Energy for the future

IFE / The Halden Reactor Project – Instruments and Measurements for Nuclear Research and Development

EURAMET Symposium, Oslo, May 26th 2016

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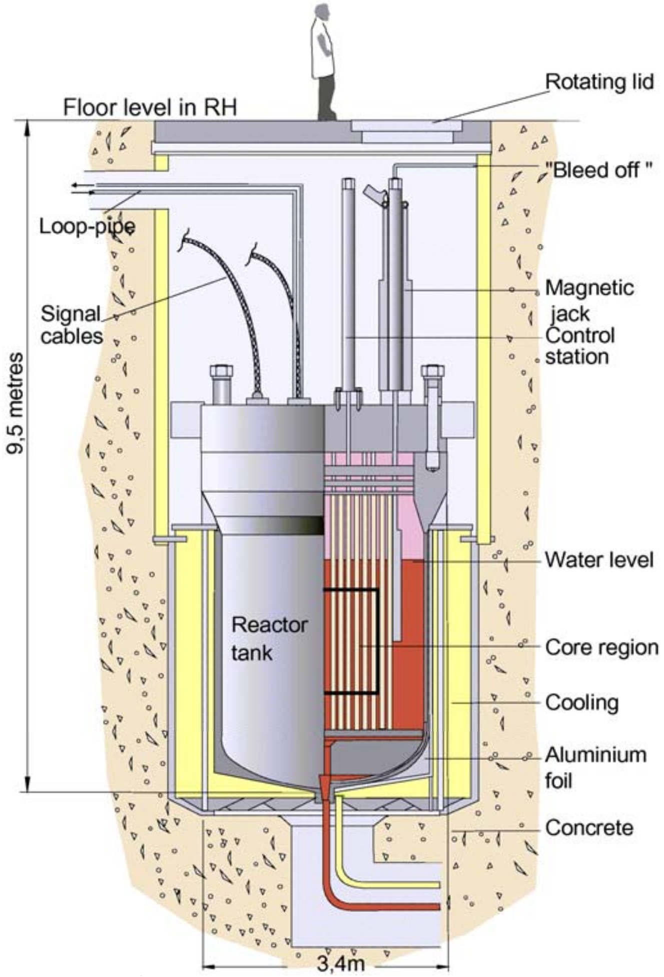
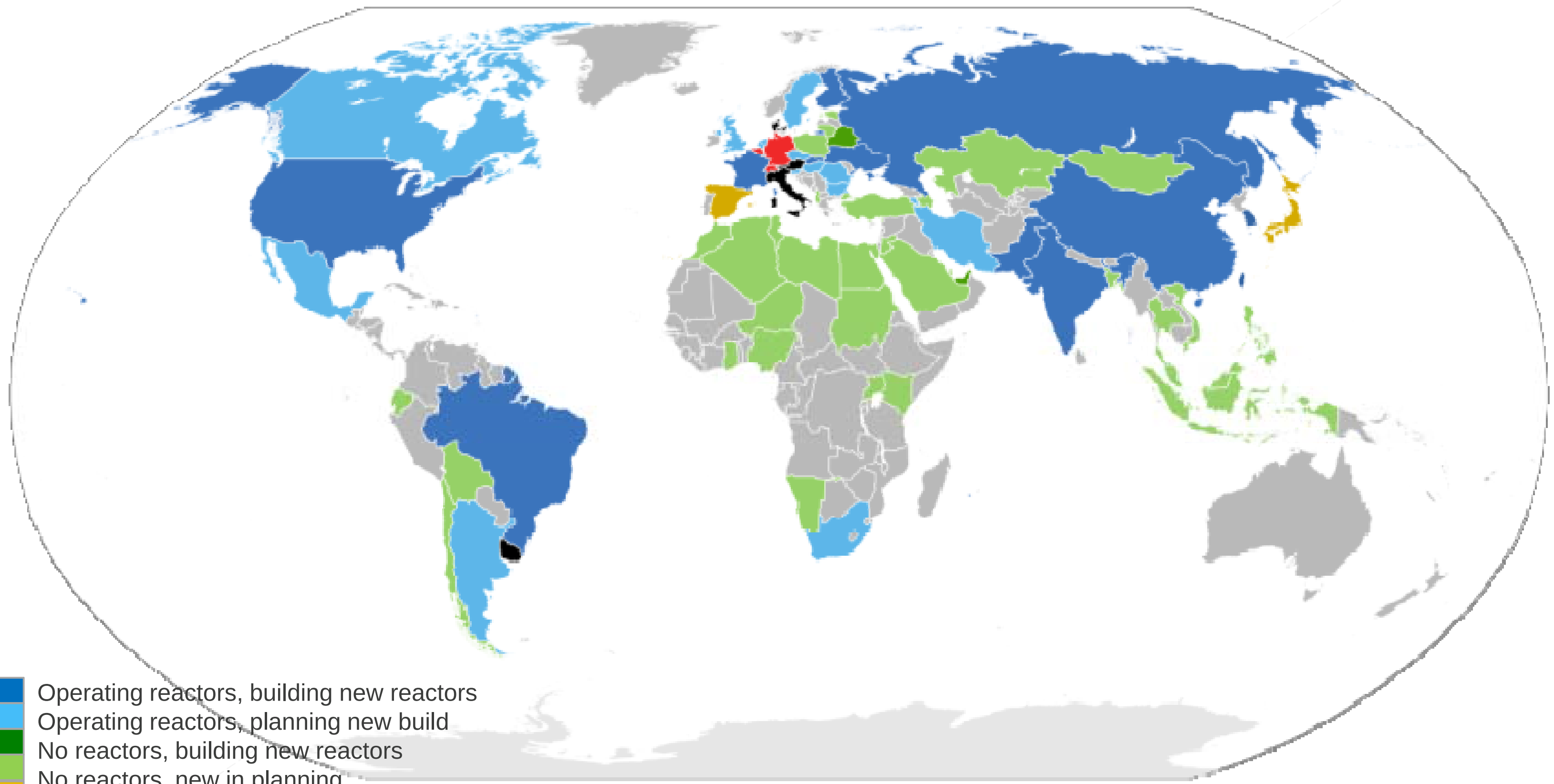


- ✓ Nuclear power today and the future of nuclear power
- ✓ New technology and challenges
- ✓ IFE and the OECD Halden Reactor Project
- ✓ In-core instruments and measurements

Global view of nuclear power (I)



- Operating reactors, building new reactors
- Operating reactors, planning new build
- No reactors, building new reactors
- No reactors, new in planning
- Operating reactors, no new build planned
- Phase-out or foregoing nuclear
- No reactors

Source data: World Nuclear Association
Update 2015

Global view of nuclear power (II)

Some numbers :

