# Spent Nuclear Fuel Management in Switzerland: Perspective for Final Disposal

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*INTERNATIONAL CONFERENCE ON MANAGEMENT OF SPENT FUEL FROM NUCLEAR POWER REACTORS: AN INTEGRATED APPROACH TO THE BACK END OF THE FUEL CYCLE.*
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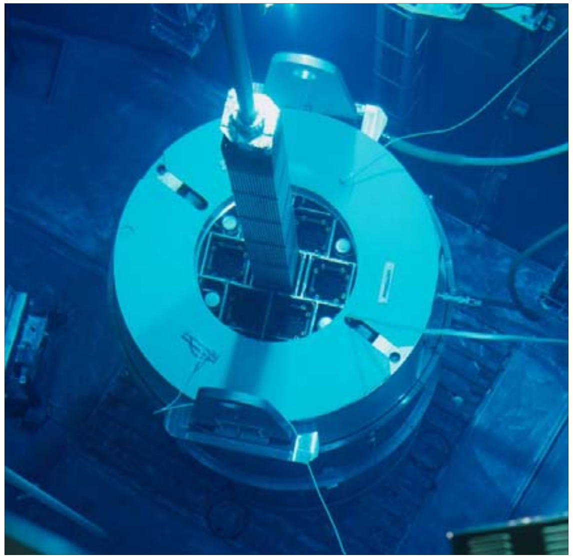
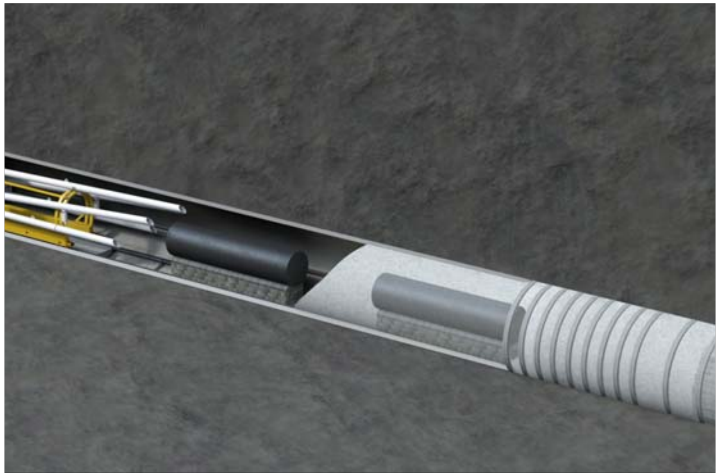
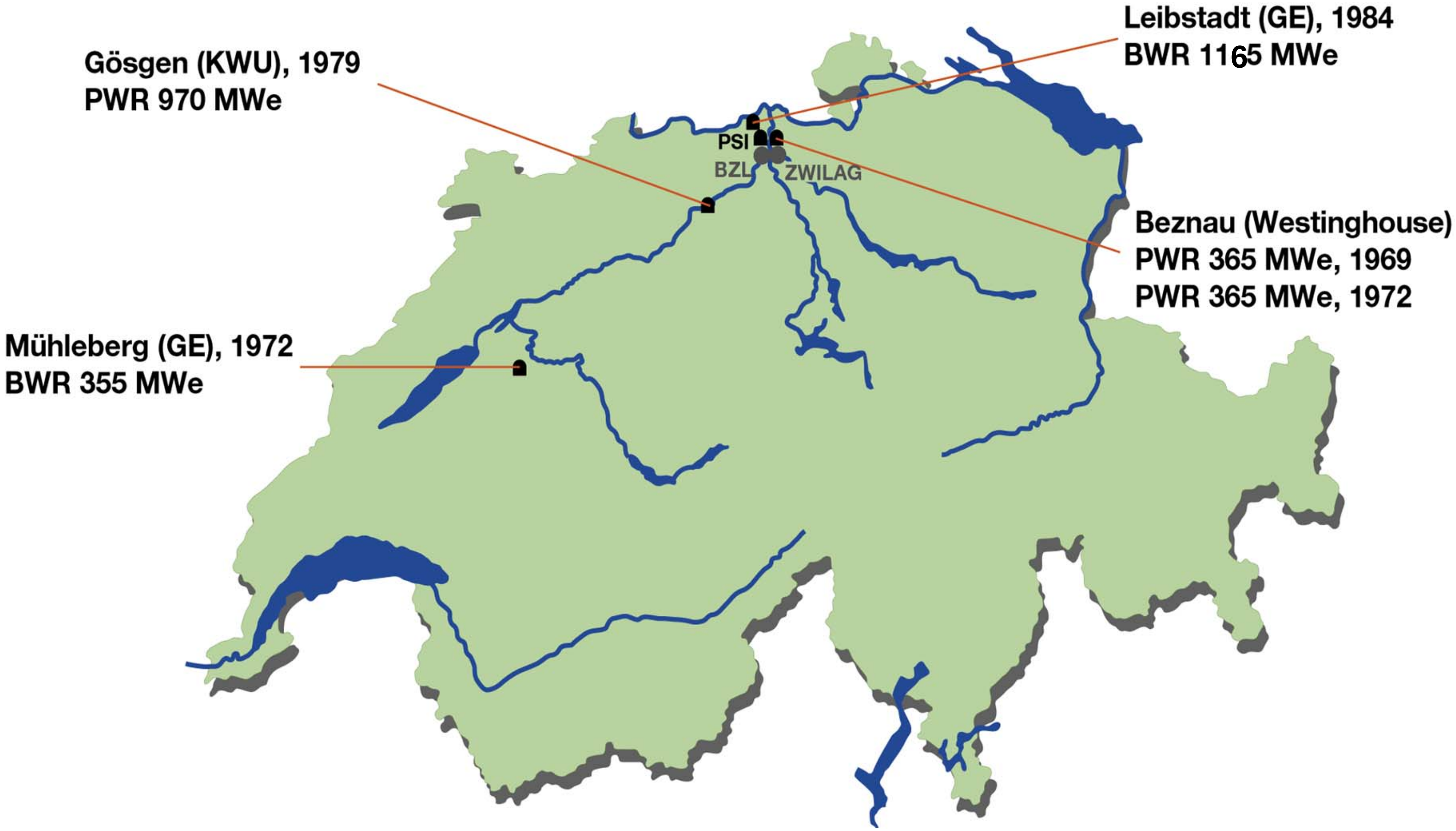
# Structure of the presentation

