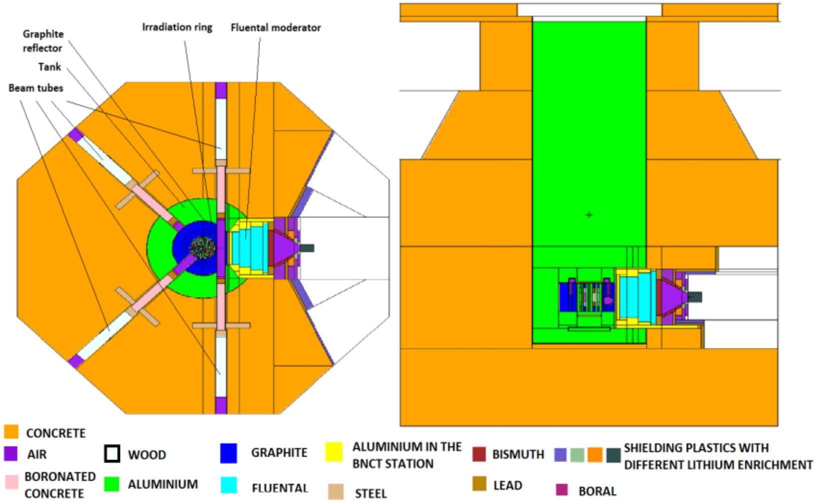
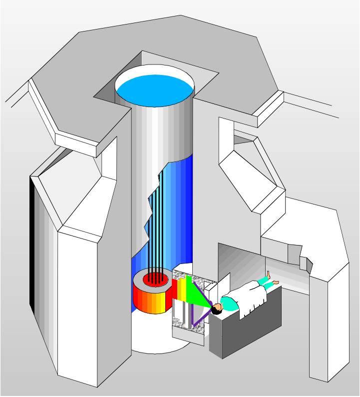
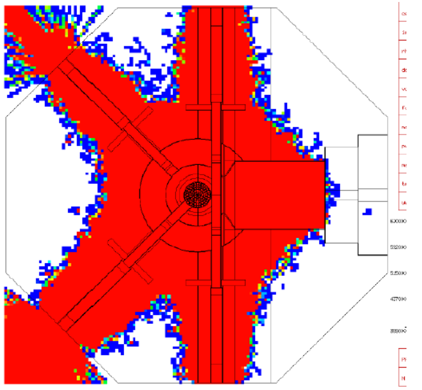
FiR1 TRIGA research reactor

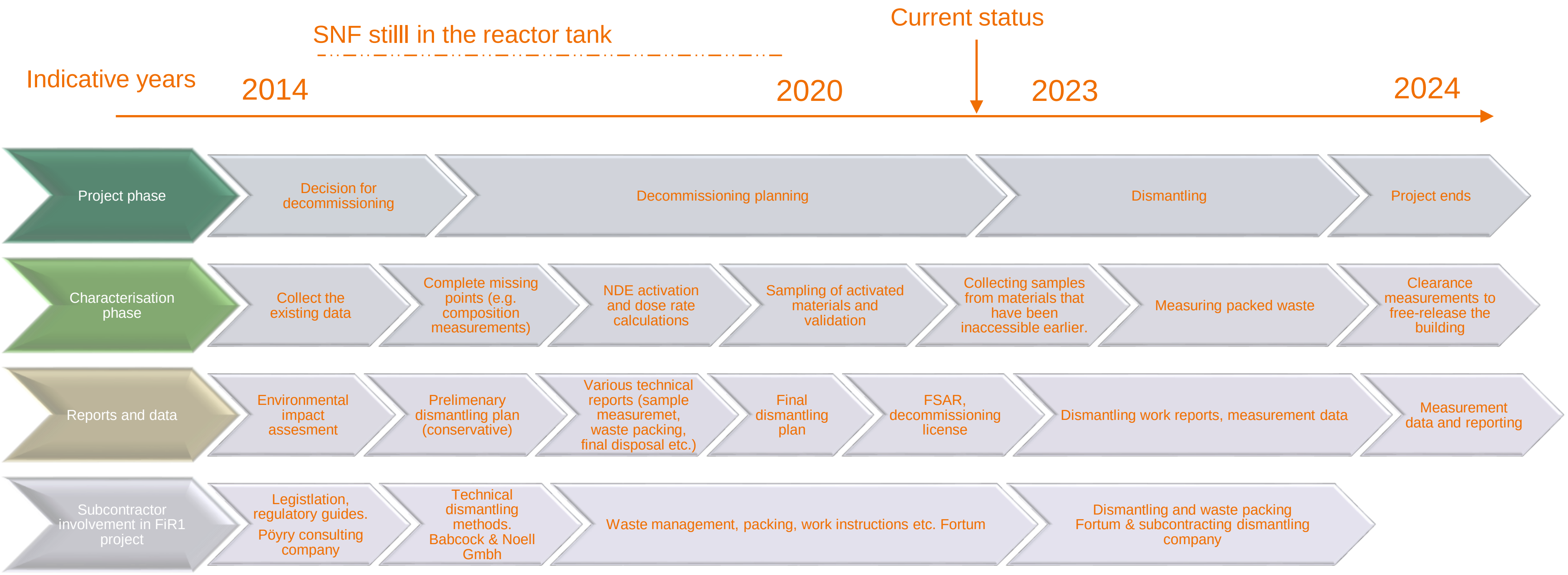
- 250 kW TRIGA Mark II type research reactor
- Operational for years 1962-2015.
  - SNF was removed in 2020
- Training, Research and Isotope production reactor, General Atomics.
- LILW waste inventory less than 5 TBq or around 100 m^3.
- Characterization approach
  - Scaling matrix method using pre-defined nuclide vector
  - ISO 21238-2007 standard
  - Loviisa waste acceptance criteria
  - Characterisation is a combination of calculations and measurements