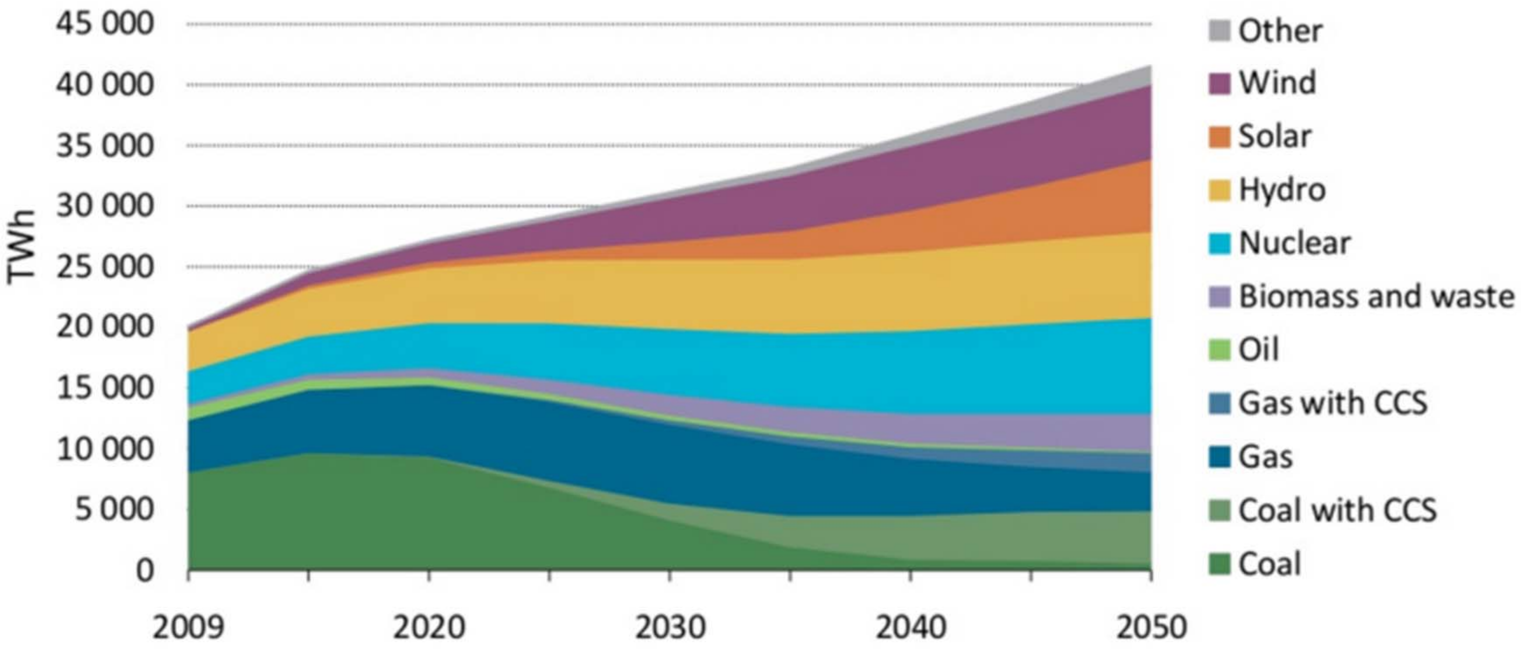
- Approximately 440 operational nuclear power reactors worldwide
- Approximately 65 new nuclear power reactors being built – mostly in China, but also in USA, France, Finland, United Arab Emirates and other countries
- European average Electricity Carbon Factor is 332 g/kWh
- Without the French nuclear power reactors the European average Electricity Carbon Factor would be 415 g/kWh
- In France the Electricity Carbon Factor is 15 g/kWh
- According to the World Health Organization (WHO), by replacing fossil with nuclear in France, approximately 300 000 premature deaths have been avoided

The controversy :

- In most public debates – nuclear (instead of fossil) is asked to be replaced by renewable energy sources

International Energy Agency 2°C Scenario :

Nuclear is Required to Provide the Largest Contribution to Global Electricity in 2050



Source: IEA

Nuclear is the second largest low-carbon power source globally (after hydro)

Fukushima Daiichi:
Learning the Lessons and Moving Forward

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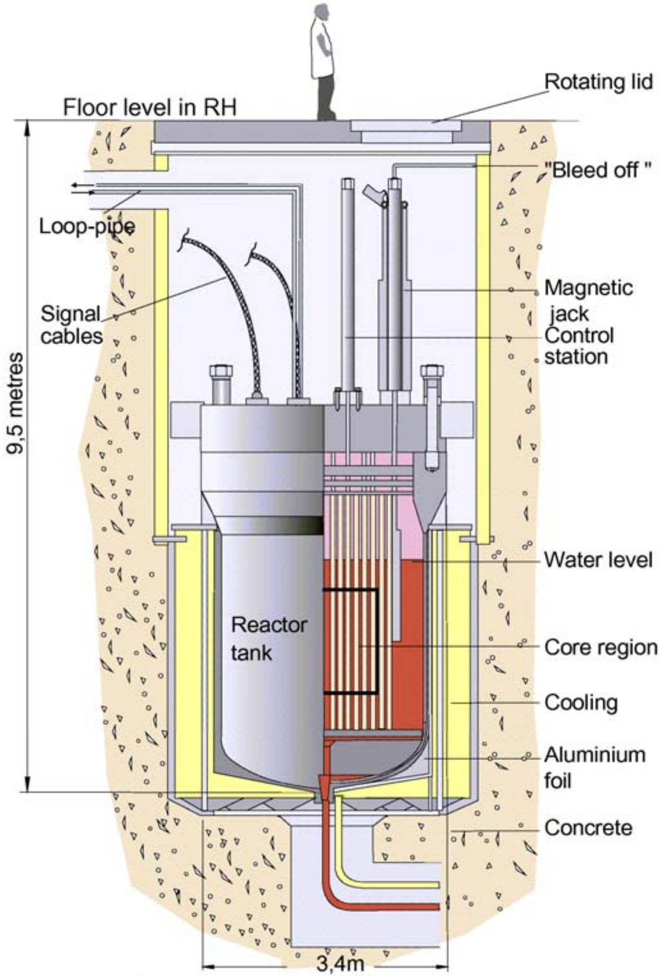

