Universidade Federal de Minas Gerais

Thermal Analysis of Spent Nuclear Fuels Repositories

(Preliminary studies)

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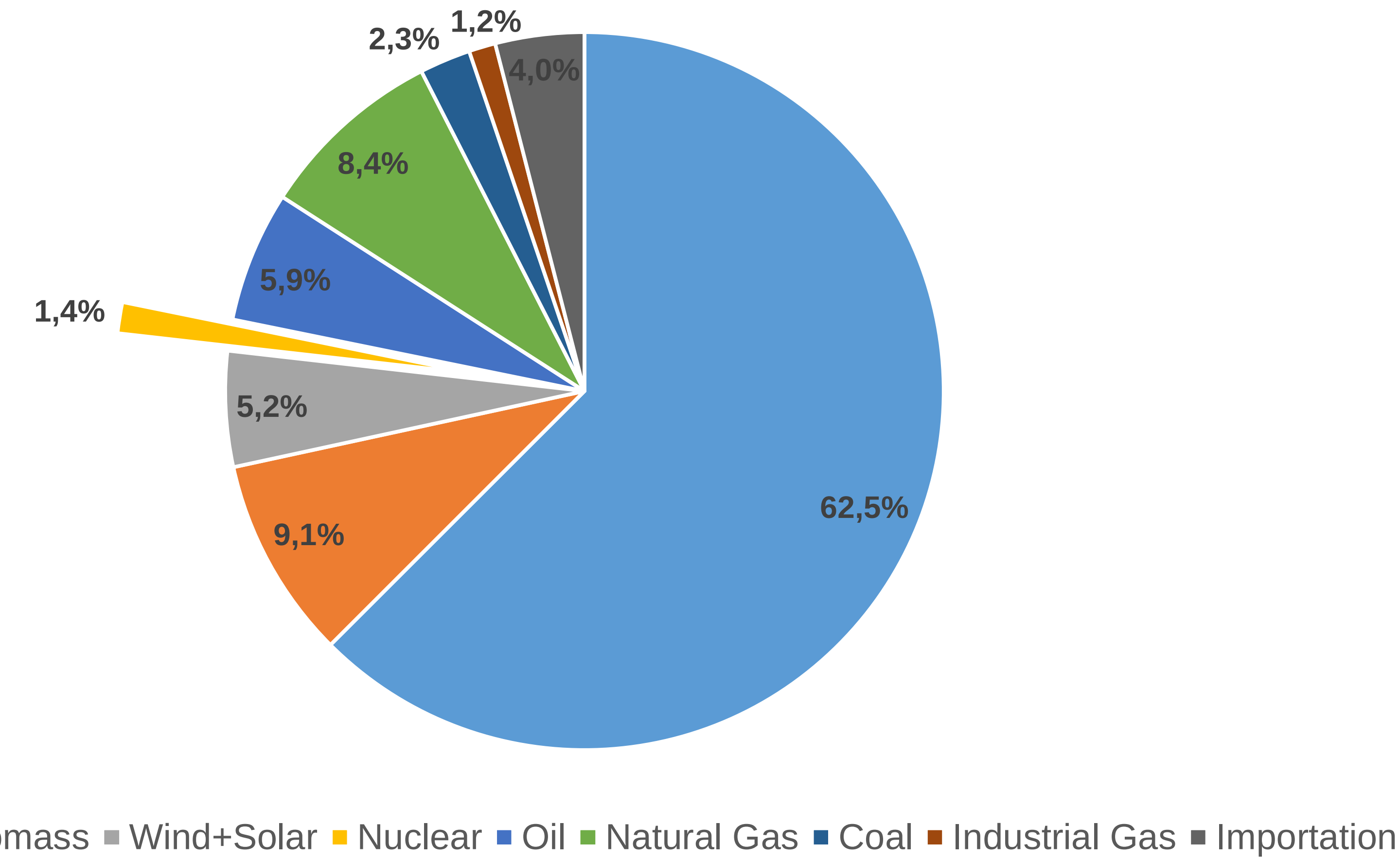
Present context of radioactive waste forms in Brazil

Brazilian power supply – 2015



Extracted from official data of governement : Free online access in: www.mme.gov.br

Brazilian nuclear power plants

ANGRA 1

Operating since 1985

Electrical power: 657 MWe

Refueling: ~12 months

121 elements of UO_2 fuel

ANGRA 2

Operating since 2001

Electrical power: 657 MWe

Refueling: ~12 months

193 elements of UO_2 fuel

ANGRA 3

Under construction

Electrical power: 1405 MWe

Refueling: ~12 months

Nuclear Central Almirante Álvaro Alberto – Angra dos Reis – Rio de Janeiro

Management of radioactive waste forms in Brazil

Low and intermediate radioactivity level wastes → 3 appropriate hangars with capacity until 2025

Spent nuclear fuel → (Capacity) Pools (Expected to be fully filled in 2021)

- ANGRA 1 – 935 elements
- ANGRA 2 – 787 elements
- ANGRA 3 – 1084 elements

→ (After 2021) Dry storage under consideration

Final repository: Geological disposal?

