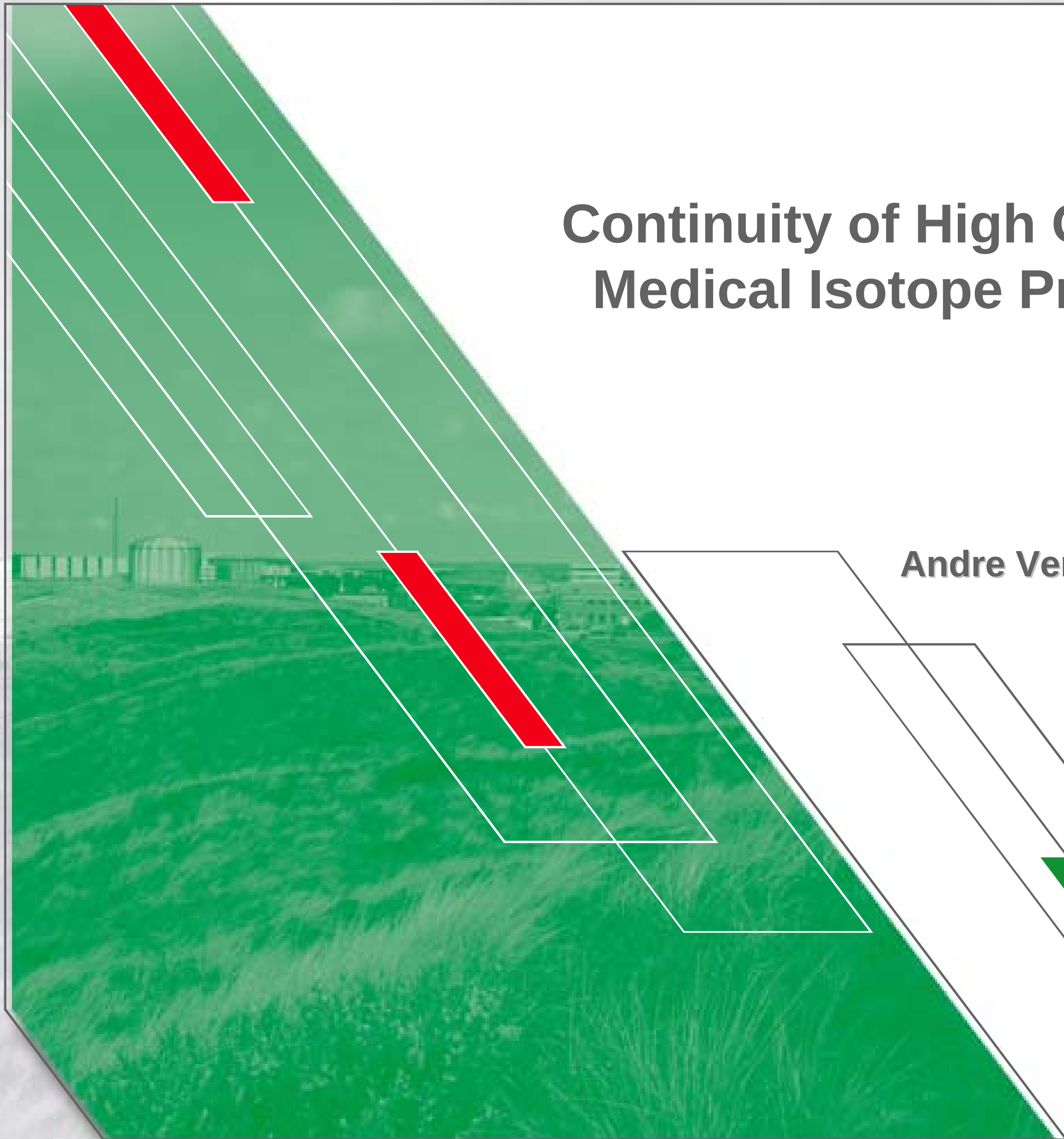

Continuity of High Quality Research & Medical Isotope Production in Petten

IGORR-12,
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2. Major Refurbishments and Upgrades
3. Status of Research and Isotope production
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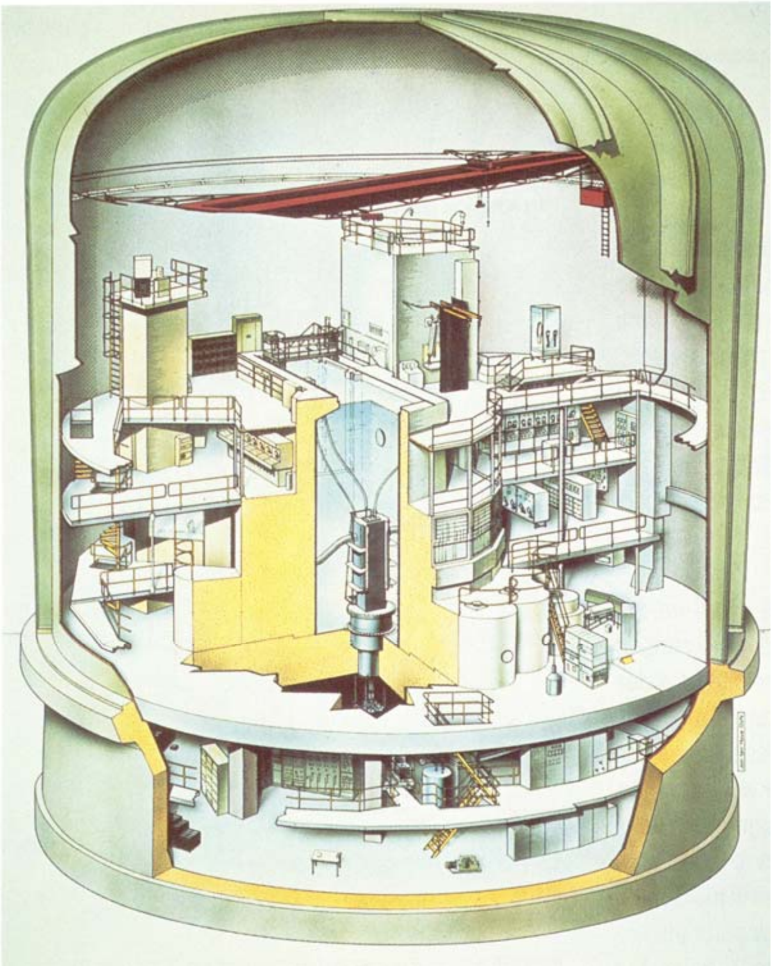
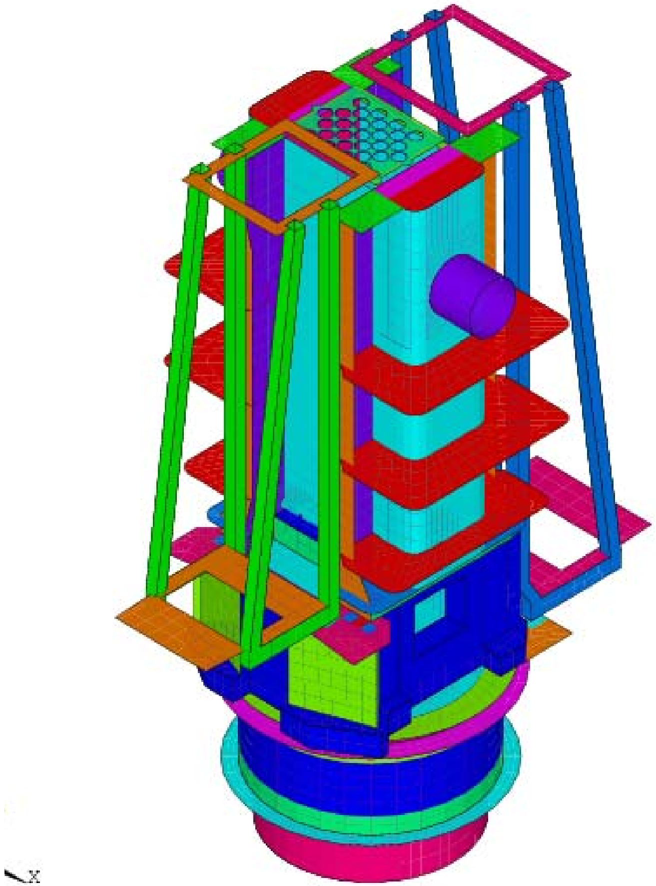
High Flux Reactor, Petten, The Netherlands



HFR power:	45 MWth
Availability:	> 285 FPD/year
Peak positions:	7 dpa/year
Mixed neutron spectrum	
Owner for a lease of 99 years: Joint Research Centre of the EU	
Operator: Nuclear Research and consultancy Group, NRG	
NRG: R&D Hot Cell Laboratory NRG: Isotope & J. Goedkoop Laboratory	
License holder: NRG, Petten	

