Concrete harvesting activities in the Netherlands

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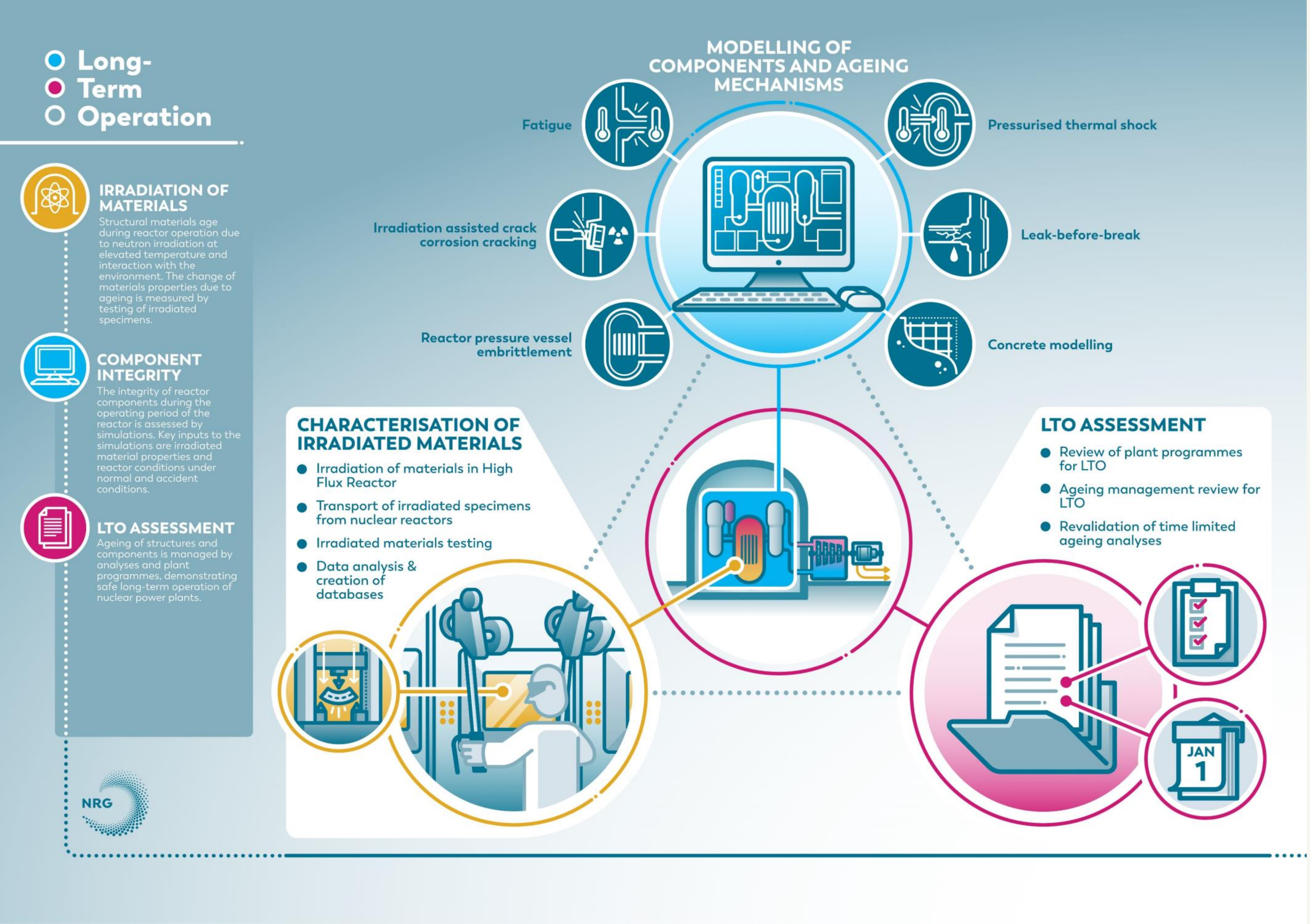
Introduction

The presentation covers **tests** (mainly mechanical) performed on **concrete cores** taken from structures of the **High Flux Reactor (HFR)** at Petten, Netherlands.