Characterization roadmap



Basic idea

- Neutron activation is a linear process and radionuclides from a same source and behavior (speciation, charge, solubility, volatility, etc) maintain a constant relationship in their final activity concentrations

$$A_i \sim N t \sigma_i \phi$$

For same materials the concentration of activating impurities is contant

Operating hours is a contant

Reaction cross sections are physical contants

The fractions of final activitity concentration remains constant regardless of the flux

- Chemical and physical properties nedd to be similar enough
  - Special consideration on volatile nuclides
  - Nuclides with non-homogeneous distribution?
  - Samples must represent the studied material and plant areas well enough
- Special cases can occur
  - Li-enriched shielding plastics: not contain any homogeneously distribution gamma emitters → characterization by sampling and measurements.

Definitions: scaling factor

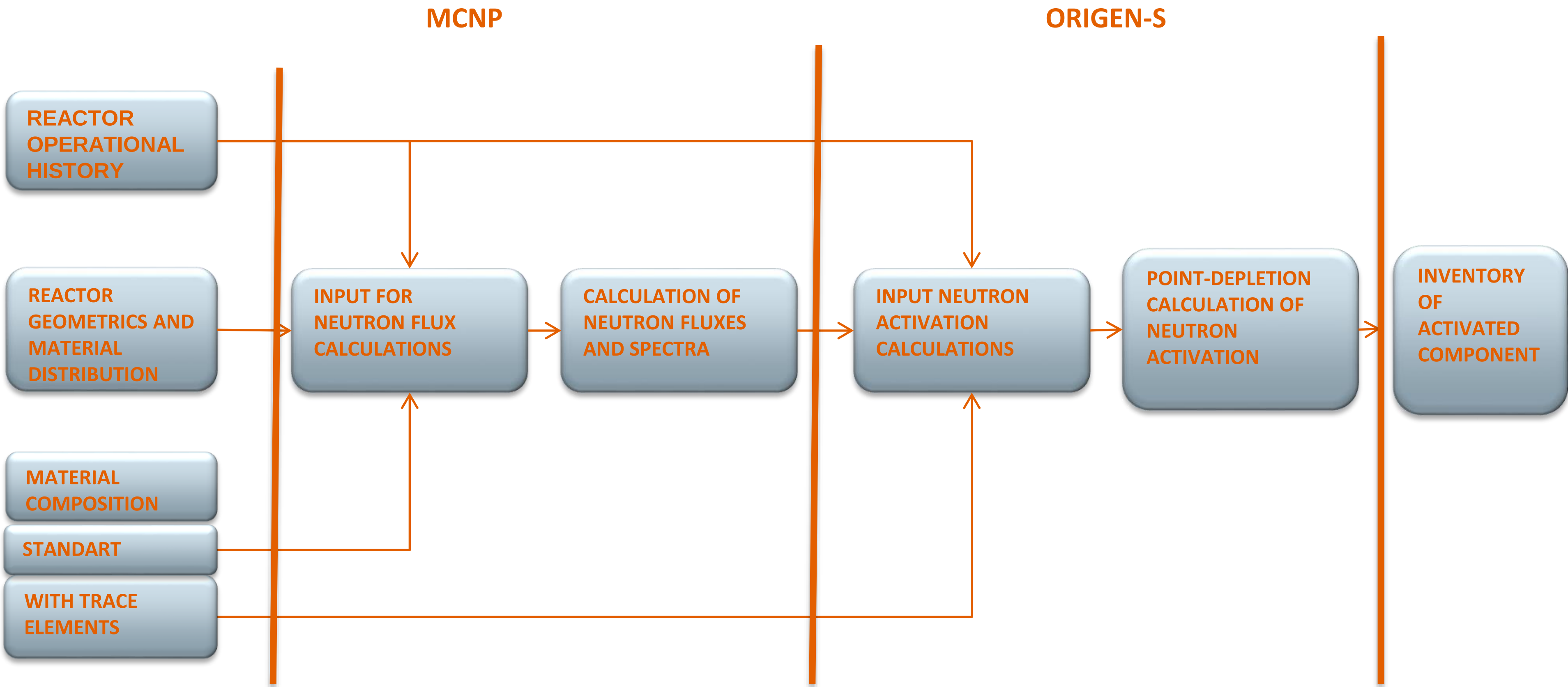
- Nuclide vector determines the fraction of different nuclides forming the total activity in the item.
- A scaling factor, *SF*, is a ratio between the activity concentrations of two radionuclides in the item.
- Activity concentration of the “denominator radionuclide” is called the key nuclide
- “numerator radionuclide” is the activity concentration of a difficult-to-measure radionuclide (DTM)
- After obtaining the SFs, activity concentrations of DTM’s can be determined by multiplying the concentration of the key radionuclide with the SF.