REACTOR VESSEL UPGRADE

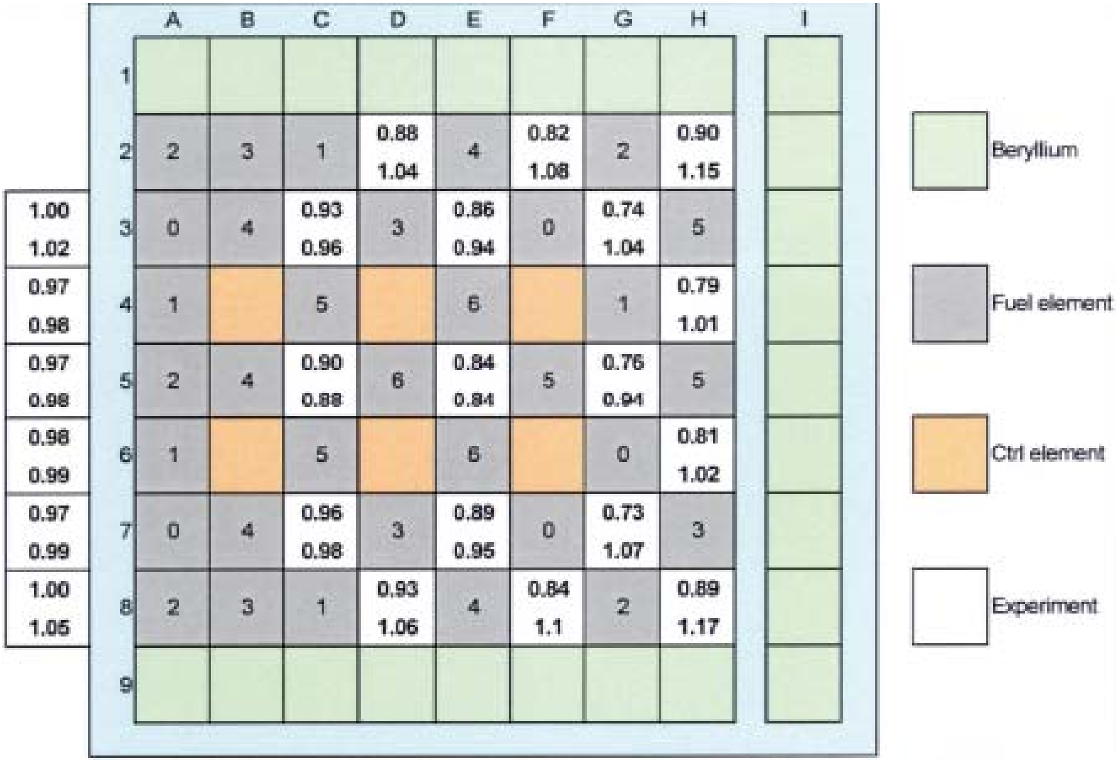


1974 – 1977: Feasibility study
1978: Decision to replace vessel
1980 – 1981: Design of reactor vessel with:
- 2 additional beam channels.
- one additional side facility

1981 – 1984: Manufacturing of components
January 1985: First criticality after vessel replacement

November 1983 – January 1985:
Shutdown period of HFR for replacement

HEU-LEU CONVERSION in HFR



PROCEDURE:

Decision: 1999

Design rules: 2003

Verification: 2001 - 2005

First element: October 2005

Final element: May 2006

LEU fuel:

U_3Si_2, density: 4.8 g.cm-3

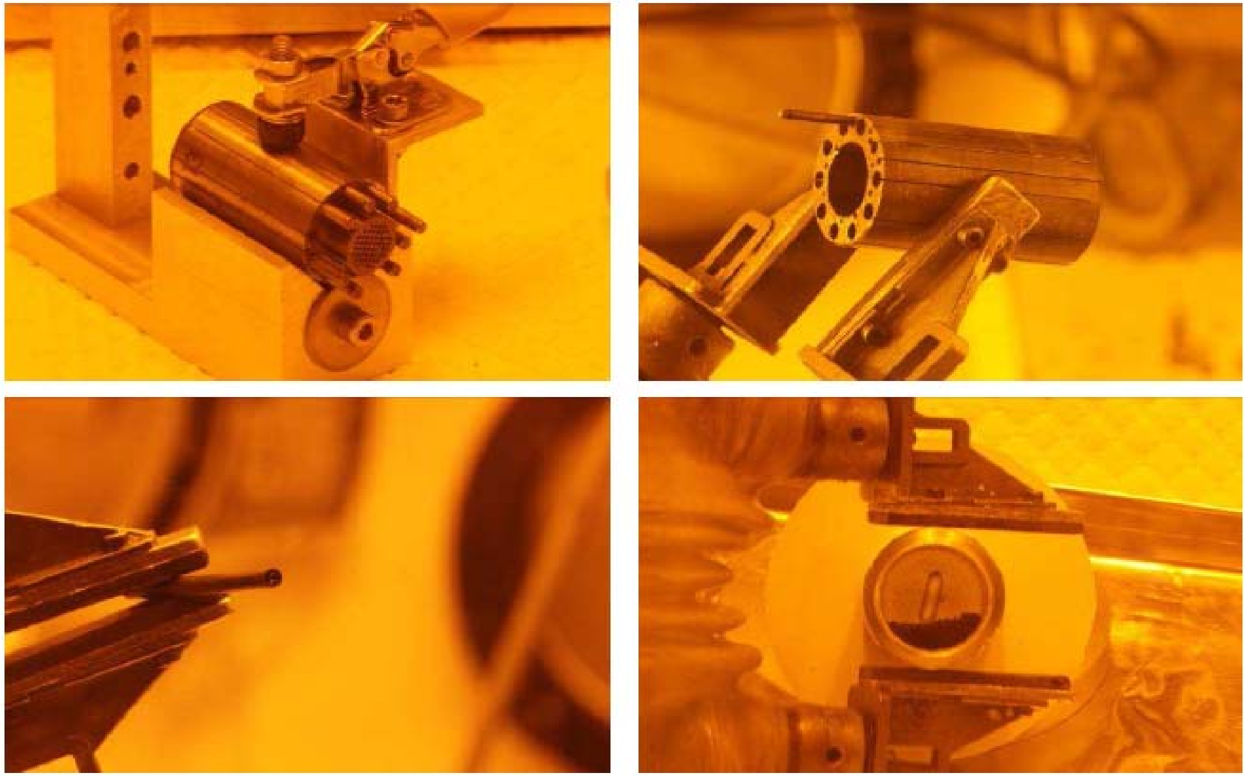
Top number == thermal flux ratio LEU/HEU

Lower number == fast flux ratio LEU/HEU

Lutetium Fabrication in the Laboratory

Location: Jaap Goedkoop Laboratory
Decision: 2004
Design & Construction: 2005-2007

NRG, PETTEN, HOT-CELL OPERATIONS



Dismantling and re-packing drums of the HIDOBE capsule with Be pebbles containers

PRESENT RESEARCH PROGRAM ISSUES

FISSION

- HTR structural materials: vessel steel en graphite.
- HTR functional materials: pebble and element development.
- LWR safety: pressure vessel toughness

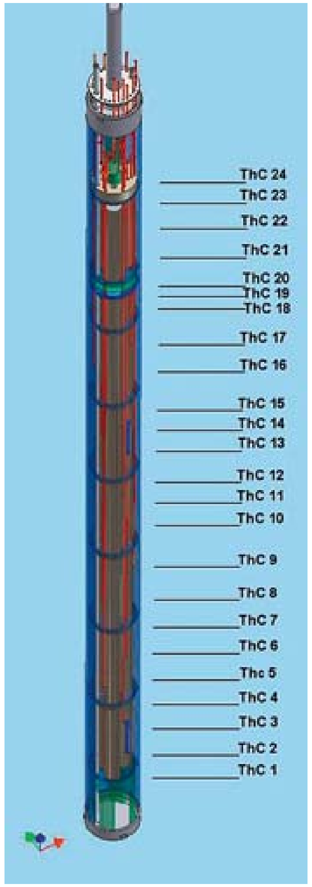
FUSION

- Structural materials: low activation steel, tungsten.
- Functional materials: lithium ceramics and lithum lead
- Component testing: divertor sections

NEUTRON BEAMS

- Neutron diffraction: weld stresses, small angle scattering.
- Boron Neutron Capture Therapy