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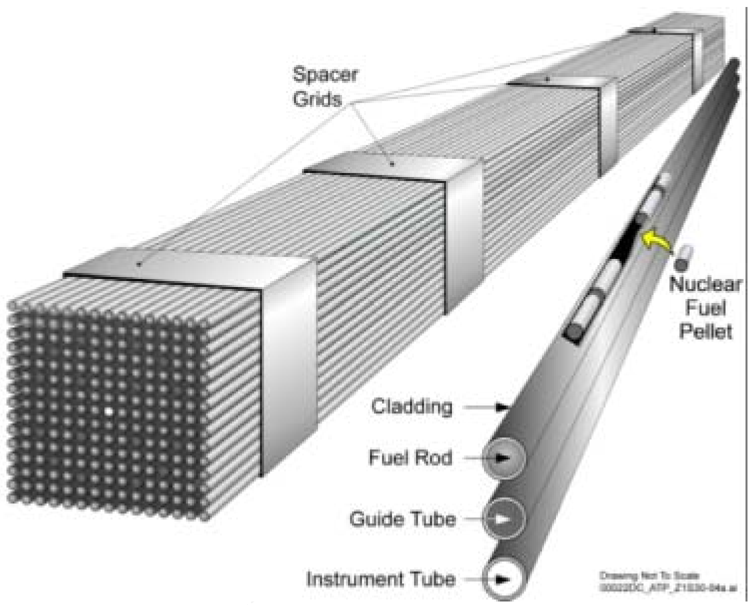
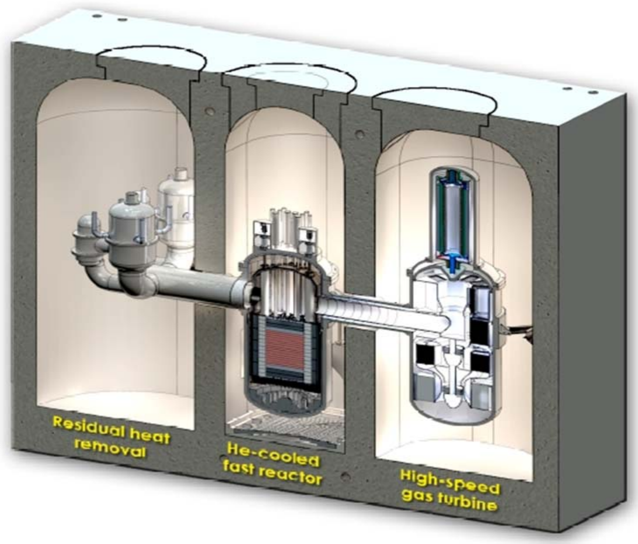
The technical challenge – building the next generation of nuclear power reactors (I) :



- The current fleet of nuclear power reactors (often referred to as Generation 3 or 3+) is based on a water-steam system following the Rankine-cycle
- Typical conditions :
  - Pressure : 165 bar
  - Temperature : 320 deg. C
- Utilizes uranium-oxide pellets in zirconium tubes :
  - Diameter : 9.5 mm
  - Length : 4.3 m
  - Heat rate : 350 – 400 W/cm
- Zirconium oxidizes relatively easy at high temperatures in a water / steam environment

The technical challenge – building the next generation of nuclear power reactors (II) :



Generation 4 reactors :

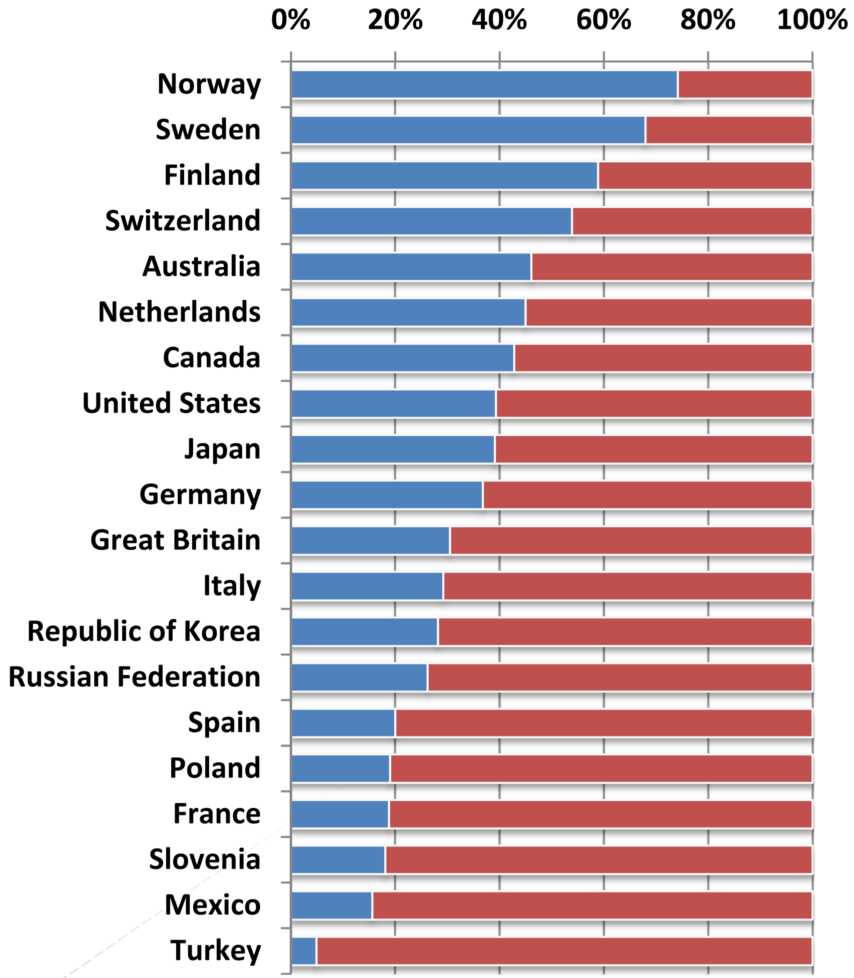
- No water or zirconium in the reactor core
- Non-pressurized primary systems (uses helium, molten salts, liquid metals etc. as primary coolant)
- Passive safety systems / inherent safe
- Higher thermal efficiency (target 50 %)
- Higher outlet temperature enabling production of hydrogen (used as a future energy carrier)
- Based on the Brayton-cycle (with a Rankine-cycle as a secondary cycle)
- Module-based (produced in a factory – not on-site)

The economic challenge – building new reactors :

Two nuclear power reactors - European Pressurized Reactors (EPRs) designed by Areva (France) – are currently under construction in Olkiluoto (Finland) and in Flamanville (France)

- **These EPRs are designed to deliver 1600 MW electric power to the grid**
- **The construction of the Olkiluoto-3 started in 2005 and the reactor was scheduled to connect to the grid in 2009**
  - **The expected start-up of Olkiluoto-3 is now in 2018**
  - **Initial budget was €3.7 billion, but expected costs are now €8.0 billion**
- **The construction at Flamanville will cost €10.0 billion (a cost overrun of €6.5 billion)**
- **Projects outside Europe does not seem to experience these problems to the same extent**

Other challenges …



The Trust Factor:
An Element of National Policy in NEA Member Countries

Respondents agreeing that :
"most people can be trusted"