Thermal analyzes in progress at DEN/UFMG on storage Spent Nuclear Fuel (SNF)

Advanced nuclear systems under study at DEN

- Fusion Fission System (FFS)

SNF reprocessed by UREX+ process and spiked with thorium

- Accelerator Driven Systems (ADS)

SNF reprocessed by GANEX process and spiked with thorium

- Very high-temperature gas-cooled reactor (VHTR)

SNF reprocessed fuel by UREX+ process and spiked with thorium

- Gas-cooled Fast Reactor (GFR)

SNF reprocessed fuel by UREX+ process and spiked with thorium

SNF properties

Spent Fuel	**Enrichment**	**Burnup**	**Operation time**	**Final amount of fissile material**
UO_2 – From PWR	3.2 %	33 GWd/tHM	3 yr	1.46 %
UO_2 –From VHTR[(1)]	15.5 %	90.2 GWd/tHM	3 yr	9.2 %
*(Th,TRU)O_2 - From VHTR	15 %	97.8 GWd/tHM	3 yr	8.05 %
**(Th,TRU)O_2 – From ADS[(2)]	12 %	2.376×10^{12} GWd/tHM	20 yr	2.04 %

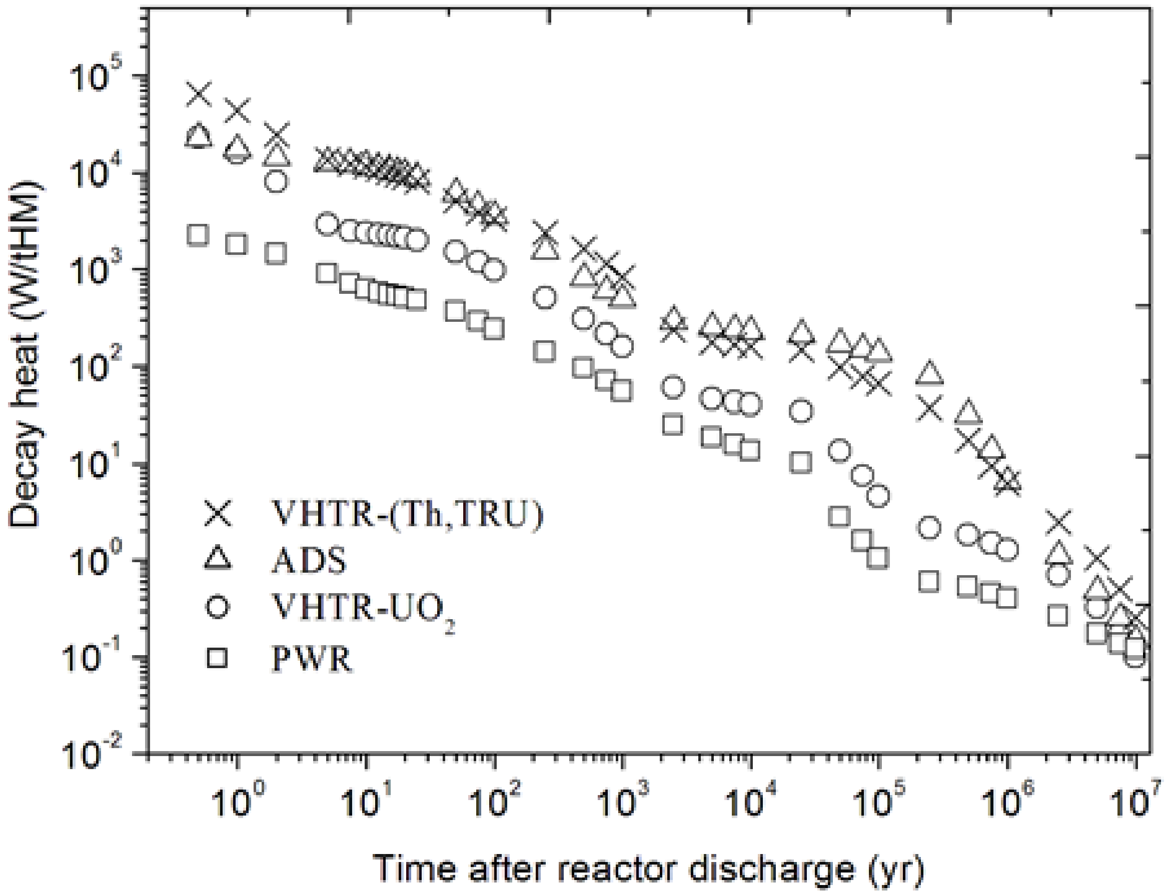
(1) Very High-Temperature Reactor; (2) Accelerator-Driven Subcritical Reactor System
*Obtained from UREX+ reprocessed technique.
** Fuel consisting mainly of transuranic obtained from GANEX reprocessed technique.