- HFR
- Reactor pool structure
- Concrete cores
- Determination of mechanical properties
- Ageing degradation due to chloride ingress
- Way forward



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About the High Flux Reactor (HFR) in Petten

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- Licensed ability of **50 MW.**
- **Light water** cooled and moderated.
- **Tank-in-pool** type.
- Constructed during **1950s**
- Operational since **1961**.
- Present age of the reactor is **63 years**

Nuclear medicines
(30000 patients per day)

Beam tube research

Irradiation services

Material testing

Site of the HFR

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energy & health campus

Site characteristics

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Coastal

- Industrial site
- North Holland dunes

Seismic

- PGA 0.1g
- MRI 10000 years

Wind

- 29.8 m/s (1 hour average)
- 40.6 m/s (gust)

Precipitation

- 43.5 mm (1 hour)
- 90.2 mm (24 hours)

Temperature

- 34.8 C highest
- -20.0 C lowest

Main plant layout of HFR

Chimney

Air treatment building

NDT building

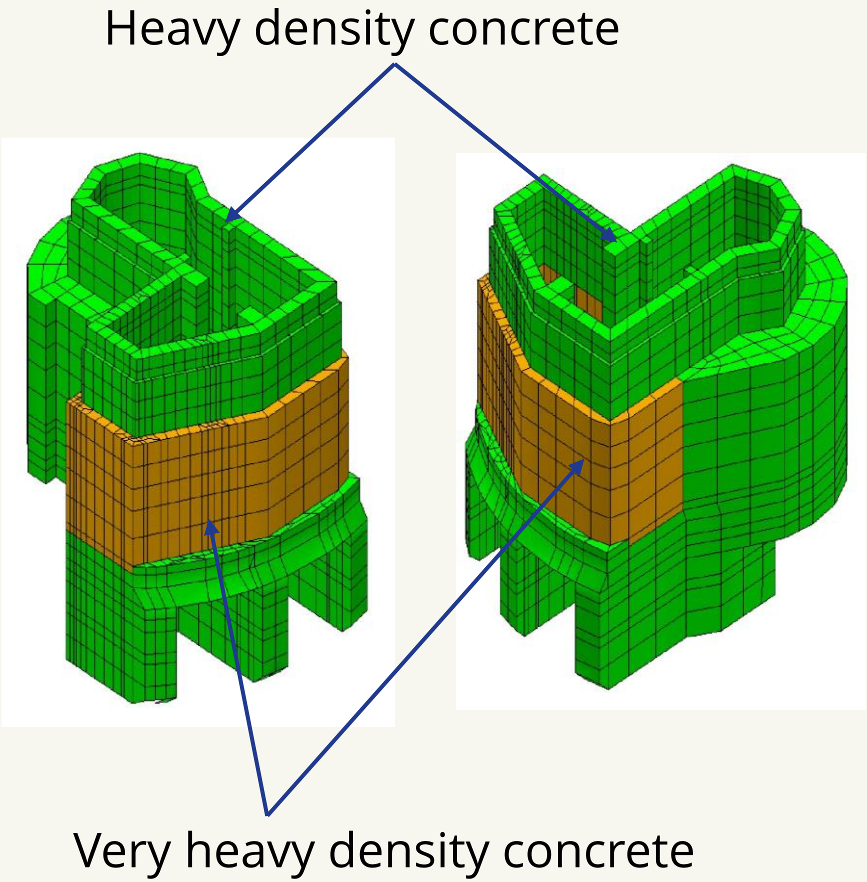
Primary Pump building

Reactor containment building

Reactor auxiliary building

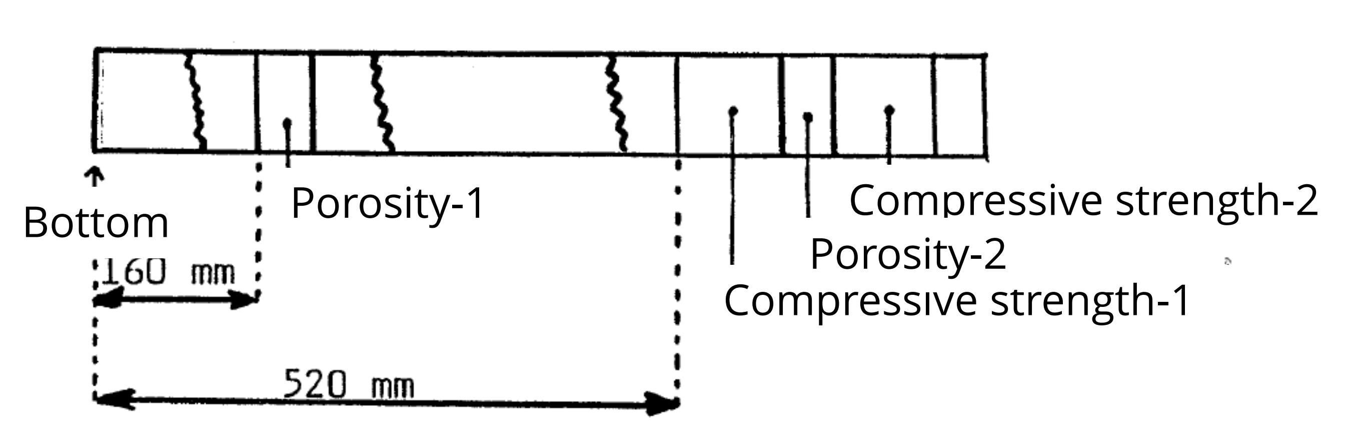
Reactor pool structure

- **Reactor pool** and **storage pools-1 & 2** are housed inside the reactor containment building.
- **Heavy density** concrete (3500 kg/m^3) and **very heavy density** concrete (4200 kg/m^3) is used for the basins.
- **Aluminium liner** used for leak tightness.
- Outside the basins, **normal density concrete** was used.
- Concrete class is **C20/25** (20.7 N/mm2).