Source:
Data from the 5th World Values Survey (2005 – 2008)

www.worldvaluessurvey.org

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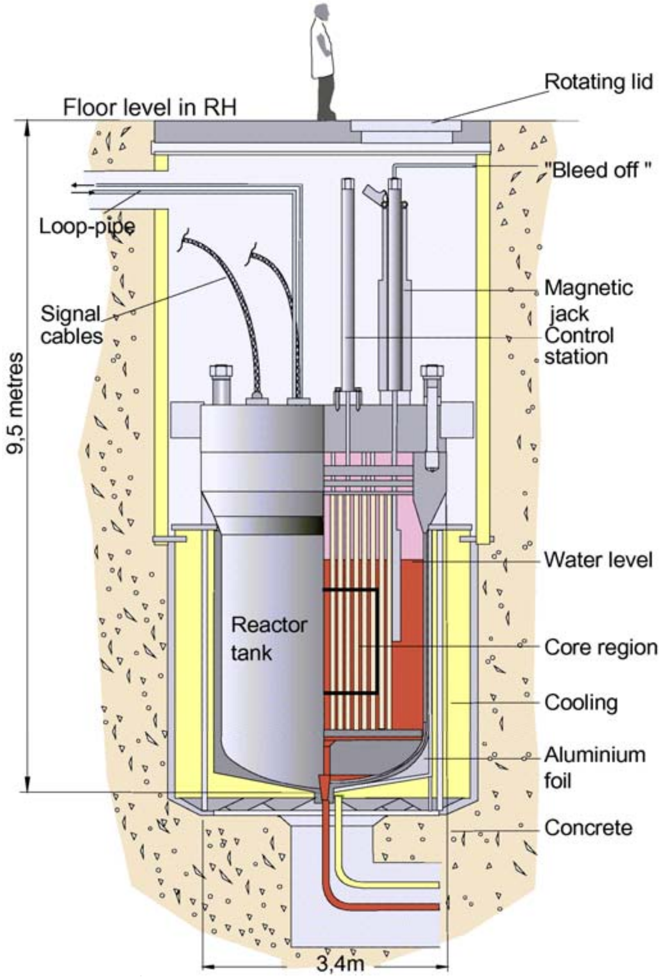

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Start of the OECD Halden Reactor Project

- 1950's: Norway needed more energy for industrial expansion than hydro power was able to supply
- A small nuclear power reactor – The Halden Boiling Water Reactor (HBWR) - was built to demonstrate energy supply (steam) to Saugbrugsforeningen (paper factory)

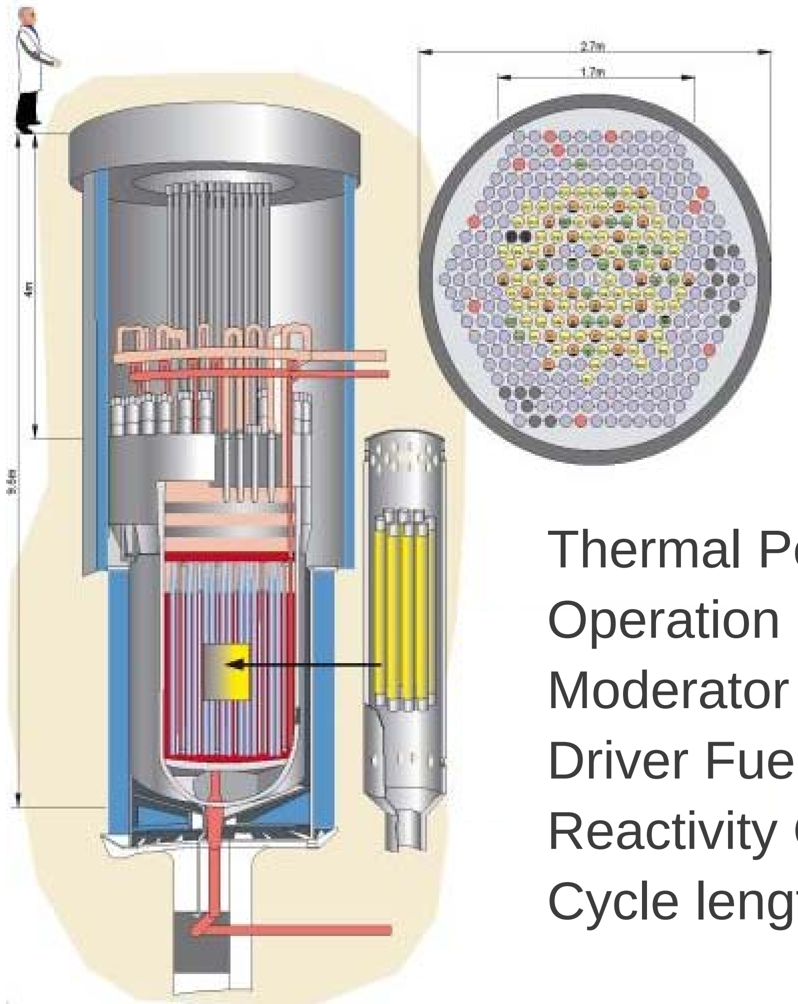
- HBWR was built during 1956 – 1959
- Norway proposed to the OECD to use HBWR for a common research project
- The Halden Agreement, establishing the OECD Halden Reactor Project, was signed 11 June 1958 by Norway and 10 other OECD countries

The OECD Halden Reactor Project

- **Norway: IFE** Inst. for Energy Technology
- **Belgium: SCK/CEN** Nuclear Research Centre
- *China*
  - ***SNERDI*** ***Shanghai Nuclear Engineering R&D Institute***
  - ***CNPRI China Nuclear Power Technology Research Inst.***
- **Czech Rep: UJV Rez** Nuclear Research Inst.
- **Denmark: DTU** Technical University
- **EU JRC: ITU** Transuranium Inst.
- **Finland: TYÖ** Ministry of Employment & Economy
- **France:**
  - **EDF** Electricity de France
  - **IRSN** Inst. for Radiological Protection
  - **CEA** Atomic and Alternative Energy Commission
- **Germany: GRS** Global Research for Safety
- **Hungary: MTA EK** Centre for Energy Research
- **Japan**
  - **NRA** Nuclear Regulation Authority
  - **JAEA** Atomic Energy Agency
  - **CRIEPI** Central Research Inst. of Electric Power Industry
  - **MNF** Mitsubishi Nuclear Fuel
- **Korea: KAERI** Atomic Energy Research Inst.
- ***Netherlands: NRG Nuclear Research & consultancy Group***
- **Russia: JSC TVEL** Fuel Company of ROSATOM
- **Slovakia: VUJE** Nuclear Power Plant Research Inst.
- **Spain: CIEMAT** Centre for Energy Environment and Technology
- **Sweden: SSM** Radiation Safety Authority
- **Switzerland: ENSI** Nuclear Safety Inspectorate
- **United Arab Emirates: FANR** Authority for Nuclear Regulation
- **UK: NNL** National Nuclear Laboratory
- **USA:**
  - **NRC** Nuclear Regulatory Commission
  - **GNF** Global Nuclear Fuel
  - **Westinghouse** Electric Company
  - **EPRI** Electric Power Research Inst.
  - **DOE** Department of Energy