- Introduction
- Spent fuel characteristics and model inventory
- Spent Nuclear Fuel canisters for geological disposal
- Handling of spent fuel in the surface facility
- RD&D activities
- Conclusions & future steps





# Introduction: Swiss nuclear power plants




- 5 NPPs – installed output: 3,200 MW
- Percentage of total power production: ca. 40 %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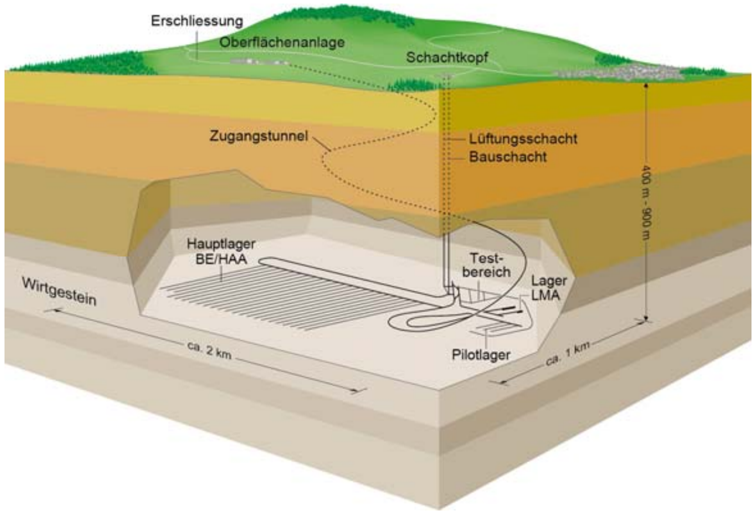
# Introduction: SNF and NAGRA