Activity of a DTM nuclide (e.g. Ni-63)

$$SF_{ij} = \frac{A_i}{A_j}$$

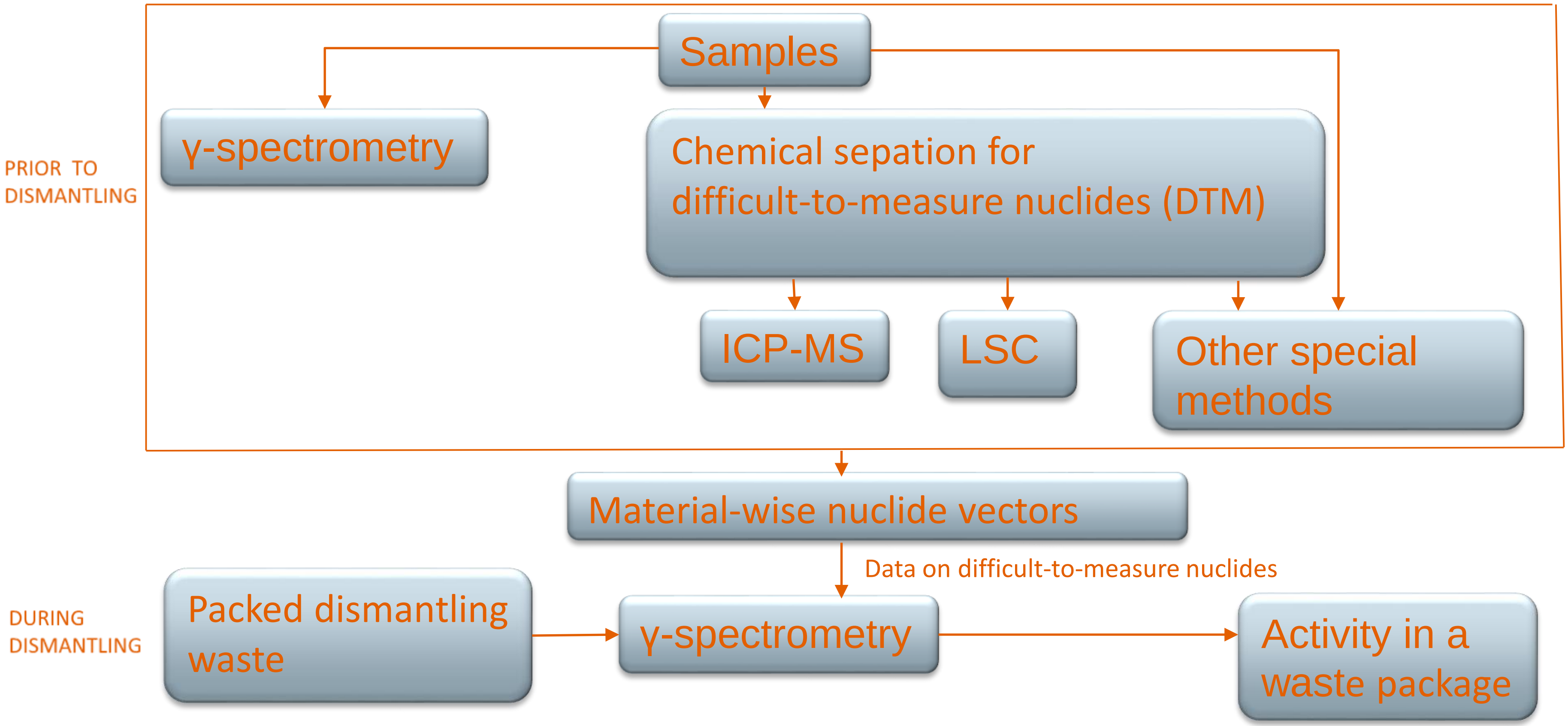
Activity of a key nuclide (e.g. Co-60)

