Testing of concrete in Norway as radiation protection shielding

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Outline – 19 slides on:

• IFE
• Background about concrete
  - Composition of Concrete
  - Properties of concrete
  - Concrete as shielding material
    - Gamma radiation effect on concrete structures
    - Neutron radiation effect on concrete structures
• Concrete program at IFE, Norway
IFE – Institute for Energy Technology

• About 600 employees
• Research areas of IFE include petroleum-, solar-, wind-, environmental and nuclear technology, Fundamental physics, MTO...
• No commercial NPPs in Norway
• Research reactors since 1951
  • JEEP II – 2MWth at Kjeller
  • Halden Reactor – 25MWth in
• NMAT supports both reactors with fuel
NMAT Activities

- Fabrication of fresh standard & experimental nuclear fuel
- Refabrication and instrumentation of pre-irradiated nuclear fuel segments
- Service and Maintenance
- Nuclear waste handling
- Intermediate storage of fresh and spent fuel
- Safety and Safeguarding

- A range of techniques for Characterization/Testing/PIE
  - Visual inspection
  - Profilometry & dimension measurements
  - Gamma scanning
  - Neutron radiography
  - Eddy current
  - Puncturing and FG analysis
  - Density measurements
  - Metallography, LOM/SEM/EDS
  - Alpha-, beta-, and gamma autoradiography
  - TGA
  - Hydrogen measurements
  - Mechanical testing (Tensile, compression, micro hardness)
Composition of Concrete

- Portland cement
  Oxides of Ca, Si and Al
- Limestone
- Granite
- Sand
- Ash
- Silica fume
- Ground granulated blast furnace slag
- Metakaolin
- Accelerators
- Retarders
- Air entering agents
- Plasticizers
- Corrosion inhibitors
- Pigments
Composition of Concrete

Meso structure of concrete
- Randomly distributed gravels, sand particles in cement paste

At time 0:

Air  Water  Cement  Aggregates

At time t after set:

Air  Water  Hydration products  Cement  Aggregates

Cement Paste
Composition of Concrete

Cement Paste (Cement + water)
- Portland Cement commonly used: Oxides of **mainly** Calcium, Silicon, Aluminium
- Structure is a mixture of:
  - Nonstoichiometric amorphous (Calcium silicate hydrate)
  - Needle like or plate like crystals (Calcium hydroxide)
  - Needle shaped crystals (Ettringite)
- Water – Free, adsorbed, chemically bound

Aggregates
- Structure of crystalline nature
- Coarse/Fine, Dense/light
- Mineralogical composition (siliceous/calcereous)
- High hydrogen content, dense aggregates and boron containing aggregates improves shielding properties
Composition of Concrete

The water content of concrete have a major influence on physical and mechanical properties...

Most of the water of concrete appears in the cement paste
Properties of Concrete

Strength, density, chemical, thermal and shielding properties of concrete are affected by several parameters:

- Chemical and mineralogical composition/quality of the constituents
- Mixing ratio of the components

The properties change over time due to changes in micro structure caused by:

- Slow hydration
- Crystallization of amorphous parts due to reactions between aggregate and cement paste
- Temperature
- Humidity
- Chemical attacks
- Radiation exposure
Concrete as Shielding Material

- Concrete is used as biological shielding and structural support for the vessels of LWRs and for interim storage facilities because of:
  - Good shielding capacity
  - Good structural support
  - Relatively low construction cost

- Exposed to neutron and gamma radiation
  - Increased dose/fluence may cause significant property changes
Concrete as Shielding Material

Neutron radiation effect
- High impact on aggregate
- Introduce lattice defects and converts the crystalline structure to distorted amorphous structure
- Volume increase of aggregates => stresses and micro crack formation of the concrete

Gamma radiation effect
- High impact on cement paste
- Absorption of gamma:
  - gamma heating
  - water radiolysis
- Water loss => shrinkage+cracking
- Temperature gradient
- Differences in thermal strain between aggregate and cement paste
- Lower strength, stiffness, ductility
- Micro cracking of the cement paste
Concrete as Shielding Material

- Still limited data available on the microstructural, physical and mechanical changes in concrete due to radiation
- Much of the available data is not relevant for LWR concrete structures
- Existing data difficult to compare due to difference in:
  - constituents
  - mixing ratios
  - specimen size
  - test conditions (temperature, humidity...)

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Concrete Program at IFE, Norway

Irradiation Test
• Irradiation of concrete under controlled and monitored conditions (relevant to LWR concrete structures) to a desired fluence/dose

Heating Test
• Temperature history same as for irradiated samples

Control Test
• Same type of samples kept at normal conditions (20C, 60%Rh)

Characterization/testing
• Standardized and adapted non-destructive and destructive techniques to characterize microstructure, physical and mechanical property changes of fresh and irradiated concrete
Concrete Program at IFE, Norway

JEEP II 2MWth

Neutron flux:
- $3.5 \times 10^{12} \text{ n/cm}^2/\text{s}$ for $E > 0.1 \text{MeV}$
- $1.5 \times 10^{12} \text{ n/cm}^2/\text{s}$ for $E > 1.0 \text{MeV}$

Moderator temperature:
- 50-55 C

IFE design and construct test rigs with online measurements of:
- Temperature
- Stack elongation (axial)
- Gas release
- Pressure
Characterization/Testing

Opening of concrete test rigs in Hotcells at Kjeller

**Design:** The Hot laboratory has 3 caves with 1 m thick concrete walls and 4 windows with 1 m thick lead glass incorporated in the front wall of the caves.

- Two of the caves measure 3 m x 3 m x 2.5 m and the third one 3 m x 6 m x 2.5 m.
- The caves are located in a row, separated with partition walls movable by remote control.

**Remote Handling:** Above each window two master-slave manipulators are mounted.

- The caves are equipped with a power manipulator, a 1.5 t overhead crane.

**Equipment:** The caves are furnished with:

- Cave periscope
- Movable equipment for refabrication/instrumentation/PIE, milling machine, etc.
Characterization/Testing

- Visual inspection
  - Deposits, cracks etc.
- Weight and dimension measurements
- Gamma scanning
  - Ortec, HPGe
- Neutron radiography
  - Reveals specimen integrity and water/moisture content/distribution
Characterization/Testing

- (Drying of samples)
  - Controlled heating, long time drying and cooling
- Ultrasonic measurements
  - Internal flaws (i.e. micro cracks)
- Mechanical testing
  - E-Modulus of elasticity
  - Compressive strength
  - HV
- Microstructural characterization
  LOM + SEM
- Thermal gravimetric analysis
Concrete Codes and Standards

- ISO / DIN / NS
- ASTM
- JIS - Japanese Industrial Standard
- SINTEF Byggforsk
- Internal safety standards

In the years to come the ongoing work at IFE will help to fill in the knowledge gaps not addressed in standards:
- Radiation and the thermal cycling of concrete shields
- Degradation in concrete's ability to shield against neutrons.
Summary/Conclusion

• Concrete is a complex material with properties that change over time and with local environment
• Concrete is used in LWRs as biological shielding and structural support
• Limited data available on the microstructural, physical and mechanical changes in concrete due to radiation in LWR relevant conditions
• New concrete program developed at IFE
  - Irradiation of concrete under controlled and monitored conditions (relevant to LWR concrete structures)
  - Standardized and adapted non-destructive and destructive techniques to characterize microstructure, physical and mechanical property changes of fresh and irradiated concrete