- **SNF:** ca. 12'000 spent fuel assemblies are expected to be discharged from the operation of the Swiss reactors
- More than 1'000 FAs are currently in interim dry storage sites: ZWILAG, ZWIBEZ
- 771 $t_{HM}$ have been sent for reprocessing in France and the UK. **634 HLW** vitrified residue canisters will be returned
- Both SNF and HLW are foreseen for deep geological disposal

- **NAGRA**, the Swiss National Cooperative for the Disposal of Radioactive Waste, plans to submit the required general licence application for a high-level waste site by **2022**
- Mission of NAGRA: to construct safe geological repositories for all types of radioactive waste (L/ILW and HLW) arising in Switzerland
- The SNF/HLW repository is expected to become operational by **2060** with emplacement until 2075

# Introduction: SNF and NAGRA

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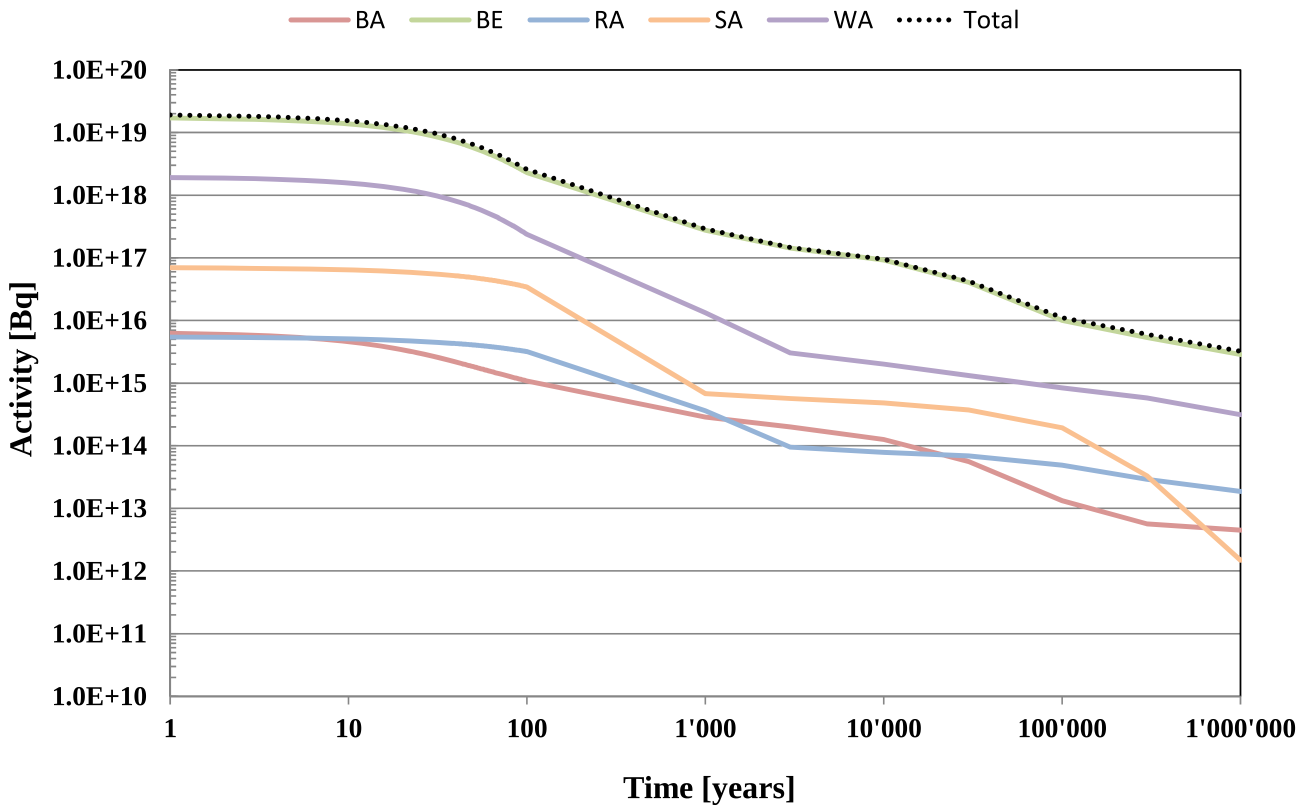
# Spent fuel characteristics