NDE calculation is a two-step process



Repeat the process for individual components or reactor structural parts.

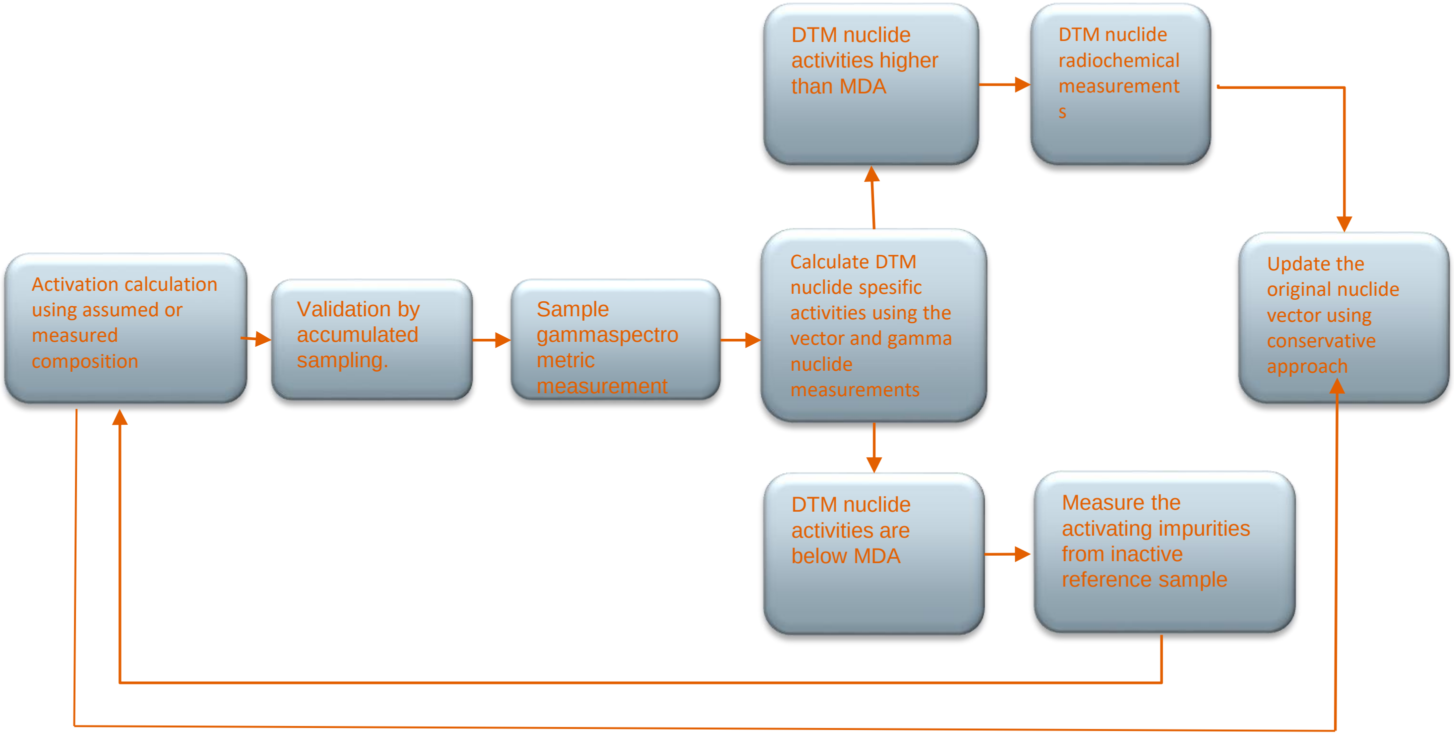
Measurements: Scaling matrix approach



Challenges regarding the methodology

- Complicated operating history, several structural modifications
  - Activation calculation had to be separated into several time periods.
- SNF still in the reactor tank until 2020
  - Some material could not be sampled, high underwater dose rates
  - Samples from outer parts of the reactor typically have very low activity