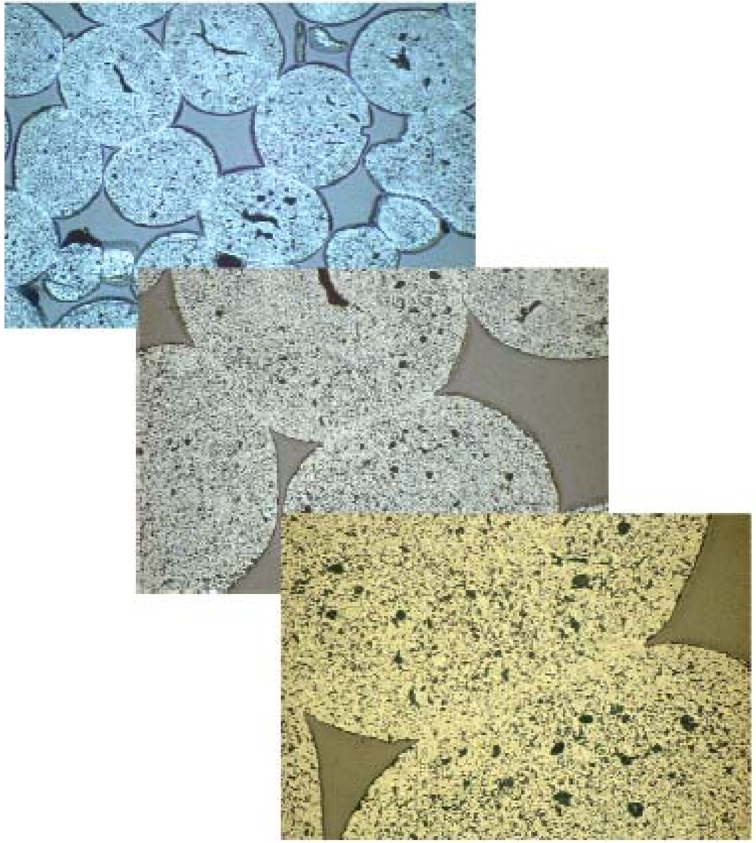
NRG participation in European Framework Project RAPHAEL for HTR's



First irradiation experiment: 750° C, 8 dpa.
with 160 specimens of 8 graphites from:
Germany, US and Japan
Reloaded in second irradiation rig up to 24 dpa.
Additional experiments at: 950° C, 8 dpa.
Reassembling for irradiation to 24 dpa.

Post irradiation testing in Petten includes:
- dimensions,
- elasticity,
- thermal expansion coefficient
- thermal diffusivity.

