Developments at the Interfaculty Reactor Institute

Adrian H.M. Verkooijen*

Introduction

The Interfaculty Reactor Institute is part of the Delft University of Technology. It is the only university institute in the Netherlands that operates a nuclear reactor. Therefore it is a central training and research facility for the Dutch universities and it has a national function for providing expertise in nuclear reactors, ionizing radiation and radionuclides to the academic community.

The institute operates a 2 MW pool type nuclear reactor with a maximum neutron flux of $1.5x10^{17}$ $m^{-2}s^{-1}$, a 3 MV pulsed electron accelerator, different positron sources and other experimental facilities for research with radio nuclides and radiation.

The reactor has been in operation for 35 years, with several upgrades during this period. Technically it is in a very good position and its technical life expectancy is at least another 10-15 years. Until 1998 the reactor used HEU as fuel but this is now converted to LEU.

To compensate for its average power and neutron flux the staff pais much attention to the development of smart instruments and experiments.

In 5 scientific departments an extensive research program is carried out:

- Radiochemistry
  - Instrumental neutron activation analysis of small and (very)large samples
  - Isotope applications in chemistry and process technology
  - Life and environmental sciences
  - Speciation of radioisotopes in bio-geochemical systems
- Reactor Physics
  - Nuclear reactor systems
  - Reactor physics
  - Defects in materials
  - Radiation and dosimetry
- Radiation chemistry
  - Radiation induced conduction in polymers and self-organizing molecule systems
  - Charge separation and energy dislocation in exited molecules
  - Radiation induced polymerization
- Radiation Physics
  - Neutron experimental techniques
  - Dynamics and structure of disordered systems
  - Properties of soft condensed matter
  - Characterization of catalysts by Mössbauer spectroscopy
- Radiation Technology

* Interfaculty Reactor Institute
Delft University of Technology
Mekelweg 15, 2629JB Delft
The Netherlands

Tel: ++31 15 278 6614
Fax: ++31 15 278 8430
E-mail: A.H.M.Verkooijen@IRI.TUDELFT.NL

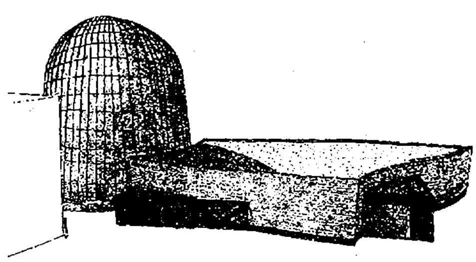
Development and characterization of new scintillation crystals
Smart silicium sensors with integrated electronics
Silicium micro gap - gas amplified sensors

For a part of this research partners take the initiative. Sometimes partners come from other faculties of Delft University of Technology sometimes from other (Dutch) universities. The institute contributes its unique knowledge and its facilities. For another part the institute develops and operates its own research program. This program is mainly aimed at increasing our knowledge, developing new instrumental techniques and instruments. Gradually it is shifting from fundamental towards more applied research. The applications are mainly in the fields of materials science, environment and biology, sensors and instrumentation, energy and sustainable production technologies.

New developments

On January 1st 1997 the institute obtained a new licence under the Nuclear Energy Law. The main purpose for obtaining this new licence was to change from HEU to LEU as a fuel and to be able to build a new beam hall.
The licensing process was, as usual, a tedious one. More than 5 years ago it started with a safety report of all the changes that were envisaged. This was followed by a Environmental Impact Statement. Then the responsible ministry could start to draw up a concept licence. This was subject of public hearing. Objections of several different natures were brought forward and changes were made to the final licence. This licence was officially granted to the institute. Once more this was made public and objections were raised, now with the Supreme State Council. Until now these objections were not of such a nature that the use of the licence was prevented. Therefore we started with the conversion process. The new LEU was shipped in caskets that also needed a new licence, now from the French, Belgian and Dutch government. In November last year the new elements were received. During a period of 4 years the total inventory of our core will be changed from HEU to LEU.
On the first of April the first two elements were introduced in the reactor. At the same time the core was compacted. Fig. 1 and Fig. 2 give the details about the conversion and compaction. Measurements showed that the flux was slightly increased at all positions except at the new elements. The flux distribution of the new core was much more even as compared to the previous one.