These SNFs are being studied under wet storage and under geological disposal conditions

SNF decay heat profiles

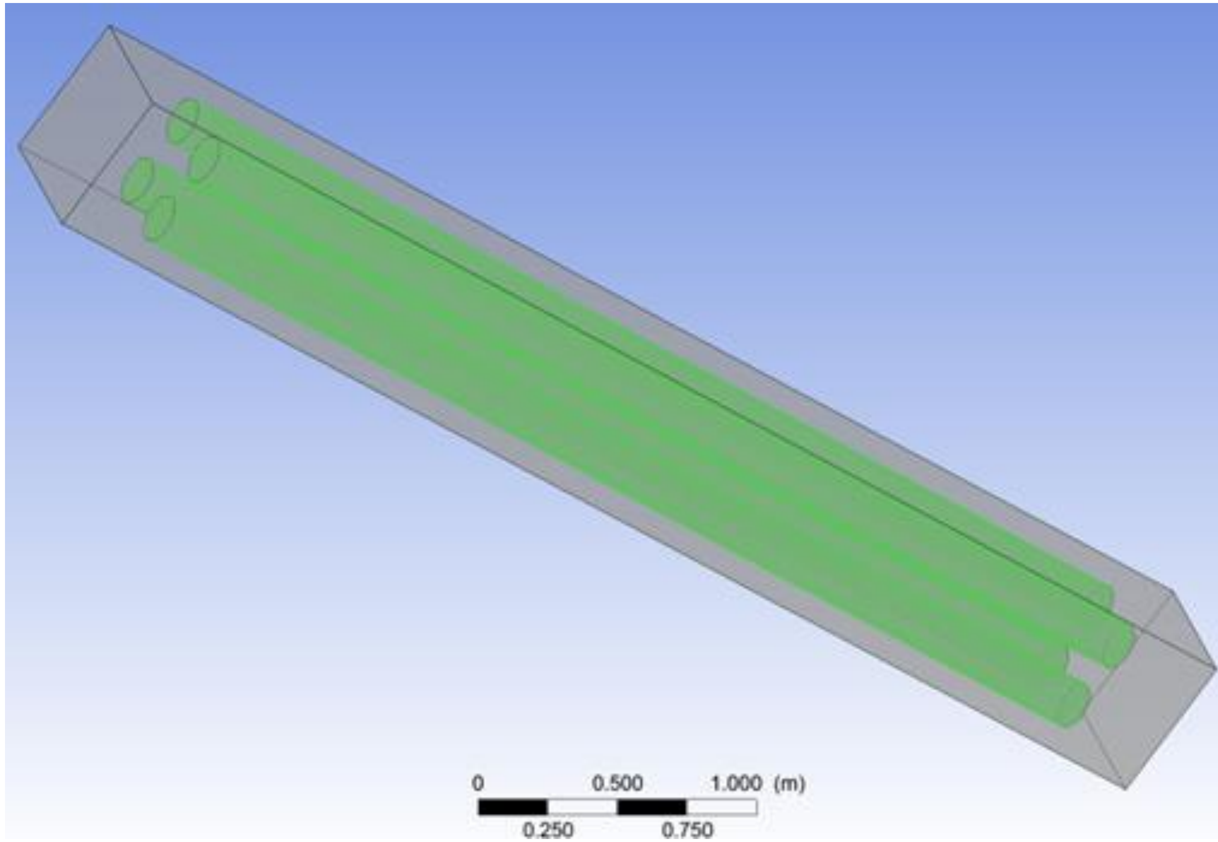
- Essential for specifying the heat sources.

- Obtained from Origen2.1 code studies.



Geometry considerations

- Spent Fuel Pool simulated (SFP):
  - ✓Pool dimensions: (0.56 x 0.56 x 5) m with 1/4 of its effective volume filled with SNF.
  - ✓SF amount stored: 4 cylinders of 8.8 cm of radius and 4m of height spaced 18.8 cm center-to-center.



Modeling

The problem:

Reactor discharge → Storage at SFP for initial cooling → No external cooling system at t=0 and t=10 yr starting from the fuel discharge → Question → How long the water takes to reach the boiling temperature?

Characteristics of heat sources

- The knowing of the heat fluxes at the cylinder surfaces

Decay heat values at t=0 and t=10 yr in W/tHM units

(Origen2.1 results)