| NPP | NPP type | Fuel type | FAs EOL |
|---|---|---|---|
| Beznau I | PWR | $UO_2$ | > 1500 |
| Beznau II | PWR | MOX | ca. 230 |
| Gösgen | PWR | $UO_2$ | > 1500 |
| Gösgen | PWR | MOX | ca. 150 |
| Leibstadt | BWR | $UO_2$ | > 7000 |
| Mühleberg | BWR | $UO_2$ | > 1000 |
| Tot $UO_2$ | | $UO_2$ | > 10000 |
| Tot MOX | | MOX | ca. 380 |
| Tot PWR | | - | 30% |
| Tot BWR | | - | 70% |
| Total | | | ca. 12000 |

- For each of the Swiss reactors, different designs of fuel assemblies have been used and, among these, the fuel enrichment and burnup also vary. Furthermore, many of these spent fuel assemblies exhibit **high burnup**
- The radionuclide inventory of the FAs, the source term and the decay heat are assessed by dedicated depletion calculations (Triton/Origen from the SCALE package)

# Spent fuel radioactivity evolution



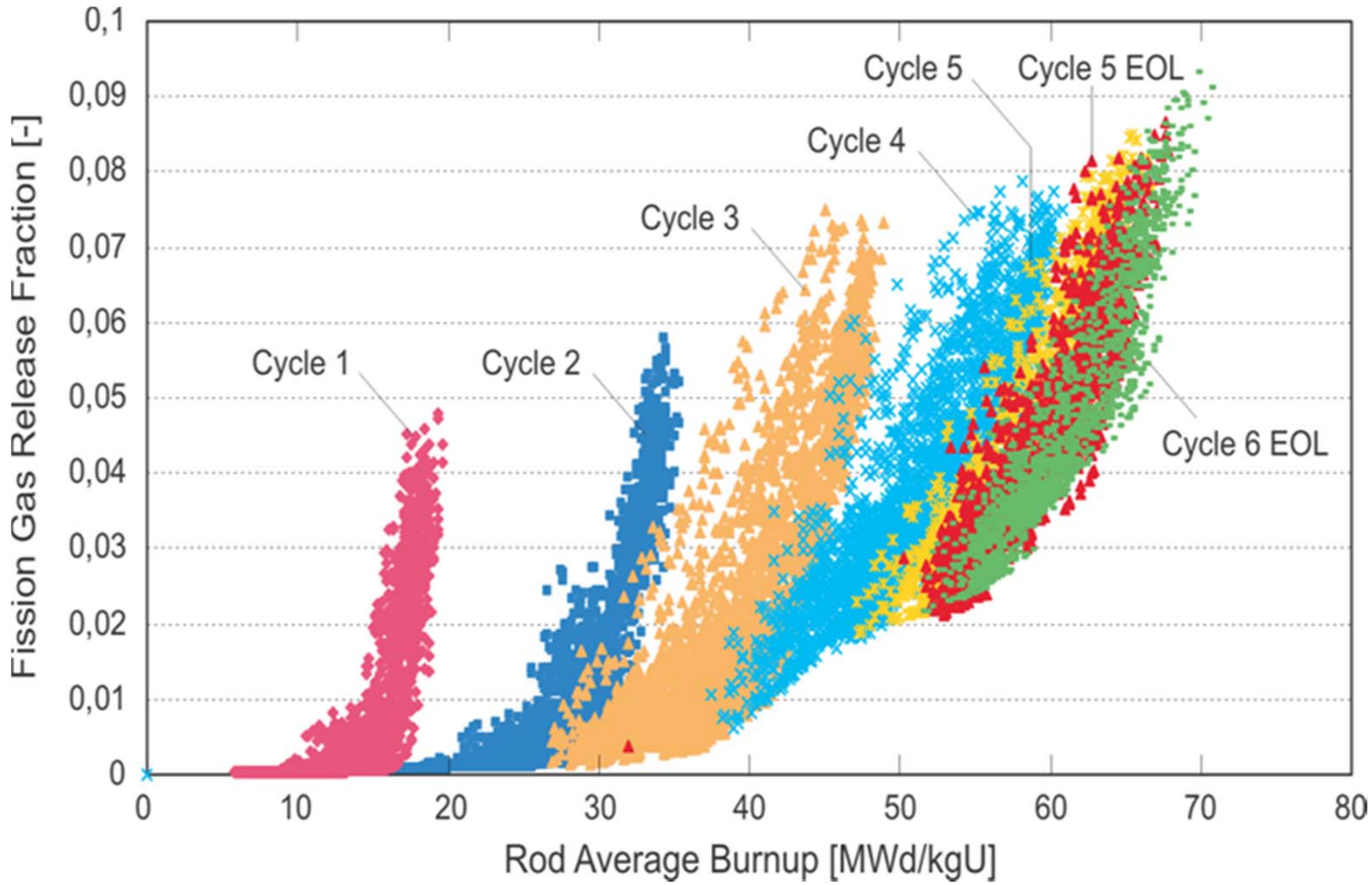

- Determined using the **M**odel **I**nventory for **Ra**dioactive **M**aterials (MIRAM 14).
- Waste-type categories: **BA** (operational waste from NPPs & other facilities), **BE** (SNF assemblies), **RA** (reactor waste), **SA** (decommissioning waste from the NPPs, ZWILAG, research facilities) and **WA** (waste from reprocessing of SNF)

# Fission Gas Release

- Quantification of fission gas release (FGR) from fuel rods is relevant for short-term as well as long-term safety analyses:
  - relevance for the safe handling and encapsulation of FAs in the final disposal canisters
  - FGR correlates with IRF, which represents the fraction of the inventory of safety-relevant radionuclides that may be rapidly released from the fuel at the time of canister breaching and contact with water
- Campaigns to calculate the fission gas release for all FAs of Swiss reactors have been carried out: NAGRA in collaboration with PSI , SKB, Studsvik and the Swiss NPPs
- It is of interest to determine the distribution and average FGR at reactor discharge end-of-life (EOL)

# Fission Gas Release

- FGR fractions as a function of burnup and irradiation cycle calculated for KKL





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- It is of interest to determine the distribution and average FGR at reactor discharge end-of-life (EOL)
- Average values for the 5 NPPs, which are used for the release model of NAGRA, are set as follow: **4.5%** for KKL and KKM, **2%/3%** for $UO_2$/MOX KKB, **14%/16%** for $UO_2$/MOX KKG
- In the case of KKG fuel, which is characterised by high power density and high burnup, the FGR reaches a maximum value of **24%** for $UO_2$ and **~30%** for MOX

# 3. SNF canister for geological disposal

- NAGRA considers three different concepts depending on the fuel loading:
  - **BE-S-1: $UO_2$-FA from BWR , with maximum 9 $UO_2$-BWR-FA per canister**
  - BE-D-2: MOX- and $UO_2$-FA mixed loading from PWR, with 1 MOX-PWR-FA and maximum 3 $UO_2$-PWR-FA per canister
  - BE-D-3: $UO_2$-FA from PWR, with maximum 4 $UO_2$-FA per canister