- Variety of materials and 1960's level of quality documentation
  - Simplify e.g. by handling all steel types with a conservative steel nuclide vector
  - Not only much information is missing, but also some of the original data is simply falce, e.g. composition impurities, but also dimensions.
- Some materials don't have a suitable key nuclide
- Non-nuclear requirements, e.g. chemical toxicity.
- How to separate contamination and activation?

Forming nuclide vectors



Different methods for different materials

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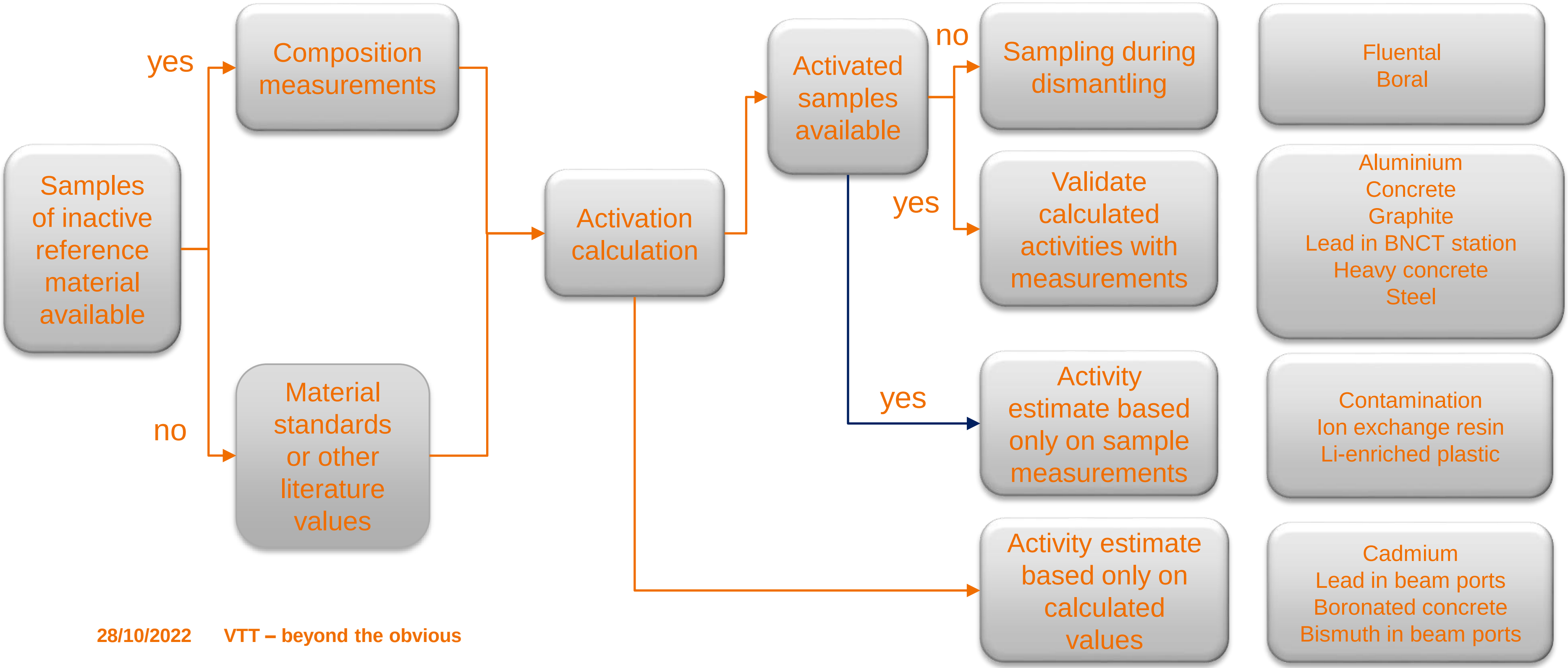