New beam hall



In July 1997 the construction started for a new beam hall. The dimensions are approximately 32 x 20 m. In this building existing instruments will be positioned along with a number of new instruments that are currently being developed. Fig.3.

Positron Instruments
- 2 dimensional angular correlation of annihilation radiation
- Positron microanalysis

Neutron instruments:
- Neutron depolarisation
- Neutron depth profiling
- Neutron diffraction
- Spin echo small angle scattering

Positron Instruments.

The positron instruments are in the first place connected with a newly developed intense positron source, which is connected to the reactor. This unique source relies on positron generation by pair formation in tungsten and copper cylinders with a large emitting surface area, ~ 2000 cm^2. Details of this project are given in [1]. The copper cylinders were covered with a thin sheath of annealed tungsten foil. This tungsten allows the moderation and emission of positrons even under bad vacuum conditions. The positrons are electrostatically extracted and further transported through a magnetic beam tube. Fig. 4. At 2 MW reactor power the intensity of the positron bundle was 0,7 x $10^8 e^+ s^{-1}$. The profile of the positron beam at 3 m distance from the reactor was gaussian with a diameter of 10 mm. Given the limitations of this system we expect an upper limit for the beam intensity of $10^9 e^+ s^{-1}$. The beam is fed to the two instruments through a tube system with a solenoid field of 10^{-2} T. In this field the positrons follow a helical path.
The micro-beam facility consists of a remoderation section coupled with a converted Scanning Electron Microscope (Philips 535-M). Fig. 5. In the remoderation section the brightness of the positron beam is enhanced by a factor of 50 however at a loss of 80% of the beam intensity. This is achieved by focussing the primary 5 keV beam on a tungsten moderator foil with a thickness of 100 nm. The thermalised positrons leave the foil at the opposite side and are accelerated again and focussed on a second foil. This process is repeated a third time. The resulting beam has a width of 800 nm and can be fed to the SEM. The remoderator has been designed to deliver positrons with a variable energy in the range of zero till 25 keV.

Neutron Instruments.

As an application of Larmor precession we are developing a method in which spin echo was used to determine small angle scattering of a sample. The sample is located between two precession coils with inclined front and end faces. The precession induced by the two coils are of opposite sign and should cancel each other. A scatter in the sample between the two coils changes the resulting polarisation. The polarisation is measured as a function with the field in the coils, which is a measure for the correlation length in the sample. Fig. 6. This method promises to be very powerful: at very short measuring times correlation lengths between 6 and 600 nm.[2]

R&D plans

During the past year new plans for future R&D have been initiated. The development started with a self-assessment of the quality of our R&D. First we developed a yardstick for measuring the quality of our research. Then the current program and the plans for the future were explicitly formulated. Future investments and major staff mutations were identified. After that the scientific productivity by volume and by impact was measured. The yardstick and these data together allowed us to determine ourselves the scientific significance of our work and our plans. In a next step the Royal Dutch Academy of Sciences installed a panel of internationally recognised experts. They made the assessment using the results of this self-assessment, a bibliometrical analysis and a site visit. The verdict covered four aspects for the quality of the institute: scientific quality, productivity, significance and viability. The outcome has a value for its own. All research programs were rated at least of satisfactory quality, while a significant number of the programs were very good to outstanding. Of more importance is the use of the results for designing a long-term perspective for the institute. We used them as an important input for the development of a new strategy. The most important aspects of this strategy are: focus the research on a smaller number of topics, increase the number of staff in a program, stimulate the co-operation between different groups of the institute in particular in areas where we can contribute to the development of new technologies that will make an impact. We also want to contribute to the development of new instruments for the next generation sources of neutrons, positrons and other radiation. So also co-operation with other international groups will be stimulated.