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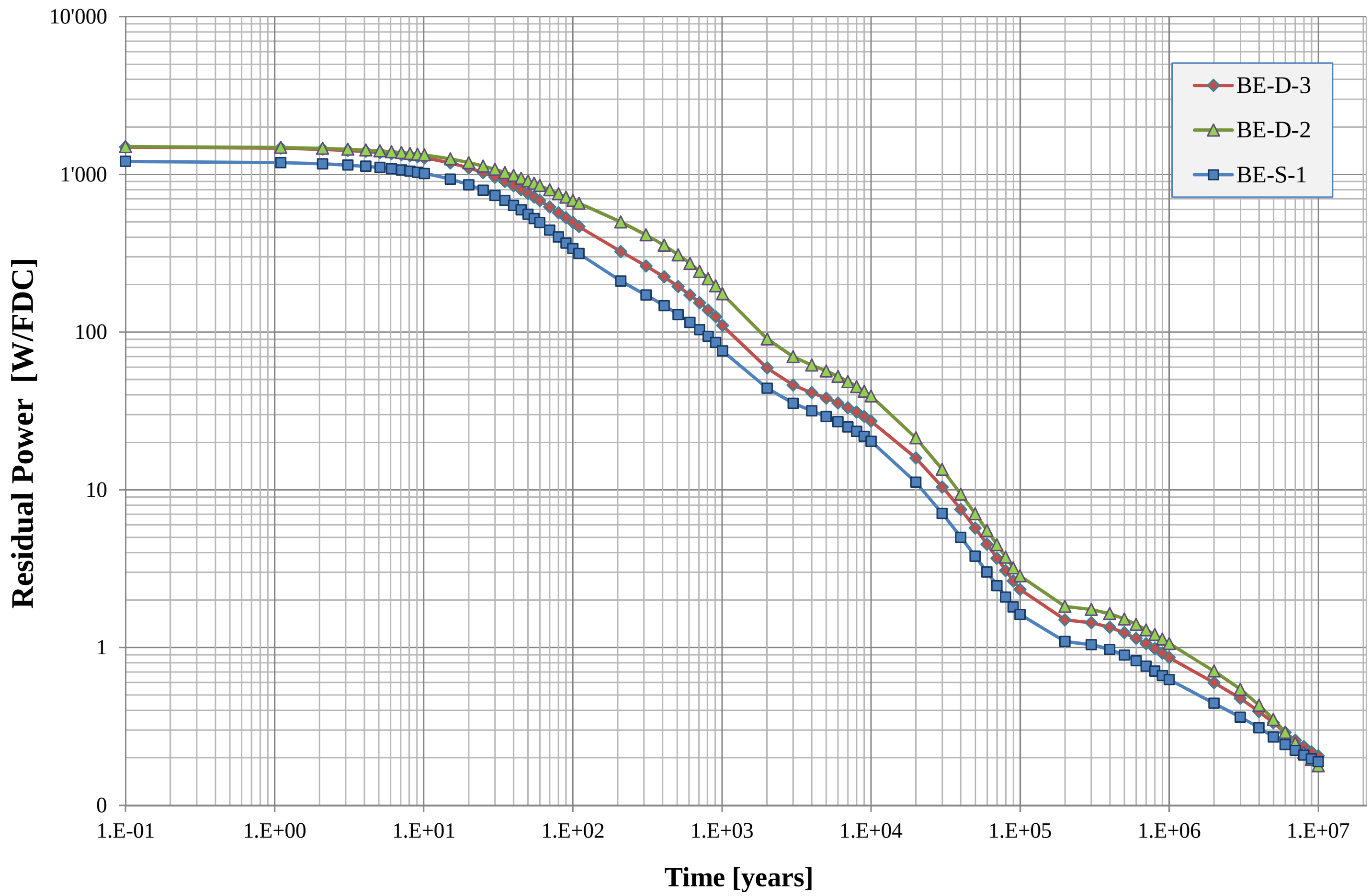
  - **BE-D-3: $UO_2$-FA from PWR, with maximum 4 $UO_2$-FA per canister**

# Residual decay heat evolution in disposal canisters

- Three types of canister. Starting point is 2060, beginning of emplacement.
- Heat limit of 1.5 kW/canister must be complied with. Some of the disposal canisters may not be completely filled.