ρ_{fuel} → Total surface area of cylinder →

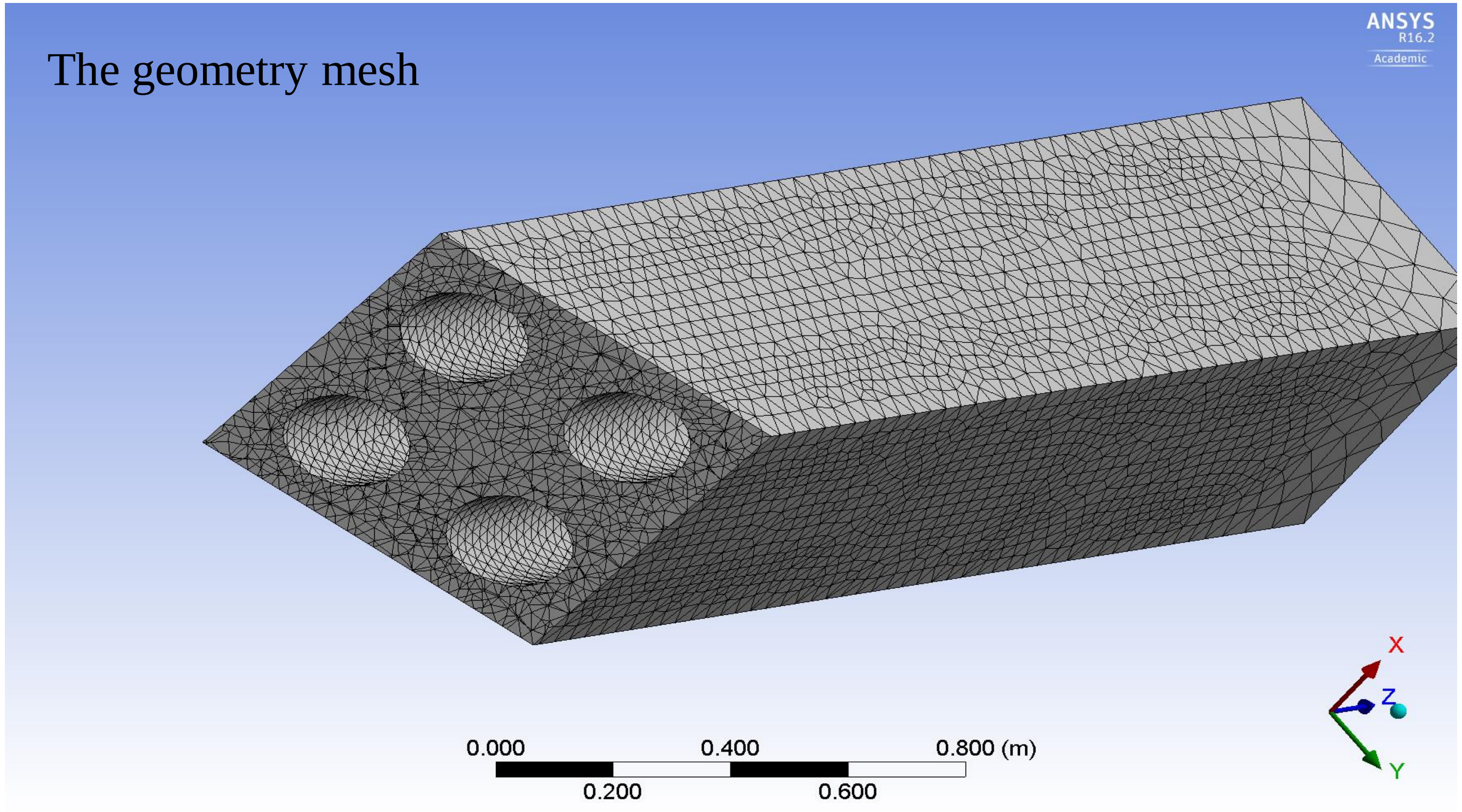
W/m^2 units

(Simulation requirement)

Modeling

Implementation

- Via the computational fluid dynamics package ANSYS CFX, based on finite elements method.



Modeling

Techniques

1 – (*Open-top*): Allows the heat transfer between the SFP and the environment.

2 – (*Sealed-walls*): All the SFP walls set as adiabatic, and the fraction of water and air fixed at 0.95 and 0.05, respectively.

Modeling

Materials physical properties and heat fluxes required

- For Water and Air
  - ✓Molar mass, density, temperature, pressure, specific heat capacity, dynamic viscosity and thermal conductivity.

Fuel Type	Flux Values (W/m^2)	
	t=0 yr	t=10 yr
VHTR-UO_2	1.4423×10^4	1.057×10^3
PWR-UO_2	4.03×10^4	2.76×10^2
ADS-(Th, TRU)O_2	6.813×10^4	5.176×10^3
VHTR-(Th, TRU)O_2	1.9865×10^5	5.087×10^3