Most countries have a consortium of organizations represented by a main Signatory to the Agreement

The Halden Boiling Water Reactor (HBWR)



Channels	: 329
Tot. No. of Assemblies	: 80 – 110
Driver Fuel	: 65 – 75
Test Assemblies	: 15 – 35

Thermal Power	: 20 MW
Operation Conditions	: 240^{o}C, 33.6 bar
Moderator / Cooling	: D_2O (14 m^3)
Driver Fuel	: UO_2 (500 – 600 kg)
Reactivity Control	: 30 Control Rods (Cd/Ag)
Cycle length	: 90 – 100 days

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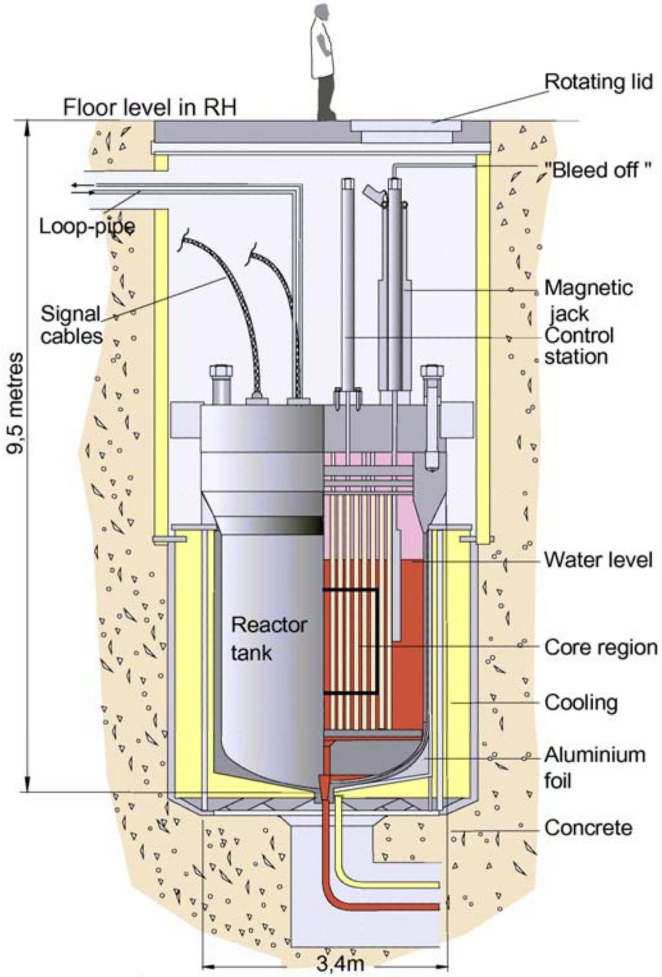

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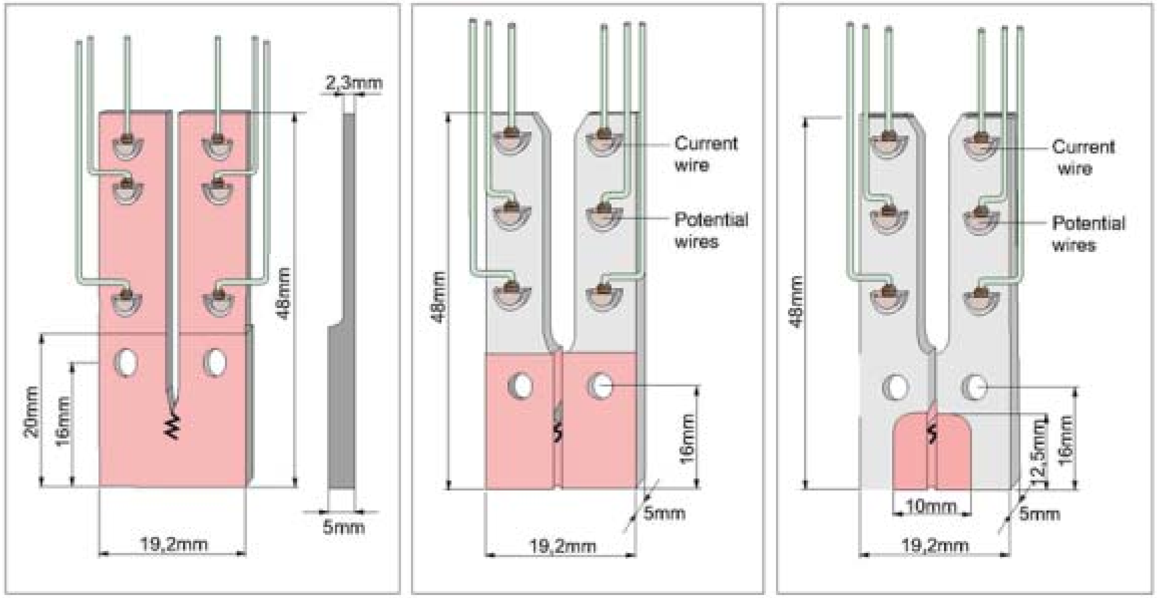
A selection of in-core test and measurements performed in the Halden Boiling Water Reactor