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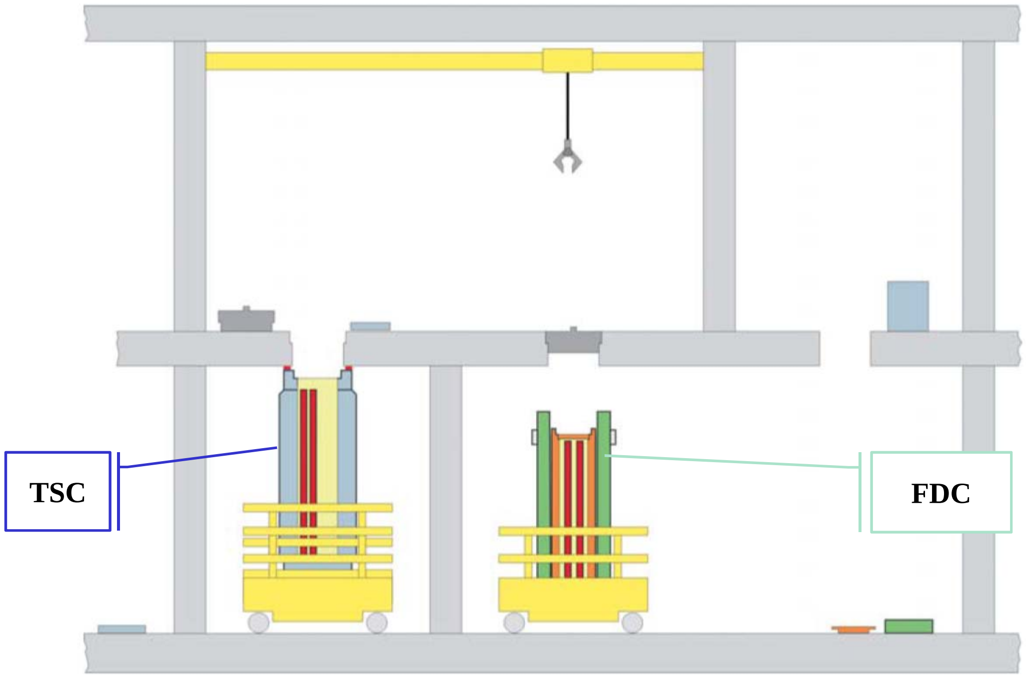
# SNF handling in the surface facility

- The SNF unloading/loading operations will be carried out in hot-cells at the surface encapsulation facility.