1985: Concrete core

- **1985:** A concrete core was drilled out from the underside of the basin.



Material property	Test No.	Value	Unit
Cylinder compressive strength	1 2	35.7 34.0	MPa
Density	1 2	3840 3930	kg/m^3
Porosity	1 2	14.4 12.3	%

2009: Concrete cores

- **2009:** Two concrete cores were drilled out from the ceiling of subpile room.

Material property	Test No.	Value	Unit
Cylinder compressive strength	1 2	32.3 36.5	MPa
Density	1 2	3490 3740	kg/m^3
Porosity	1 2	12.3 14.3	%

- Based on its mass, appearance and magnetism, it was suspected that the aggregate used is **Greigite** and not **Barite, Magnetite and Hematite** were was previously assumed.

2010: Concrete cores

- **2010:** A vertical drilling was carried out over approximately 1.9 m of the total 2.235 m thickness of reactor floor.
- The floor was drilled from the bottom in **4 steps (cores).**
- **Ten cylinders** were sawn off from the four drilled cores from the reactor floor.
- **Six** cylinders were used to determine the **tensile** strength.
- **Four** cylinders were used to determine the **compressive** strength and volumetric weight.
- The large range of compressive strength is given by the **voids present in the concrete**.

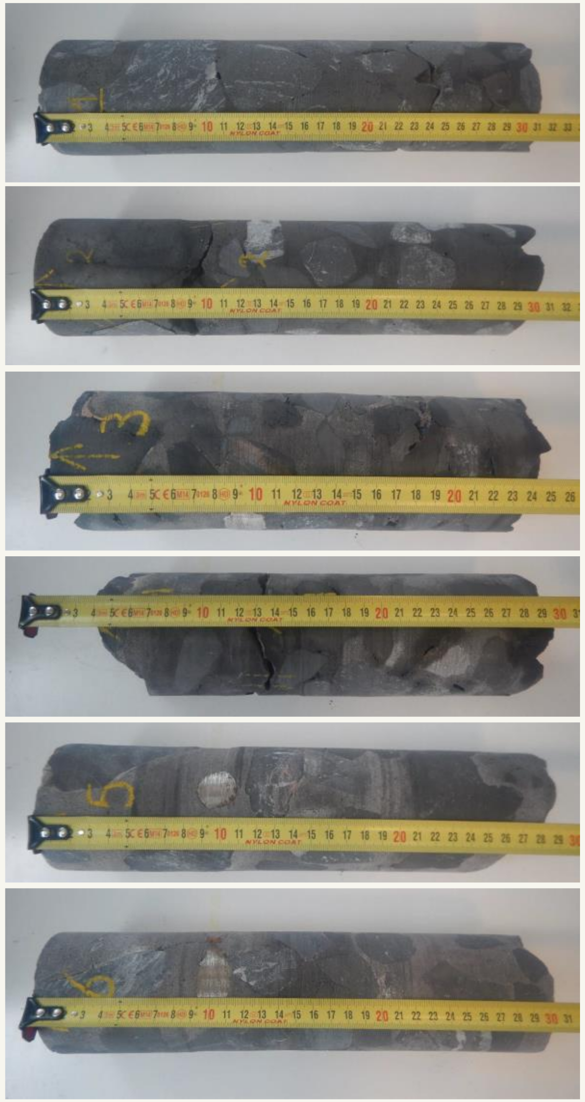
2010: Concrete cores

Property	Value	Unit
Split tensile strength	1.99 2.73 3.22 3.72 2.90 3.48	N/mm^2
Average Split Tensile Strength	3.01	N/mm^2
Design value concrete tensile strength	0.99	N/mm^2
Volumetric weight	3709 3825 3548 3607	kg/m^3
Cylinder compressive strength	27.3 34.2 45.8 44.6	N/mm^2

2017: Concrete cores

- 2017: Six cores were used from pipe corridor (two from walls and four from ceilings).