Litterature:

1 A. van Veen, F. Labohm, H. Schut, J. de Roode, T. Heijenga, P.E. Mijnarends, Appl.Surf.Sci., 116 (1997) 39.

2 M. Th. Rekveld, Nuclear instruments and methods in physics research B, 114 (1996) 366-370

A1 Be	B1 Be	C1	D1 Be	E1	F1 Be
A2 HEU 0.44 1.64	B2 HEU 0.60 2.39	C2 HEU 0.68 2.94	D2 HEU 0.70 3.95	E2 HEU 0.59 3.04	F2 HEU 0.48 1.87
A3 Be	B3 HEU 0.78 3.41	C3 HEU 0.87 2.15	D3 HEU 0.88 5.70	E3 HEU 0.76 2.90	F3 HEU 0.59 2.80
A4 Be	B4 HEU 0.86 4.73	C4 HEU 0.97 5.60	D4 HEU 1.00 6.61	E4 HEU 0.87 5.22	F4 HEU 0.68 3.30
A5 Be	B5 HEU 0.80 3.24	C5 HEU 0.90 2.59	D5 HEU 0.94 5.84	E5 HEU 0.80 2.96	F5 HEU 0.63 2.96
A6 HEU 0.52 1.79	B6 HEU 0.70 2.82	C6 HEU 0.80 3.22	D6 HEU 0.80 4.07	E6 HEU 0.70 3.46	F6 HEU 0.57 2.21
A7 Be	B7 Be	C7 HEU 0.60 2.21	D7 HEU 0.60 2.37	E7 HEU 0.55 2.01	F7 Be

CORE 97-03

Legend

Standard Fuel Element

F3 HEU 0.59 2.80

- **GRID POSITION** - HEU- OR LEU-TYPE
- THERMAL FLUX DENSITY (NORMALIZED)
- FRACTIONAL POWER PRODUCTION [%]

Control Fuel Element

C3 HEU 0.87 2.15

- **GRID POSITION** - HEU- OR LEU-TYPE
- THERMAL FLUX DENSITY (NORMALIZED)
- FRACTIONAL POWER PRODUCTION [%]

Reflector Element

B7 Be

- **GRID POSITION** - BERYLLIUM TYPE

Flux values normalized to position D4,
$\Phi_{th} = 2.3 \cdot 10^{17}\ m^{-2}.s^{-1}$ at 2 MW # 1.00

Power and flux distributions are for the xenon-free state

Maxima in axial direction of radially averaged flux densities per fuel element,

Fig. 1 Radial power and thermal flux density distributions for the last full HEU core of the HOR

A1 Be	B1	C1 Be	D1 Be	E1	F1 Be
A2 Be	B2 HEU 0.67 2.98	C2 HEU 0.77 3.63	D2 HEU 0.78 4.20	E2 HEU 0.71 3.62	F2 Be
A3 Be	B3 HEU 0.84 3.86	C3 HEU 0.98 2.29	D3 HEU 0.97 5.91	E3 HEU 0.84 3.05	F3 LEU 0.46 5.24
A4 Be	B4 HEU 0.86 4.54	C4 HEU 0.98 5.71	D4 HEU 1.00 6.20	E4 HEU 0.97 5.27	F4 HEU 0.74 3.42
A5 Be	B5 HEU 0.86 3.34	C5 HEU 0.98 2.67	D5 HEU 0.95 5.41	E5 HEU 0.90 3.18	F5 LEU 0.51 5.78
A6 Be	B6 HEU 0.73 2.74	C6 HEU 0.83 3.48	D6 HEU 0.81 3.91	E6 HEU 0.83 3.46	F6 Be
A7 Be	B7 Be	C7 HEU 0.57 2.08	D7 HEU 0.55 2.13	E7 HEU 0.52 2.00	F7 Be

CORE 98-01

Legend

F3 LEU 0.46 5.24

Standard Fuel Element
- GRID POSITION - HEU- OR LEU-TYPE
- THERMAL FLUX DENSITY (NORMALIZED)
- FRACTIONAL POWER PRODUCTION [%]

C3 HEU 0.98 2.29

Control Fuel Element
- GRID POSITION - HEU- OR LEU-TYPE
- THERMAL FLUX DENSITY (NORMALIZED)
- FRACTIONAL POWER PRODUCTION [%]

B7 Be

Reflector Element
- GRID POSITION - BERYLLIUM TYPE

Flux values normalized to position D4, $\Phi_n = 2.4 \cdot 10^{17}\ m^{-2}.s^{-1}$ at 2 MW # 1.00

Power and flux distributions are for the xenon-free state

Maxima in axial direction of radially averaged flux densities per fuel element,

Fig. 2 Radial power and thermal flux density distributions for the first mixed HEU/LEU core of the HOR