- Four docking stations dedicated to transport casks and four dedicated to disposal canisters are planned to operate simultaneously.



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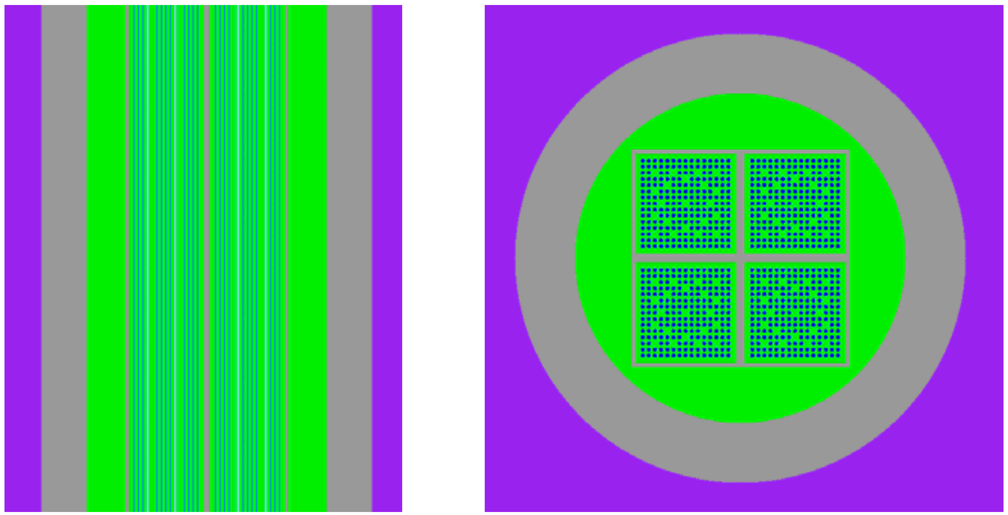
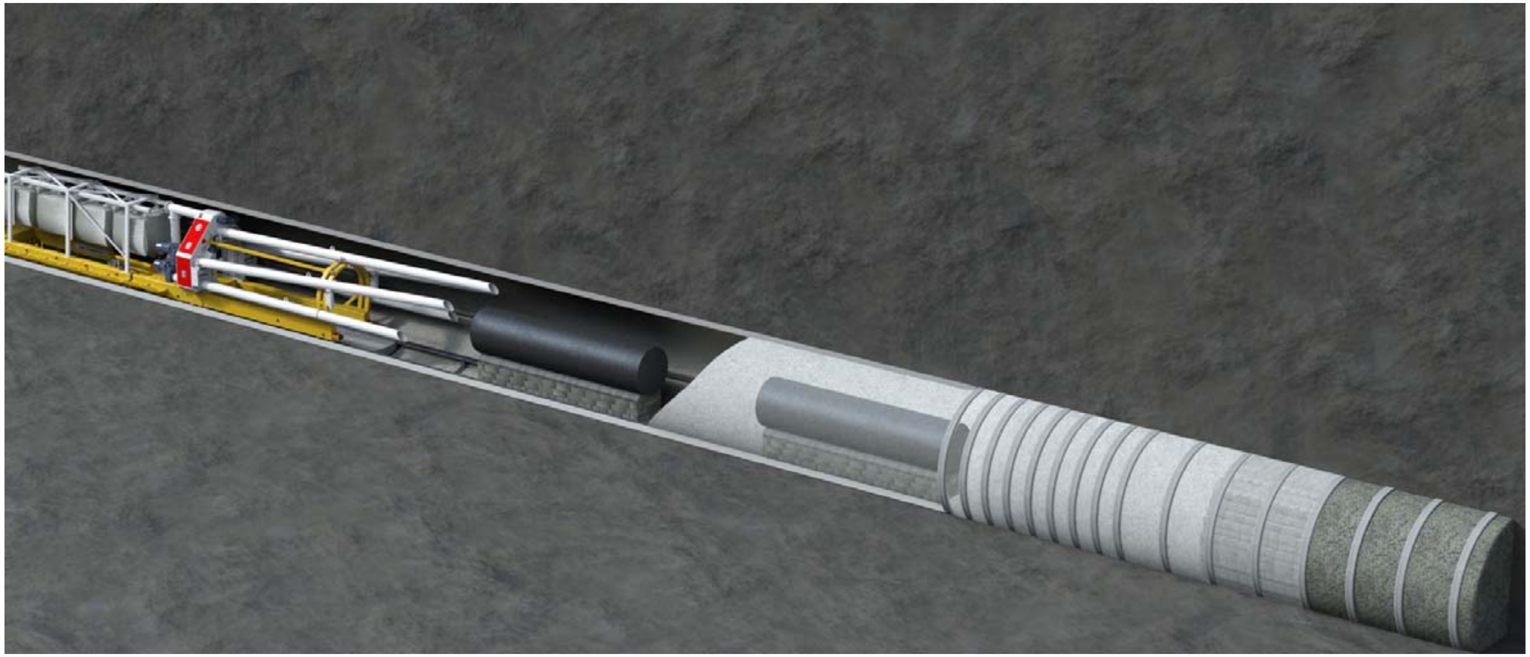
# Criticality safety studies