Example: Concrete in FiR1 biological shield

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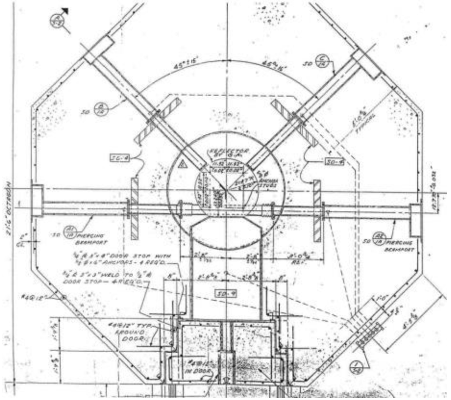
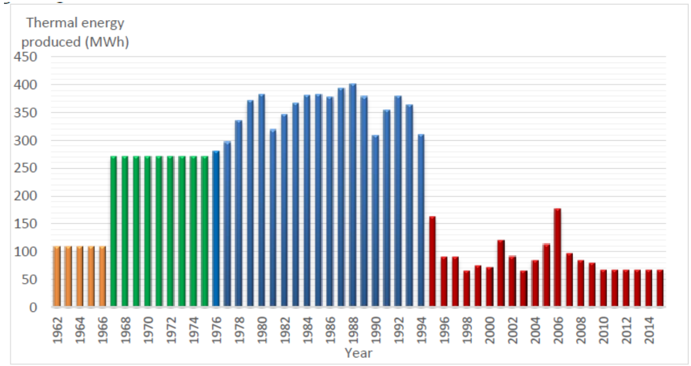
1. Step 1: Collect the existing data
2. Complete missing points (e.g. composition measurements)
3. Activation and dose rate calculations
4. Sampling plan and validate the results
5. Dismantling plan (ALARA and optimizing the amount of active waste), waste packages and waste management
6. Dismantle the reactor. Measure the waste packages and classify them.
7. Collect samples from waste packages for possible need for further validation
8. Possible pre-treatment and intermediate storage or final disposal
9. Clearance measurement to free-release the building

Step 1: Collecting the existing data

- Construction drawings, dimensions, operating history (operating hours).
- If there significant changes in the reactor structures (power increase or such), the operating history need to be divided into different periods.
- Material composition may lack data on activating impurities
  - Effect on mechanical properties may be small.



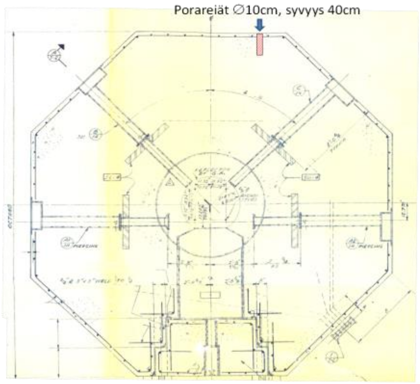


Step 2: Complete the missing data

- Composition measurements from inactive parts.
- Prelimenary identification of the materials and structures to be dismantled
- Verifying the accuracy of original construction drawings
- Measuring dose rates and gamma spectra

If some data is missing, use conservative assumptions:

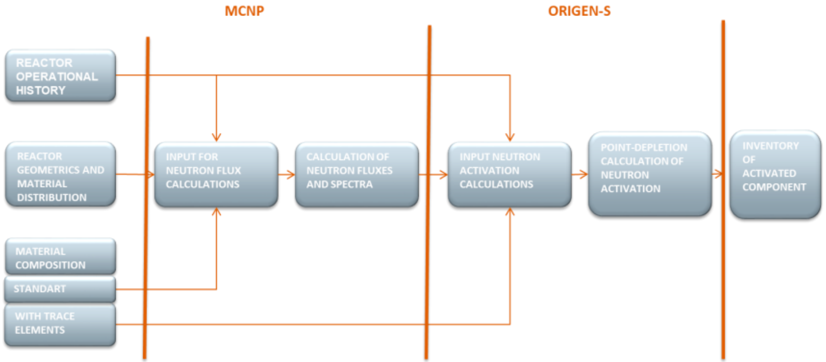
- Underestimate neutron shielding structures and material shielding properties
- Overestimate activating impurities
- Overestimate operating hours or underestimate cooling time.