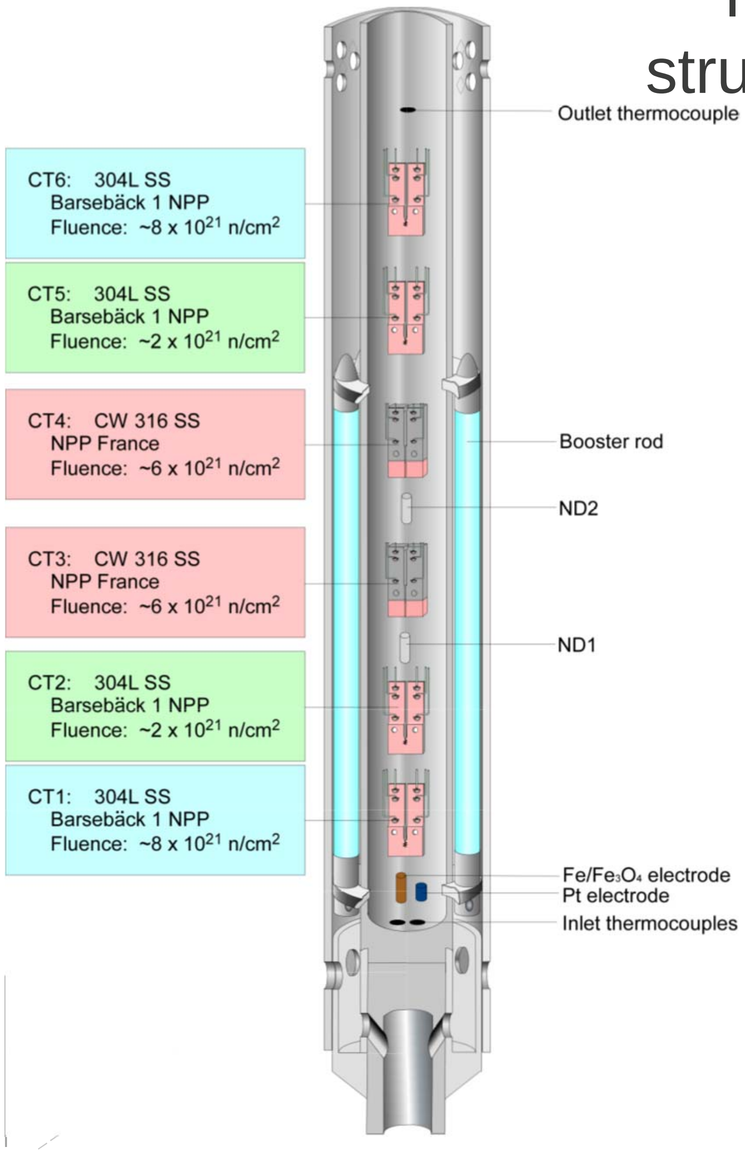
- ***Nuclear materials (the pressure vessel and internals) :***
  - Crack-growth in structural materials / stainless steels
  - Embrittlement
  - Corrosion fatigue
  - Creep and stress-relaxation
  - Others …
- ***Nuclear fuels :***
  - Thermal conductivity
  - Mechanical stability
  - Fission gas release
  - Cladding corrosion
  - Failed Fuel Accidents (Fuel Degradation)
  - Loss of Coolant Accidents
  - Others …

In-core crack-growth monitoring in structural materials / stainless steels (I)

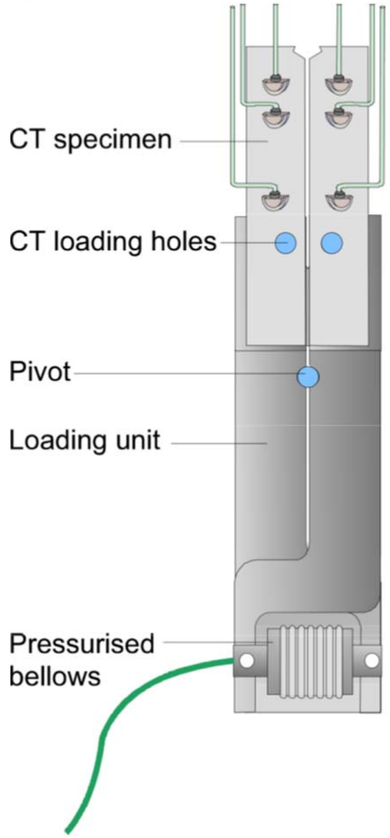


- **Irradiated material samples taken from commercial nuclear power plants**
- **Instrumented Compact Tension (CT) specimens made in a hot cell laboratory**
- **CT specimens installed in an irradiation rig and irradiated in the Halden Boiling Water Reactor**

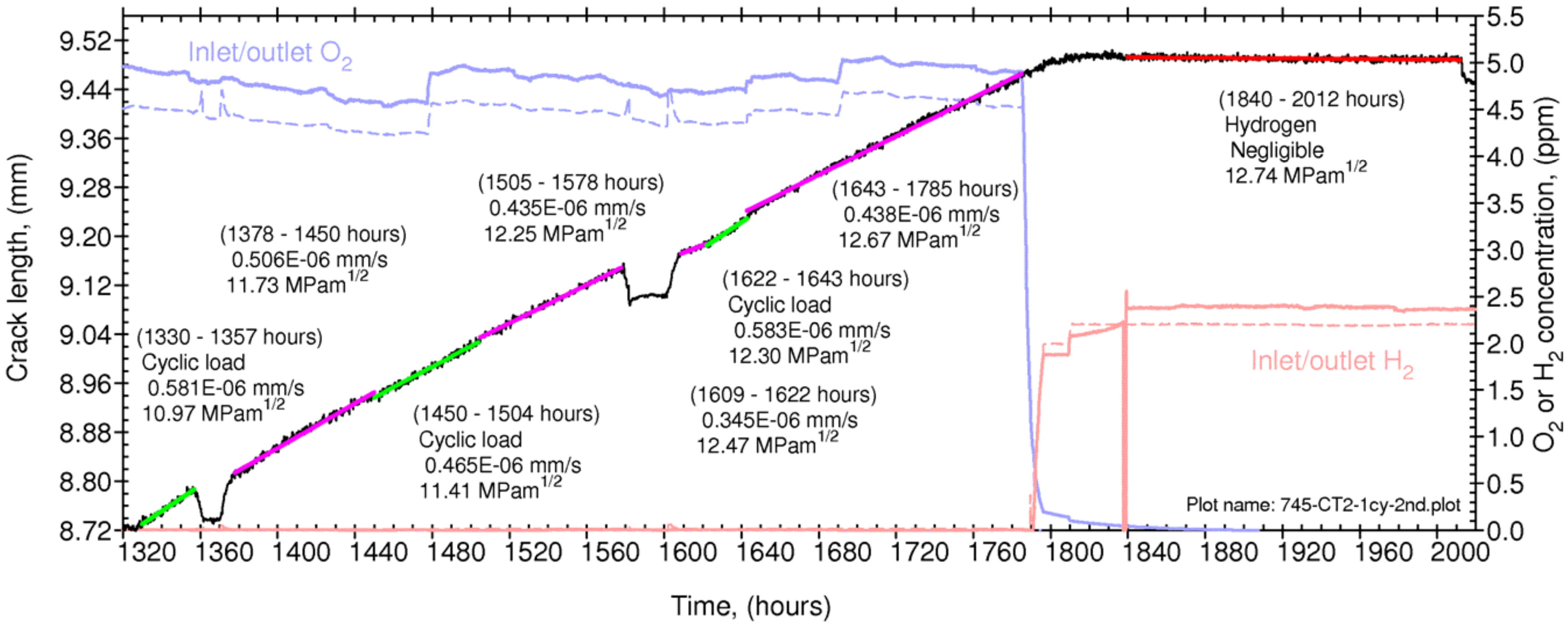
In-core crack-growth monitoring in structural materials / stainless steels (II)



- Develop understanding of key parameters affecting material behaviour
- Assess benefits of countermeasures
- On-line measurements of: load, dimensional change, cracking, water chemistry ....