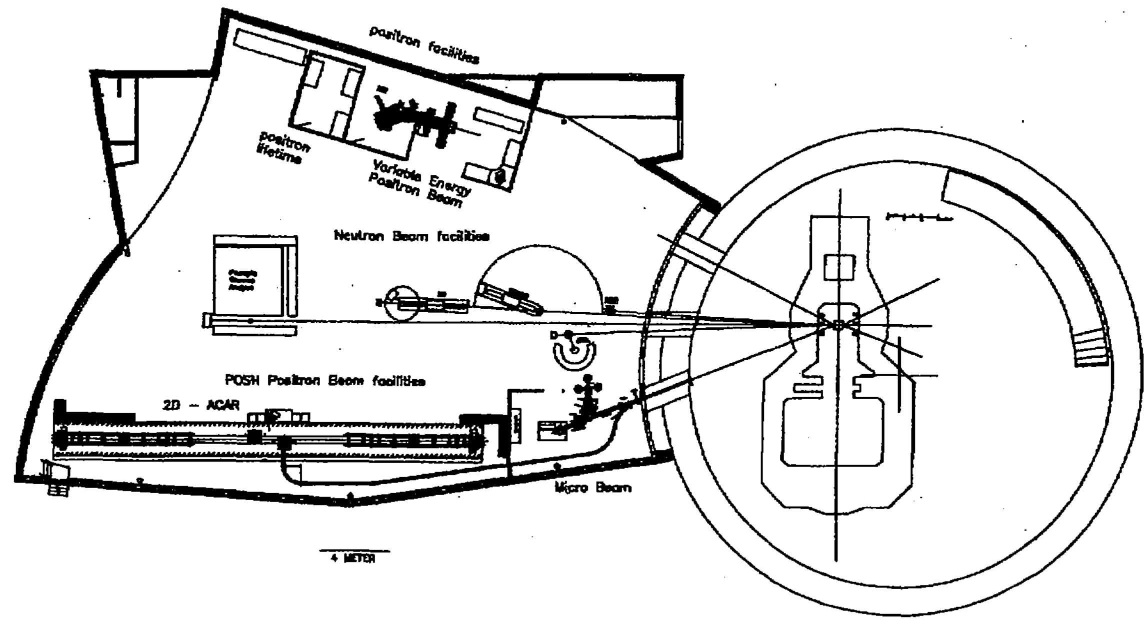


Fig.3
Layout of the instruments in the new beam hall.