Results

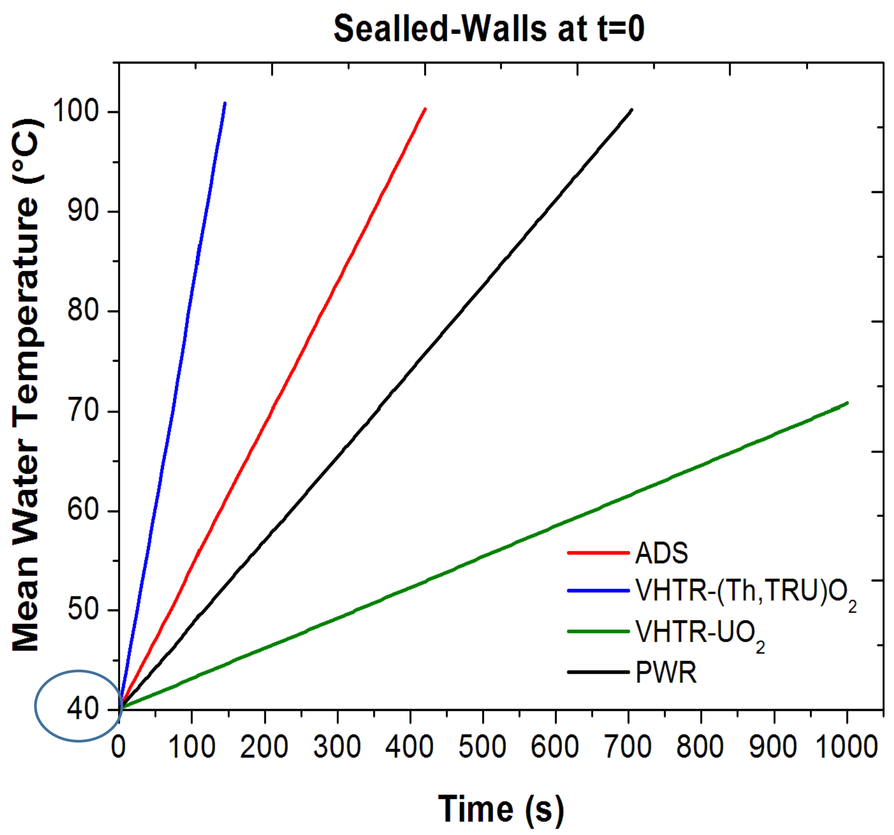
Increasing water temperature rate (R_T) of the SFP in °C/s, and boiling time of water (T_b)

Spent Fuel types	**t = 0 yr sealed-walls R_T; T_b**	**t = 0 yr open-top R_T; T_b**	Spent Fuel types	**t = 10 yr sealed-walls R_T; T_b**	**t = 10 yr open-top R_T; T_b**
VHTR-UO_2	0.031; 32.3 min	0.027; 37 min	PWR-UO_2	5.863×10^{-4}; 28.4hr	5.151×10^{-4}; 32.4hr
PWR-UO_2	0.086; 11.6 min	0.074; 13.5 min	VHTR-UO_2	0.0023; 7.25 hr	0.0019; 8.8 hr
ADS-(Th,TRU)O_2	0.145; 7 min	0.125; 8 min	VHTR-(Th,TRU)O_2	0.0108; 1.54 hr	0.0092; 1.8 hr
VHTR-(Th,TRU)O_2	0.422; 2.4 min	0.359; 2.8 min	ADS-(Th,TRU)O_2	0.0110; 1.5 hr	0.0095; 1.75 hr

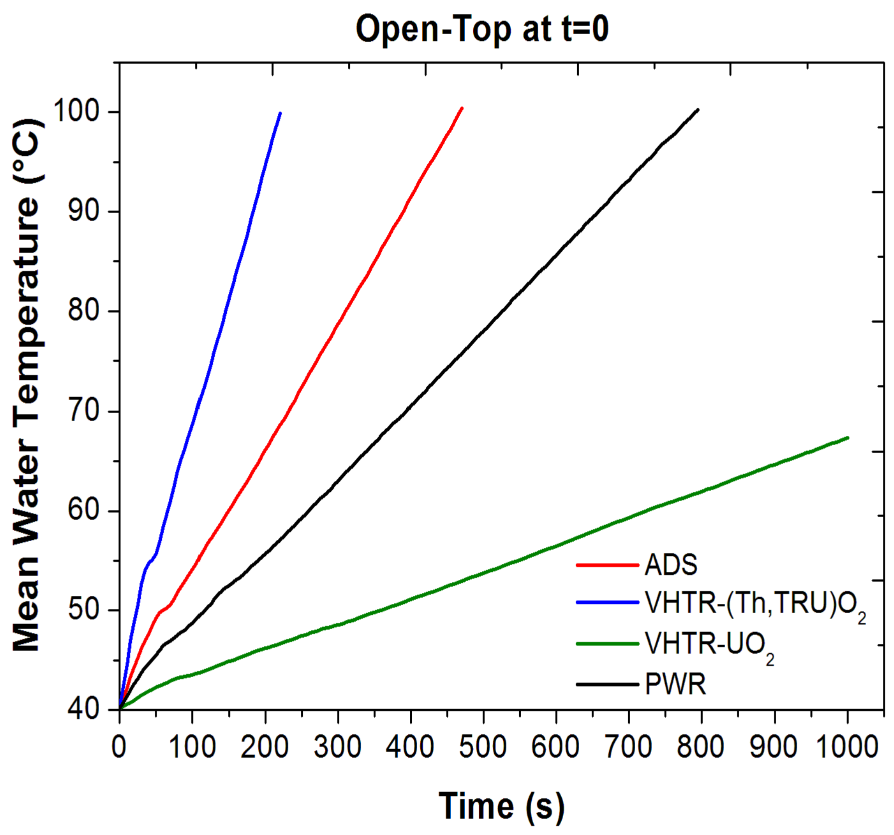
- The sealed-walls and open-top values differ by less than 16%.