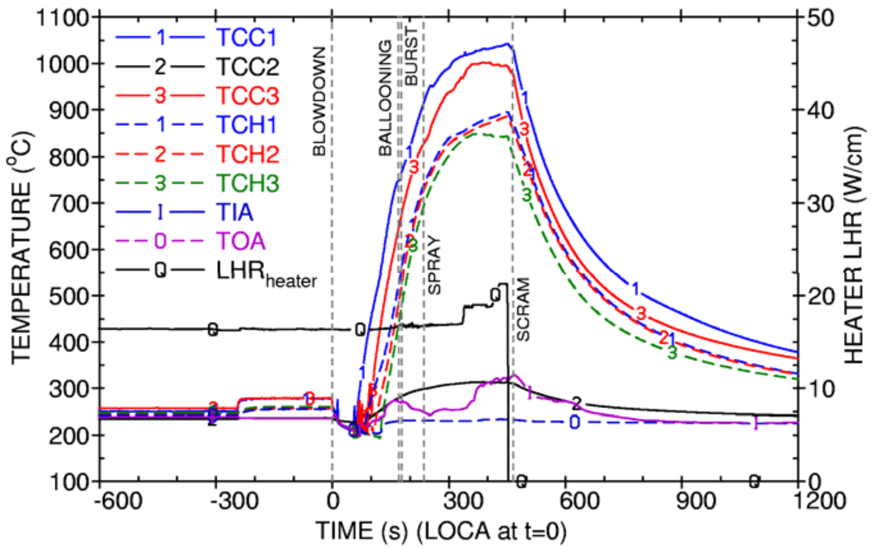


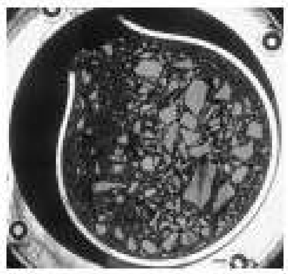
In-core crack-growth monitoring in structural materials / stainless steels (III)

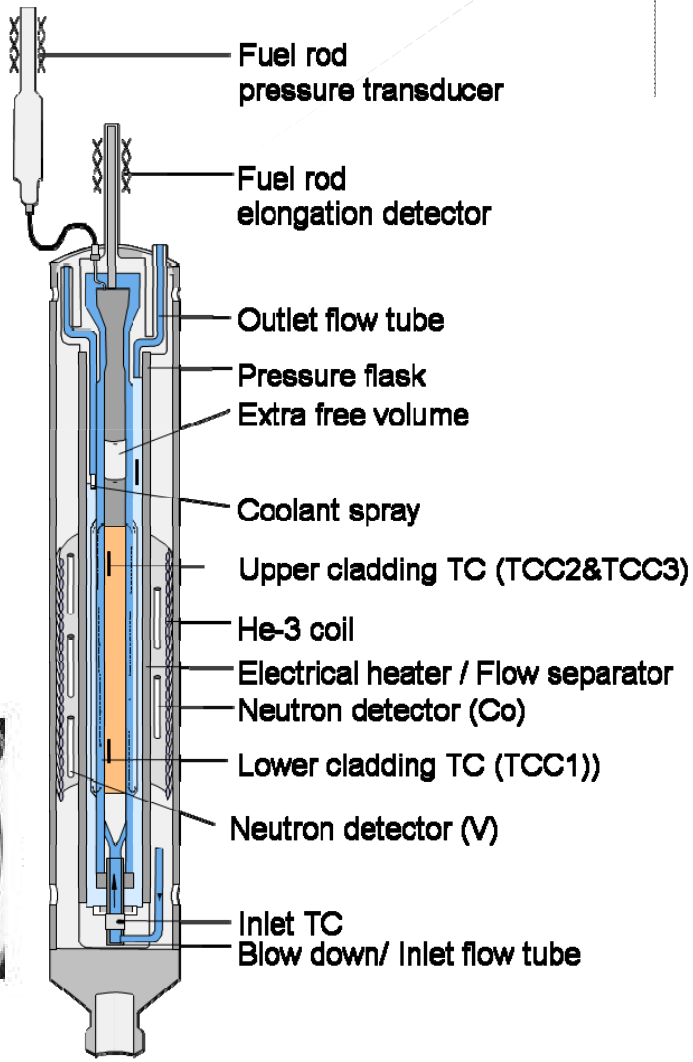


LOCA Testing - Assessing Safety Criteria

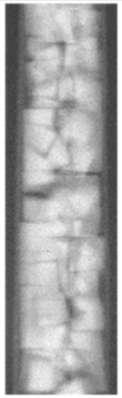
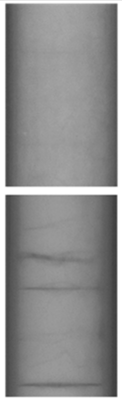
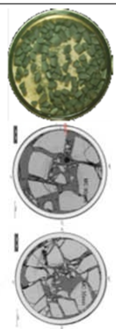
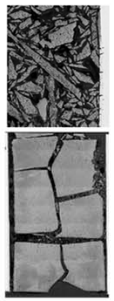
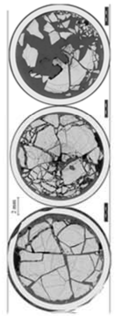
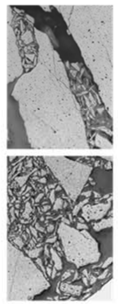
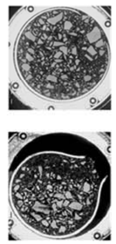
- Aimed at demonstrating performance of different fuels in accident situations
  - effect of fuel/clad burn-up on clad ballooning & burst, and fuel pulverisation, relocation and dispersal
  - effect of fuel relocation to balloon region on over-heating, oxidation, secondary hydriding