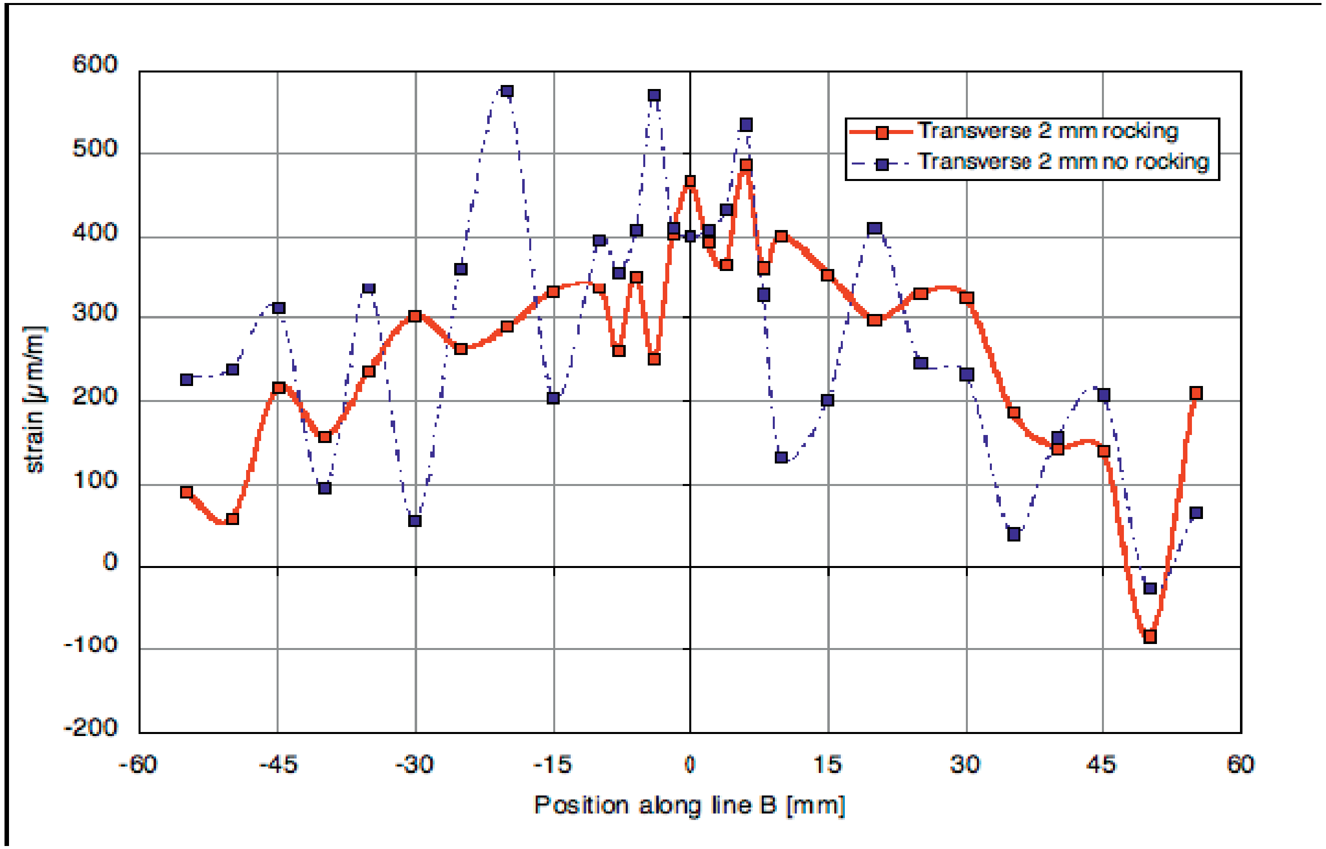
HOT CELL CERAMOGRAPHY OF SINTERING



ITER test blanket module relevant tests in HFR.

Titanate particles show sintering at 800 ^{o}C, particle size diameter about 1 mm,

HFR NEUTRON DIFFRACTION of WELD STRESS



Specimen "rocking" reduces scatter in data from a coarse grained weld in steel plate

Major Isotope Applications today

NRG

Isotope	Half time [d]	Application
Molybdeen-99/ Technetium-99m	2.75 0.25	Diagnosis heart-, kidney-, & lung-, diseases, and bone tumors
Jodium-131	8.04	Treatment Thyroid
Xenon-133	5.25	Diagnosis lung diseases
Strontium-89	50.5	Palliative use for bone cancer.
Iridium-192	73.8	Treatment of several cancers
Samarium-153	1.95	Palliative use now, wider use underway
Rhenium-186	3.78	Palliative use for bone cancer.
Jodium-125	60.1	Treatment prostate cancer
Yttrium-90	2.67	Treatment of artritis
Erbium-169	9.4	Treatment of artritis
Lutetium-177	6.71	Treatment of several cancers

Demands and Needs of Society & Economy in the 21st century

1.Strategic area Safety & Environment

- Safety is an important issue for existing generations of ageing nuclear reactors, many will operate beyond 2040.
- Environment profits from partitioning & transmutation research for remnant waste reduction

2. Strategic area Energy & Security of Supply

- Rising energy demand & Security of energy supply requires new power plant generations and fuel cycles.
- Research reactors check feasibility of thorium fuel cycles and tritium blanket technology.

3. Strategic area Healthcare.

- The ageing world population and the increasing wealth drive rising demands for existing diagnostic and therapeutic isotopes.
- Applications for new isotopes are in the pipeline for improved diagnoses and therapies.