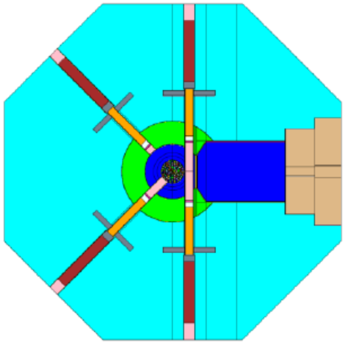


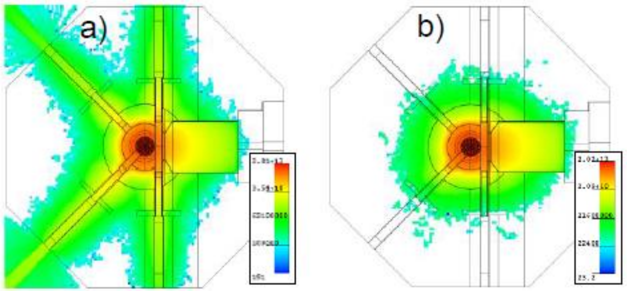
	näyte A ppm	näyte K ppm	näyte Y ppm
Al	70300	67900	68050
B	< 100	< 100	< 100
Ba	860	840	840
C	1730	1835	2165
Ca	91000	79000	95000
Cl	55	56	59
Co	12	13	13
Cs	1,9	1,7	1,7
Eu	2,1	2,0	2,2
Fe	23000	21000	23000
H	4290	4150	4430
K	35300	36450	33650
Li	36	27	39
Mg	9000	7700	8500
Mn	350	310	370
N	< 200	< 200	< 200
Na	19000	20000	19000
Ni	< 50	< 50	< 50
P	< 500	< 500	< 500
S	3200	2400	2900
Si	258000	258500	258500
Sm	8,3	8,0	13
Ti	1380	1210	1370
U	3,0	3,4	4,0

Step 3: Activation and dose rate calculatios

- Two step process: neutron transport calculations and activation calculations.
- In case of power increase (or other modifications), build separate models for each operating period.
- Utilize the results for prelimenary dismantling and waste management plans

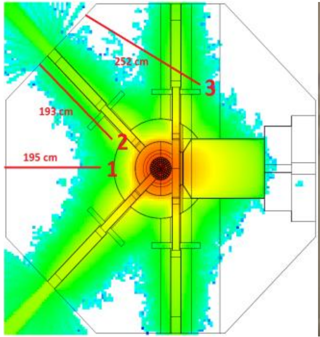


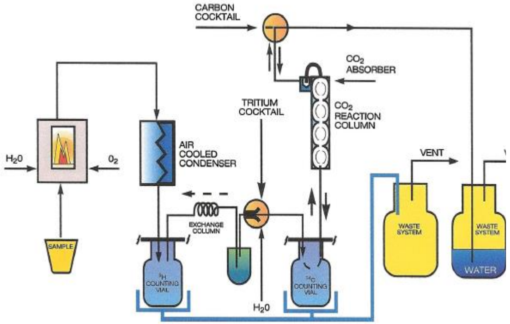


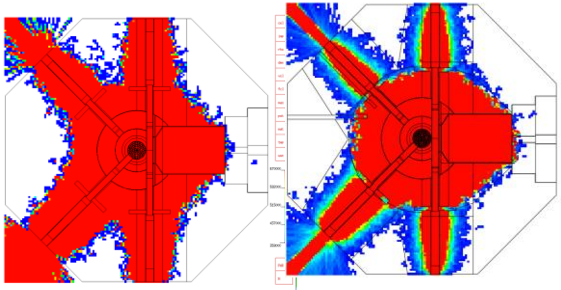


Step 4: Sampling and validation

- Collect samples of the activated parts
- Measure the nuclide-wise activities and form the SFs
  - Validate and/or update the calculated data.
- Refine the data for dismantling and waste managements plans
  - If conservative assumption had been used, the amount of activated waste may be smaller.
  - Some part of volatile nuclides may have diffused, but use conservative assumptions.