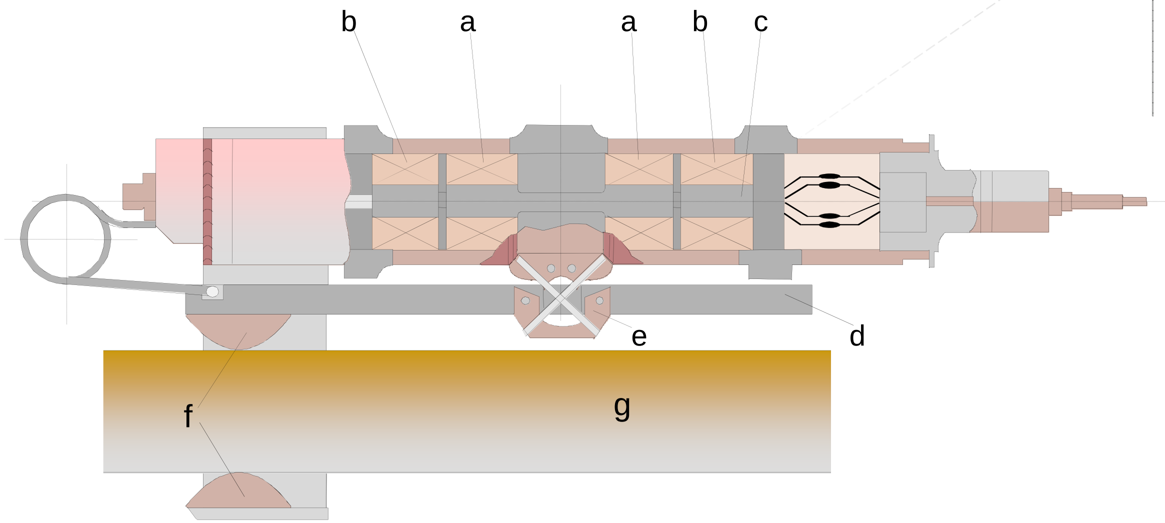
Making an overview from multiple tests: LOCA

test #	2	7	6	11	10	12	13	3	5	9	4
burnup, MWd/kg	0	44.3	55.5	56	60	72.3	74.1	81.9	83	90	92
balloon strain, %	54	23	49	25	15	40	45	8	15	61	62
radio-graphy											
ceramo-graphy							not yet available				
fragment size	coarse	coarse	coarse	coarse	coarse & some fine	coarse & fine	coarse (& fine?)	medium & fine	medium & fine	medium & fine	medium & fine

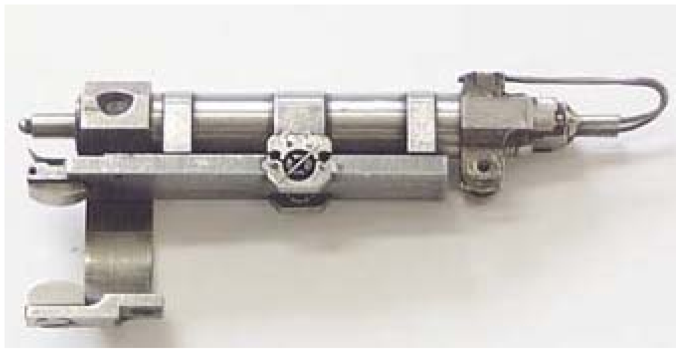
↖ ↗
VVER segments

Diameter Gauge

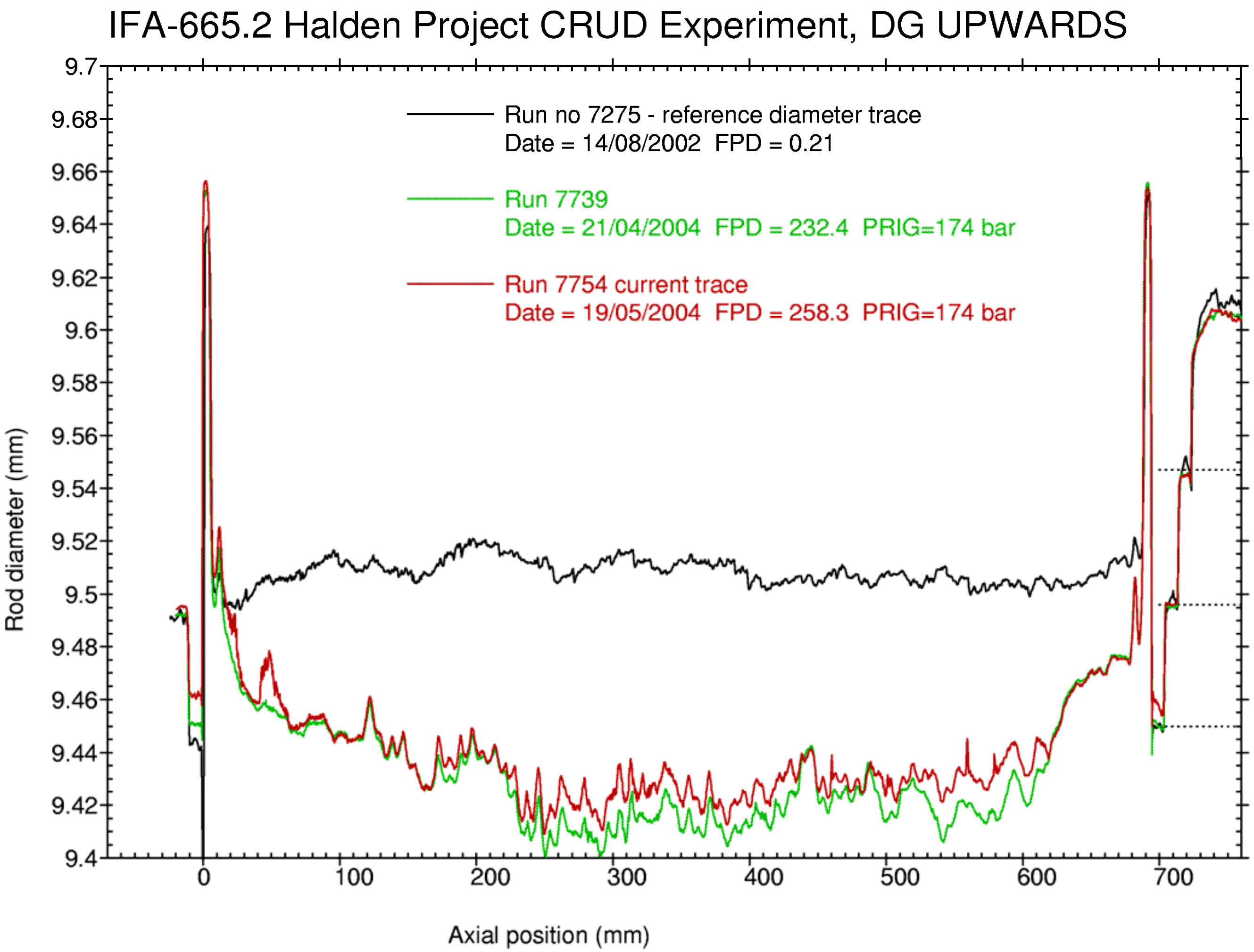
- Provides data on fuel rod diameter profile
- Instrument based on the LVDT principle
- Differential transformer with two feelers on opposite sides of the fuel rod.
- Diameter Gauge moved by hydraulic system while a position sensor senses the axial position along the rod
- Operating conditions: 165 bar, 325°C



a: Primary coil
b: Secondary coil
c: Ferritic bobbin
d: Ferritic armature
e: Cross spring suspension
f: Feelers
g: Fuel rod



On-line evidence for crud loading by use of DG measurement



Thank you for your attention !