Future Science & Engineering Programs

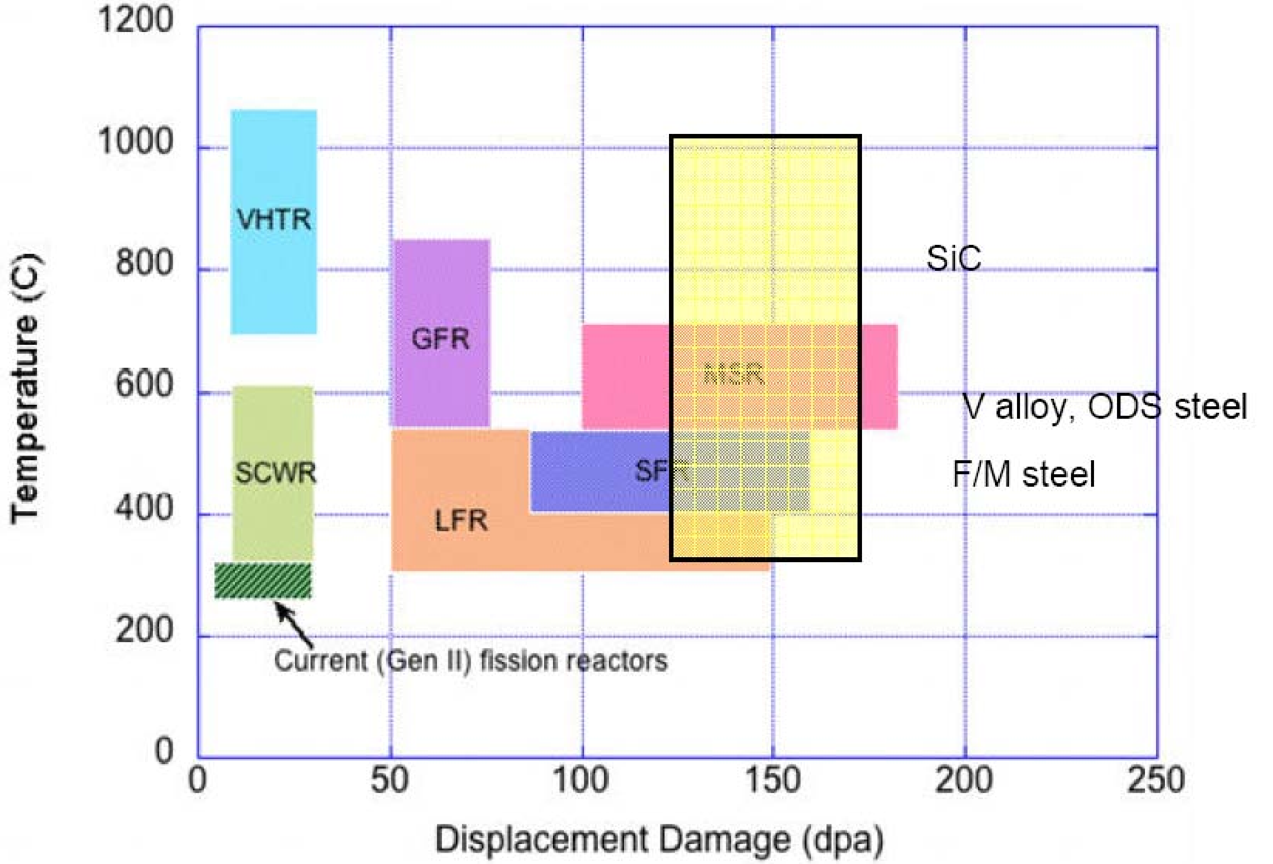
Fission

- Innovative fuels & cladding for high burn-up will be tested. GEN-4 reactors will benefit from the results.
- Lifespan increase of power plants to 60 years or more needs support of structural materials reactors tests.
- In-core structures of existing & innovative power plants will need increased life times.

Fusion

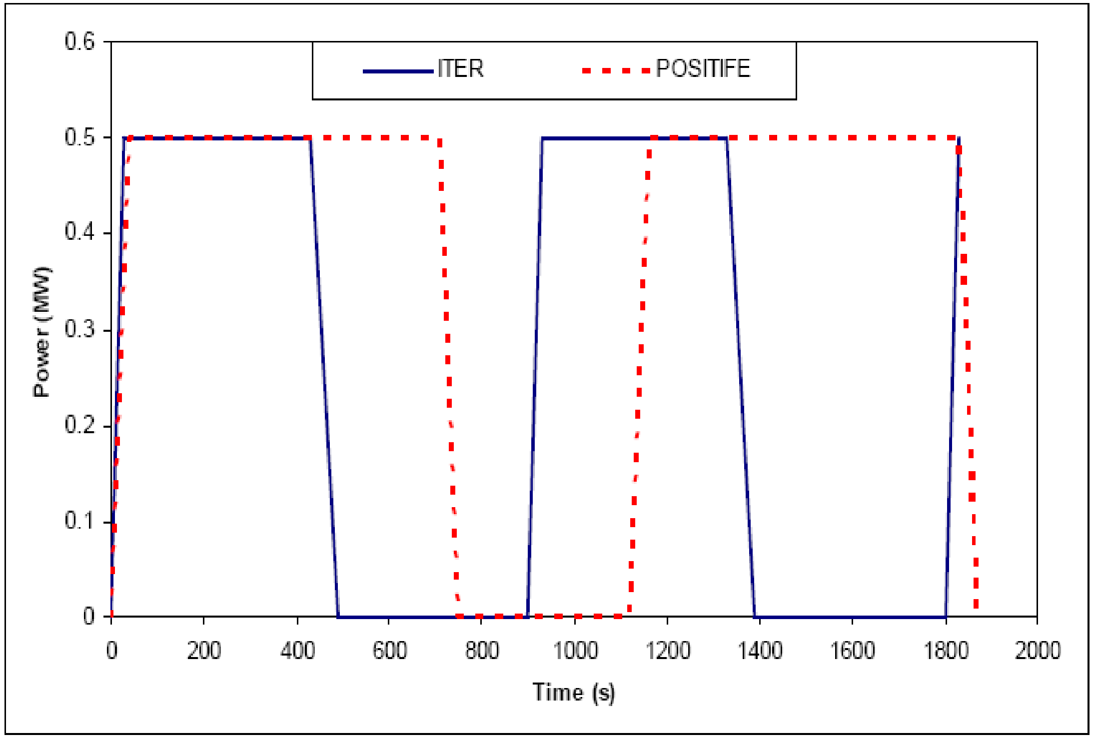
- PALLAS offers testing of ITER & DEMO tritium blanket breeding with liquid lithium-lead or lithium ceramic blankets that IFMIF cannot offer.
- Diverters encounter high, cyclic heat loads that can be simulated in PALLAS under neutron loads.
- Higher application temperatures point to oxide dispersion & nano-microstructured ferritic steel.