- Criticality studies needed for the general licence application
- Sub-criticality would be maintained in disposal canisters for all reasonably conceivable evolutions and for the full range of burnups and enrichments expected for the cases of PWR and BWR $UO_2$ and MOX fuels
- A basis for burnup credit must be developed, as sub-criticality cannot be argued without it
- Research Program Agreement between Paul Scherrer Institut (PSI) and Nagra: «Development of burnup credit methodology for applications to long-term geological disposal of spent nuclear fuel» (BUCCS-R)



# RD&D activities

- Full-Scale Emplacement (FE) Experiment at the Mont Terri Rock Laboratory
- Full-scale multiple heater test in a clay-rich formation ('Opalinus Clay'), which simulates the construction, waste emplacement, backfilling and early post-closure evolution of a spent fuel repository tunnel
- Investigate: induced thermo-hydro-mechanical coupled effects on the host rock, bentonite as buffer material, engineering aspects, etc



# Conclusions

- Focus on some of the relevant nuclear aspects of the Swiss programme on SNF management:
  - Both wet and dry interim storage sites are used in Switzerland
  - Deep geological disposal of SNF and high-level waste (HLW) is required by law
  - A general licence application by NAGRA to construct a geological repository to dispose of all SNF and HLW is expected to be submitted by 2022
  - Studies on SNF characterisation are ongoing, focusing on both short-term and long-term safety aspects
  - Investigations on the optimum final disposal canister design are ongoing
  - Ongoing RD&D activities for long-term and operational safety (see BU credit, FE, etc.).

Based on the studies currently being carried out and on the future developments foreseen for the coming years, a consistent approach to the definitive disposal of SNF will be developed, with the aim of addressing the questions and uncertainties related to this complex topic.

**Thank you for your attention**

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