$$T_b \propto 1/q$$

Results

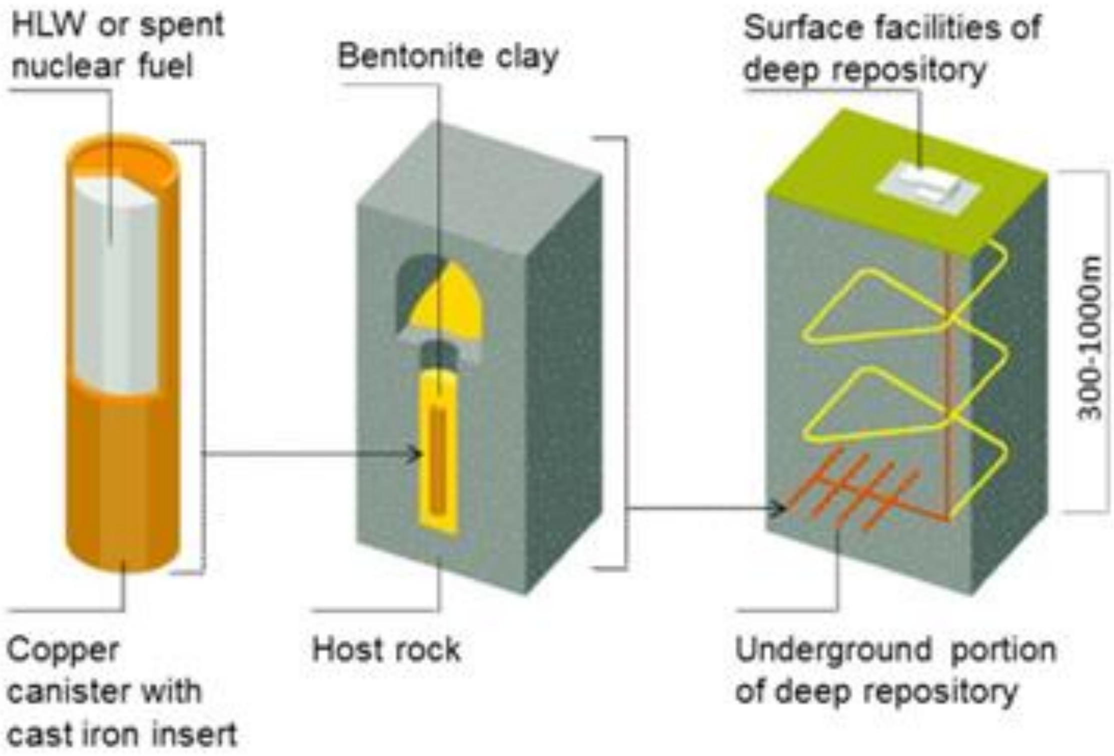


Sealled-Walls at t=0
Mean Water Temperature (°C)
Time (s)
ADS
VHTR-(Th,TRU)O2
VHTR-UO2
PWR

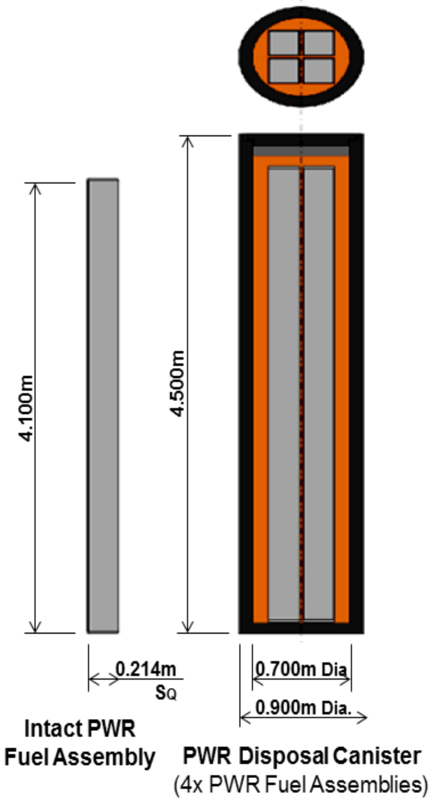


Open-Top at t=0
Mean Water Temperature (°C)
Time (s)
ADS
VHTR-(Th,TRU)O2
VHTR-UO2
PWR