Application temperature and displacement damage windows for Materials Research



Fisson domain: Colored fields.
Fusion domain: Yellow box
[from Zinkle ORNL, Oak Ridge, US]

Plasma cycles ITER compared with design cycle times POSITIFE in HFR



Pre-design irradiation parameters **POSITIFE**

Fluence:
- (E>0.1 MeV 1024 n.m-2) 8.4
- (E>1 MeV 1024 n.m-2) 4.2

Neutron damage (dpa in Be): 1
Temperature: 200 ° C

ISOTOPES FUTURE

- Early detection of diseases such as cancer and dementia are essential to allow cost effective and efficacious therapy.
- Molecular imaging will allow to develop personalized medicine improving:

  - Diagnosis of the disease at the molecular level,

  - Determination of disease stage and prognosis,

  - Identification of therapy response and progression,

  - Delivery planning of targeted therapy.
- Molecular imaging is complementary to the anatomical information from diagnoses as CT, MRI and ultrasound.
- Isotope therapy provides in an analogous manner specifically targeted and fractionated doses of therapy.
- PALLAS will be essential for the development and deployment of medical breakthroughs in the next decades.

Overview of Research Reactors in 2035

Co-operation in the EU and the World

- CEA, GEN-4 & Fusion
- CRPP, Swiss, Generation-4
- ENEA, Italy, Fusion
- ESKOM, South-Africa, Generation-4
- FZJ, Germany, Fusion
- FZK, Germany, Generation-4
- JAEA, Japan, Generation-4, Fusion
- JRC-IE, EU, Generation-4
- KAERI, South-Korea, Generation-4
- KURCHATOV, Russian Federation, Fusion
- ORNL, Tennessee, US, Generation-4
- PNL, Washington, US, Fusion
- RID, Delft
- SCK, Belgium, Generation-4, Fusion

Pycasso collaboration for HTR coated particle layers from KAERI, CEA and JAEA in the HFR up to 1100 ^{o}C

PALLAS Design & Building

- Compact flexible core with a moveable Be - reflector
- Ample space for test rigs, loops, and isotope production.
- Power range 30 - 80 MW to optimize fuel & Be utilization.
- UMo fuel soon after qualification; before that: silicide.
- Peak thermal neutron flux: two to three times the HFR value.
  Peak fast neutron flux: near twice the HFR value.
- Tank-in-pool for reliable handling.
- Over 300 full power days in about 10 cycles per year to:
  - Increase the flow of scientific experiments,
  - Provide a regular supply of isotopes,
  - Less than 50 days for maintenance and inspection needed.
- The residual reactor heat to be used by enterprises as low temperature process heat in the community.

Comparison of research reactors in the EU

Reacteur Jules Horowitz:

- Spaceous component ramp tests facilities
- Ample in-core loop facilities
- Room for isotope back up

PALLAS:

- High density (medical) and bulk (silicon) isotopes.
- Structural & functional materials test rigs
- Sub size components & loops GEN–4 & Fusion

MYRRHA:

- Fast neutron & liquid metal coolant oriented

ILL and FRM-2

- Excellent neutron beams for the next decades.

Reacteur Jules Horowitz and PALLAS:

- No beams, because of ILL and FRM-2 excellency

CONCLUSION

1. With refurbishments and upgrades the HFR, Petten, plays a crucial role in R & D, and the supply chain of isotopes.
2. The Petten responsibility for the continuity in medical isotope supply are supported by projections for their demands.
3. The development of the Generation-4 reactors and fusion power plants are on the roadmap for research in the EU.
4. Fission research reactors are important for fusion until 2050, when dedicated fusion devices will start component testing.
5. Replacement of the HFR is necessary to comply with the new nuclear research programs, and isotope production.
6. The PALLAS tender process now underway, will lead to design and construction with first criticality in 2016.

PALLAS: Essential for a Sustainable Society

PALLAS continues to increase:

- the high quality research, and

- medical isotope production