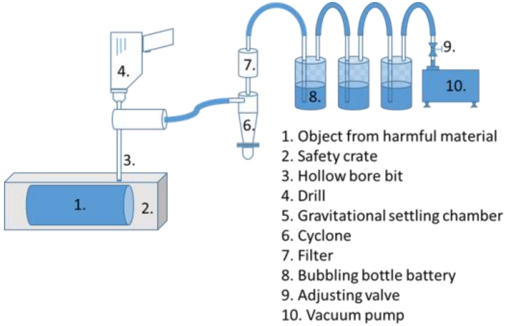


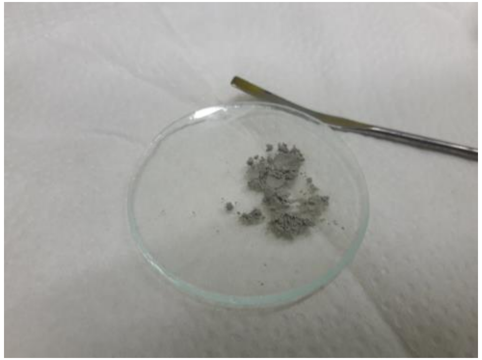
Step 4: Sampling and validation – closer look at the experimental work

- General concept
  - Elemental and DTM analyses with destructive methods
  - ETM analysis with non destructive methods
- DTM analyses
  - Destruction of the matrix
  - Separation of the radionuclide of interest
  - Measurement
- Validation of the DTM analysis
  - No commercial reference materials
  - Intercomparison exercises organised
    - Activated steel
    - Activated concrete
    - Spent ion exchange resin

Step 4: Sampling and validation – closer look at the experimental work

- First sampling campaign for determination of chemical composition for activation calculations
- Second sampling campaign for ETM and DTM analyses
  - Coring of activated concrete cores
  - Subsampling of cores to produce fine power subsamples
  - Determination of volatile H-3 and C-14 during sampling
    - Same method utilised also for subsampling of activated graphite



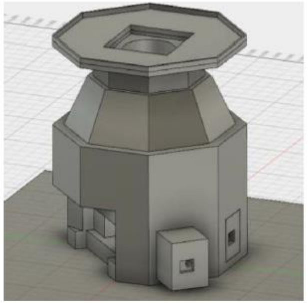


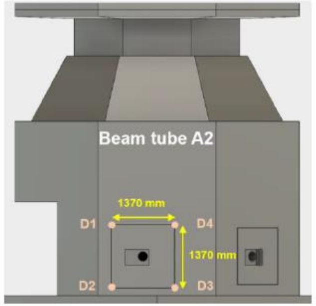
Step 4: Sampling and validation – closer look at the experimental work

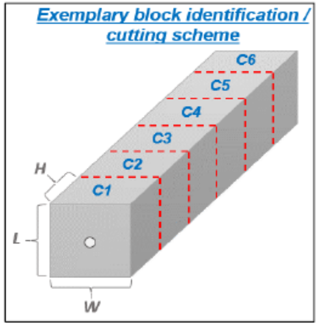
- Radiochemical method development
  - FiR1 decommissioning project
  - KYT-DEMONI project with Helsinki University
  - Various MSc studies
- Method validation via an intercomparison exercise
  - Participants from several Nordic laboratories, partially NKS funding
  - Difficulties with solubility
  - Difficulties with low activity

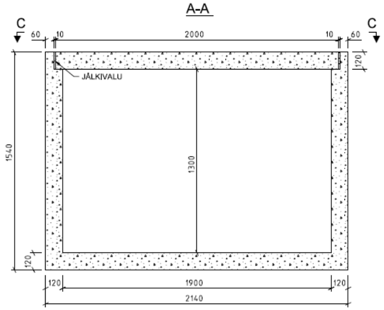
Step 5: Dismantling and waste management plan

- Choose the dismantling method
  - Include mechanical requirements (e.g. drilling vs. wire saw)
  - Logistics (both inside the reactor hall and highway transportation)
  - Dose estimate to personnel and contamination control
- Plan the packages
  - Logistics (both inside the reactor hall and highway transportation)
  - Compatibility at the waste final disposal site









Lessons learned

- Scaling factor approach enables fluent dismantling by performing most of the characterization work beforehand.
- Reseach reactor contain special characteristics, which require assumptions and simplification in basic methodology.
- Having real samples is crusial for characterisation
  - Real compositions and operating history are crusial for the calculations.
  - Radiochemical method development cannot be performed with only pure reference materials.
  - Samples or redundant construction material should be available in early phase of a decom project.
- The decommissioning project and related KYT and NKS projects have contributed to method development, sampling, activity validation and education of experts.
  - Fit-for-purpose sampling techiniques (e.g cross contamination, volatility, form)
  - Material specific radiochemistry methods, method validation via intercomparison exercise
  - 1 PhD thesis, 5 MSc theses, ~10 peer-reviewed journal articles on characterisation topics.

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