Geological repository concept

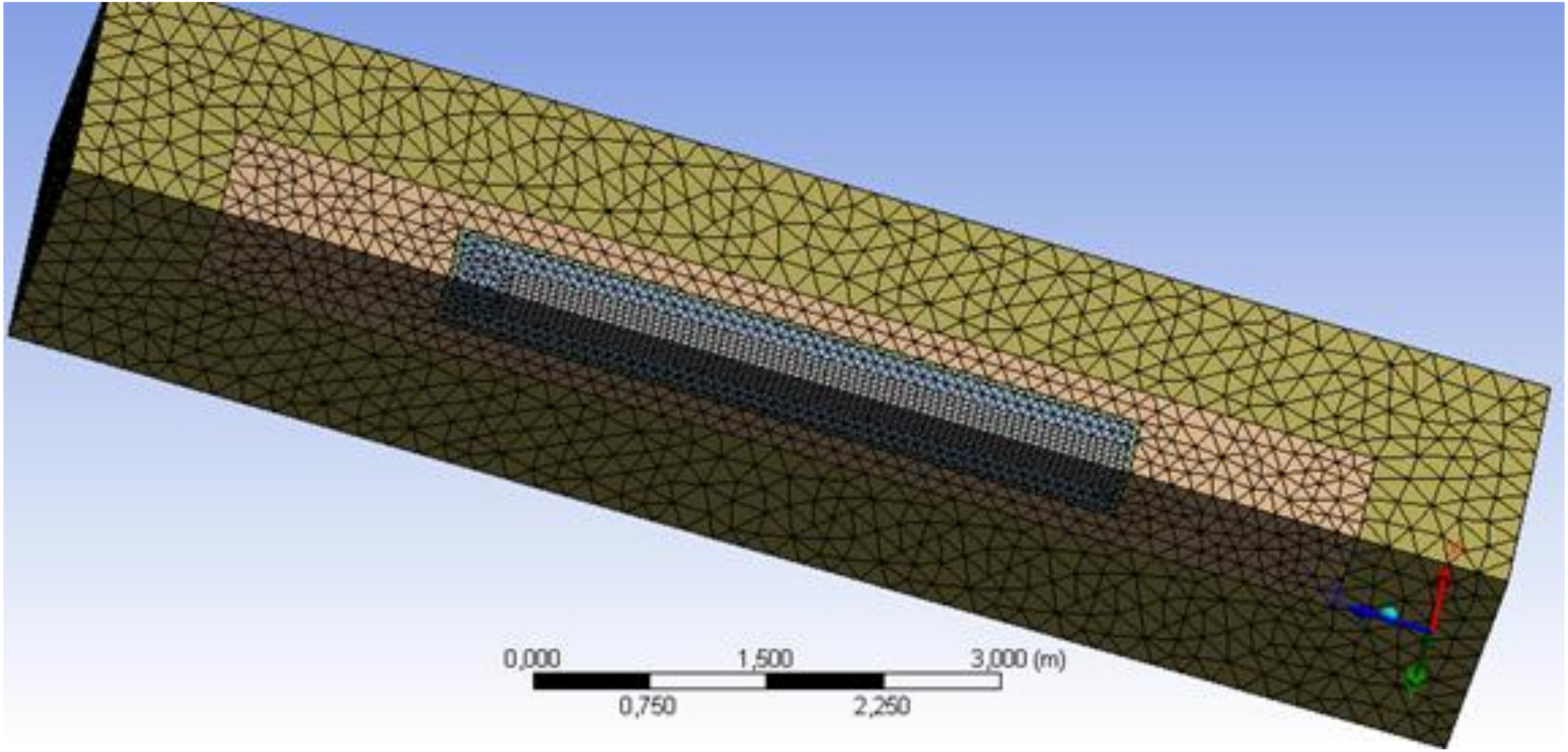


Swedish KBS-3V concept.



PWR disposal canister design (Nirex Ltd., 2005).

Ansys geometrical modeling



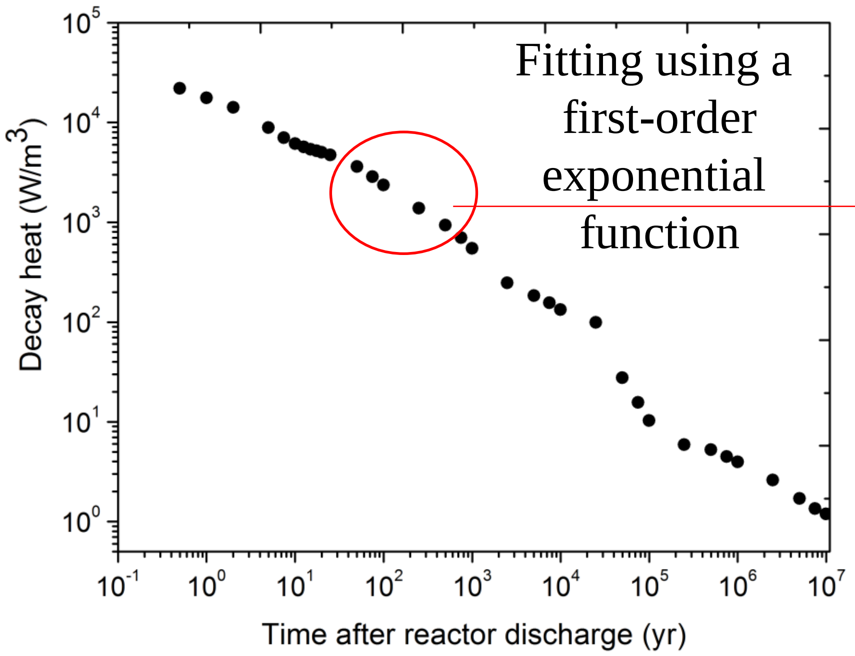
Modeling description

- It was used the Ansys transient thermal module.
- The four PWR fuel assemblies were represented by a parallelepiped with the real height of the fuel assembly.