Property	Unit	Value (walls)	Value (ceiling)
Volumetric weight	kg/m³	3620 3560	3320 3640 3390 3540
Cylinder compressive strength	N/mm²	24.9 20.7	17.5 50.5 54.6 62.6



Statistics of measured mechanical properties

Material property	Parameter	Value	Unit	Measurements
Density	μ	3630	kg/m^3	12
	σ	190	kg/m^3	
Porosity	μ	13.33	%	4
	σ	1.18	%	
Cylinder compressive strength	μ	39.63	MPa	12
	σ	12.28	MPa	
Splitting tensile strength	μ	3.01	MPa	6
	σ	0.62	MPa	
Modulus of elasticity		32310	MPa	1

Equivalent strength class

- Equivalent **strength class** for each material property:

Material property	Value	Unit	Strength class
Cylinder compressive strength	20	MPa	C20/25
Splitting tensile strength	2.06	MPa	C18/22.5
Modulus of elasticity	32.8	GPa	C30/37

- There is a **visible difference** between the corresponding strength class of each material property.
- In order to generalize the concrete material properties of low-density heavy concrete and ordinary reinforced concrete civil structures with **one unique class strength**, C20/25 was assumed for design.
- The choice of the strength class is **very conservative**, and the same strength class is taken into consideration for the high-density heavy concrete as well.

Ageing degradation due to chloride ingress

- High concentration of chlorides in concrete lead to corrosion of rebars.
- A **chloride ingress model** is being developed based on the in-situ properties of concrete.
- The current model has been **calibrated** using data from the **chimney** using:
  - Density of cores
  - Chloride concentration with depth
  - w/c ratio (using compressive strength)
- This model can be incorporated in the **FE analysis** to simulate aged concrete with active corrosion.

Chloride ingress model for chimney

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- **Ingress of chloride ions** was evaluated based on **Fick's law** of chloride diffusion where critical time (t_{crit}) or the time when the chloride reaches the depth of the reinforcement was estimated using:

$$t_{crit} = \frac{x_{rebar}^2}{4 \cdot D_a \cdot \left(erfc^{-1}(C_{crit}/C_s)\right)^2} = 21.14\ years$$

- **Corrosion rate** was determined based on model developed by **Vu and Stewart** (2000),

$$i_{corr(t_p)} = \left(\frac{[3.78(1-w/c)^{-1.64}]}{cover}\right) \times 0.85 \times t_p^{-0.29} = 0.426\ \mu A/cm^2$$

- **Rust production** was determined in the form of :
  - Reduced rebar diameter: $D_{rb} = 24.59\ mm$
  - Volume of steel consumed per unit length of anodic steel: $\Delta V_s = 16.12\ mm^3/mm$
  - Internal pressure developed due to corrosion: $\mathrm{P} = 2.96\ MPa$
- Due to the **heterogeneous nature** of concrete, it is difficult to determine a deterministic value of the internal pressure that will lead to cover cracking

Future works

- In-situ material properties of the **very high-density concrete** needs to be determined.
- Further investigations required to determine the real nature of the **aggregates** (magnetite / barite/ greigite).
- **Chloride ingress model** needs to be updated based on more data from the reactor pool structure.
- **Reinforcement coupons** may be extracted to determine the properties of rebars.
- Impact of **Alkali silica reaction (ASR)** needs to be investigated on the reactor pool structure.

References

- K.M. Browning, L. Hasa, F.H.E. de Haan –de Wilde, '*Development of conservative material properties to account for concrete degradation mechanisms with specific emphasis on rebar corrosion due to chloride ingress*', PVP2023-105650, Proceedings of the ASME 2023 Pressure Vessels & Piping Conference PVP 2023, Atlanta, Georgia, USA (2023).
- L. Hasa, F.H.E. de Haan –de Wilde, '*An update of the assessment methodology for civil ageing management: Damage development in concrete structures of a reactor due to ageing mechanisms*', PVP2022-84008, Proceedings of the ASME 2022 Pressure Vessels & Piping Conference PVP 2022, Las Vegas, NV, USA (2022).

Thank you!

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