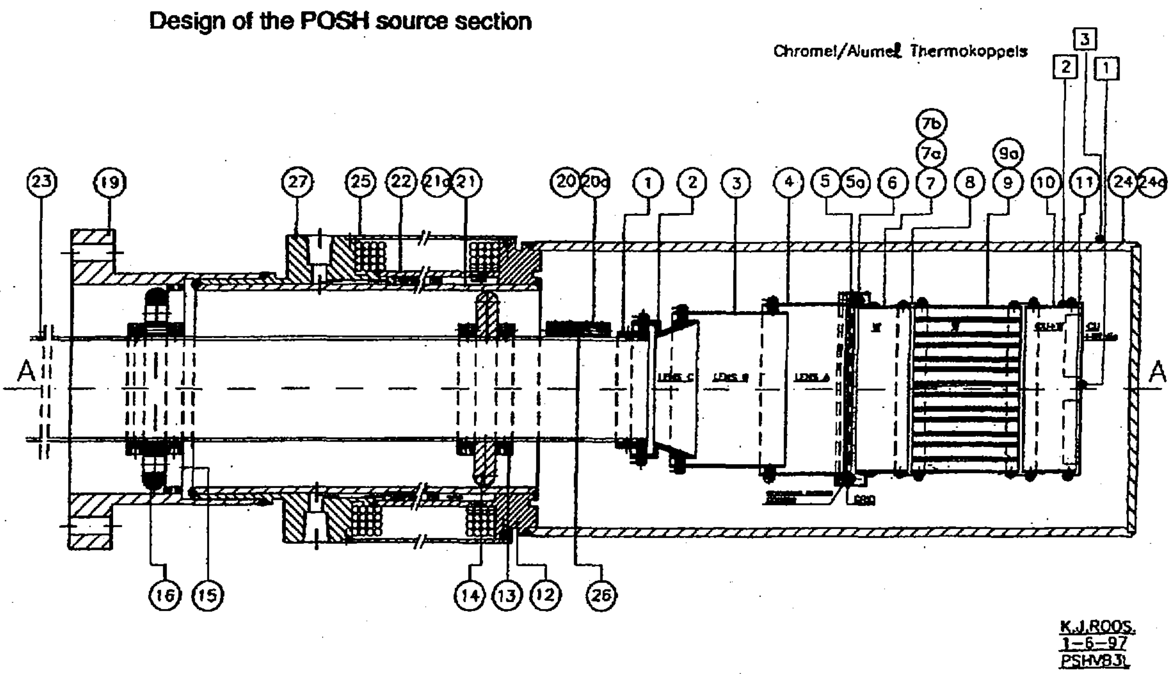


Fig. 4
Reactor coupled positron source.

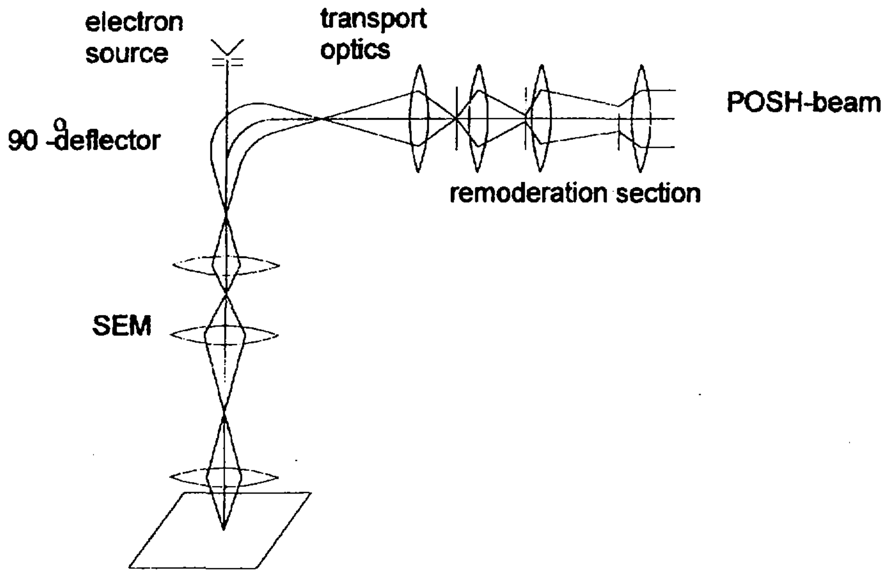


Fig. 5.
Set-up of the positron microanalysis facility.

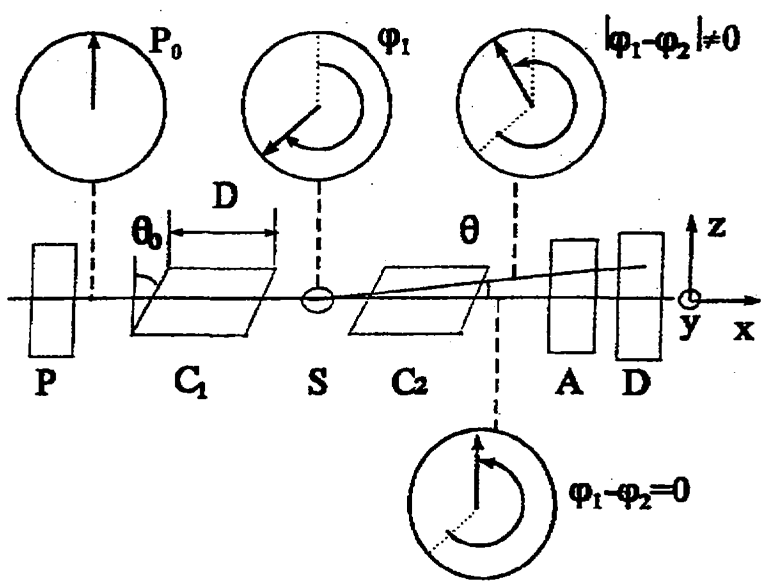


Fig. 6
SESANS Instrument. C_1 and C_2 are precession coils which compensate each other completely for unscattered neutrons. P is polariser, A is analyser.