Modeling description

- Ansys quantity: *Internal heat generation*, in W/m^3.

$$\left(W / tHM \xrightarrow{\rho_{SF}} W / m^3\right)$$



$$q'''(t) = 0.24927 + 0.98919 \exp\left(-4.87282\times10^{-10} t\right)$$

with t in seconds.

Modeling description

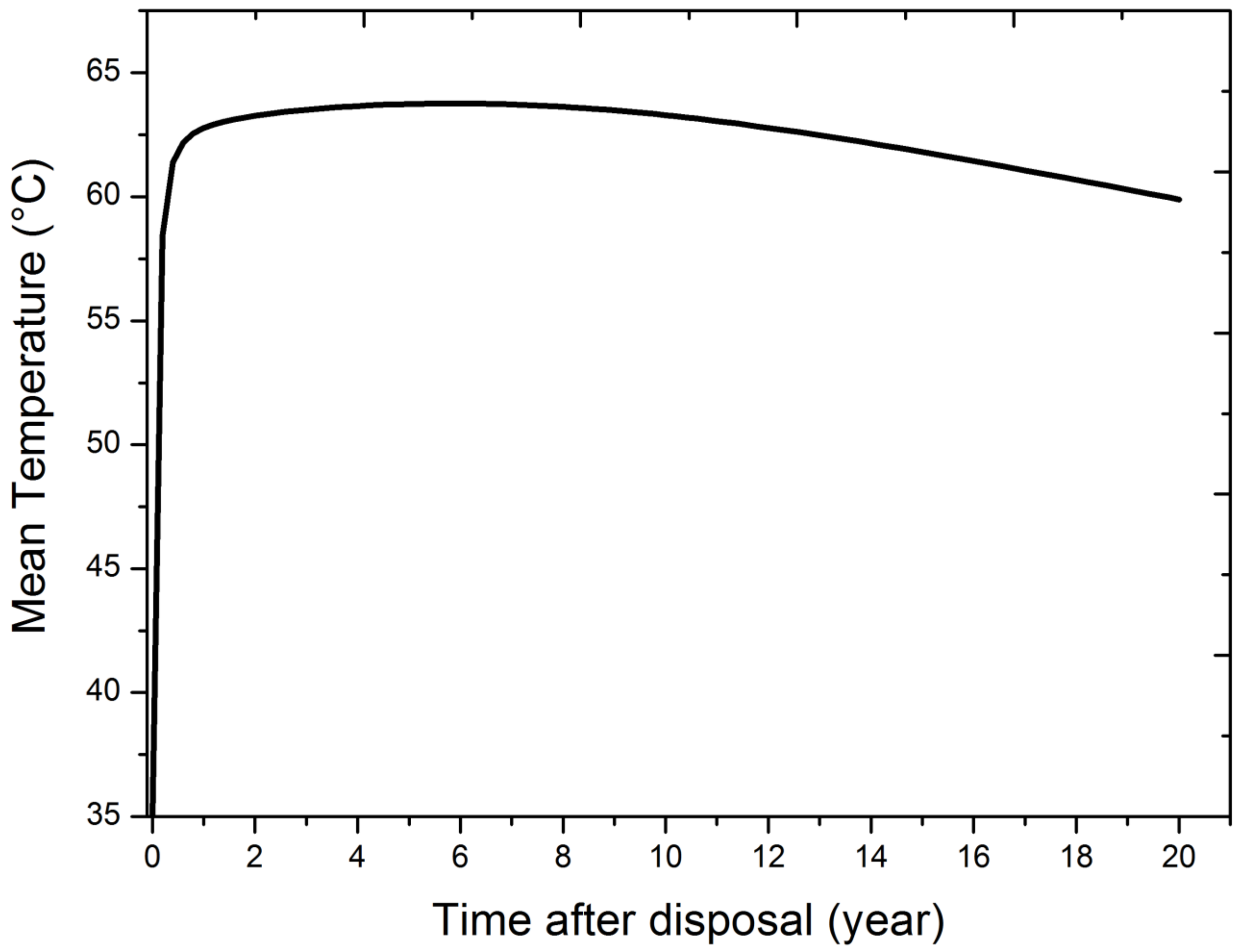
Material	Density (kg/m^3)	Thermal Conductivity (W/m °C)	Specific heat (J/kg °C)
PWR SF	9870	0.135	2640
Cast iron insert	7200	52	504
Cooper Canister	8900	386	383
Bentonite	1970	1	1380
Backfill	2270	3.2	1190
Rock	2650	3.2	815

Data from Choi, 2008; Lee et al., 2010.

✓Thermal gradient along the vertical layer of rock: 30°C/km

Results

Temperature as a function of time on a PWR canister surface.



In progress …

- Studies of spacing between canisters for PWR, VHTR and ADS spent fuels.

Acknowledgment

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