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**Research Reactors - Dutch dream of new HFR.**
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*A new research reactor envisaged for the Netherlands, Pallas, will have the capacity to be the world's largest producer of medical isotopes.*

In the European Union, the first generation of research reactors is inevitably approaching operational retirement. Maintenance costs are increasing and continuity of operations is compromised by the aging of materials and components. The High Flux Reactor (HFR) in Petten, The Netherlands, is one such reactor. Nuclear Research and Consultancy Group (NRG), the current license holder and operator of the HFR, therefore plans to build a new research reactor called Pallas, named after the Greek goddess of wisdom, science and engineering. This will be a state-of-the-art reactor equipped to meet the growing world demand for both nuclear knowledge and services and the production of essential medical isotopes.
The tender process for Pallas began in 2007 and will continue through 2010-2011, following the EU rules for competitive tendering of complex, one-off design and construction projects. NRG is currently still actively pursuing the acquisition of funding (public and private) for the project.

**Introduction**
The middle decade of the 20th century saw the start of the design and building of a large fleet of research reactors. In the EU the first generation of the larger types of research reactors is now being phased out after operational lives of 40 years and more. Maintenance costs are increasing and continuity of operation is compromised by the aging of materials and components.
The HFR in Petten, one of this generation of reactors, was built in the 1950s and began full operation in 1961. A recent shut down for repairs of the long-term corrosion of primary cooling water systems at the 45MW water underlines how it is ageing. These issues, together with economic considerations, left NRG with the choice of either undertaking a second vessel replacement (the first vessel was replaced in 1984) or building a new reactor.

In 2004 NRG took the initiative to start working on the design and construction of a new nuclear reactor: Pallas, at the European Institute of Energy's site in Petten. This reactor is not only intended to function as a centre of research (material testing, development of nuclear fuels and components etc.) but also as a workhorse for the pharmaceutical sector (in particular medical isotopes, especially Mo-99).
The requirements for Pallas are derived from three main strategies:

- Healthcare for the world population, which is increasing both in age and standard of living, stimulating increasing demand for existing isotope diagnostics and therapies, and development of new isotope-based treatments
- Protection of safety and the environment in relation to nuclear energy generation, with existing nuclear power reactors and the partitioning and transmutation research to reduce remnant waste
- Energy and security of supply to satisfy rising energy demand with even more effective power plants and fuel cycles, such as the thorium fission cycle and tritium generation technology for fusion reactors.

The main feature of Pallas is its operational flexibility. The core so flexible that it can react immediately to the fluctuating demand for research and isotopes. For example, global isotope production capacity is extremely limited, so reactors must have the capacity to take over the production of medical isotopes from each other very quickly if unexpected maintenance is required or malfunctions occur. Other key elements in the design of Pallas are safety, reliability and efficiency of operation.

The design envisages a tank in pool design (like the HFR) with a flexible reactor core. To allow production capacity increases and reductions according to market demand, fuel assemblies and reflectors in the reactor core can be reconfigured and shuffled. As a result, the reactor can operate over a power range from 30 to 80 MW. The core and reflector design would always allow ample space for isotope production, in positions less attractive for most experiments. This design provides a baseline isotope production for the reactor. Depending on market demand, total isotope production could range up to several times current HFR output.

The planned Pallas primary system includes the core with control elements, experiments and isotope capsules, primary piping and pumps, filters, water conditioning, and heat exchangers. A secondary system would use pumps to draw in and expel cooling water, and a heat exchanger to deliver remnant heat to clients. Pallas will not have beam tubes, since Munich, Germany's FRM-2 and Grenoble, France's RHF reactor already provide neutron beams. Otherwise, the basic design has not been set, and depends on specific tenders.

The driving fuel assemblies will contain low-enriched (less than 20% fissile uranium) uranium silicide in the early years of operation. Later, as soon as it has been qualified, low-enriched uranium molybdenum, UMo, fuel will be used. UMo has more attractive properties in the core and in the re-processing phase. The core design allows the use of either HEU or LEU targets for the production of Mo-99 isotopes for Tc-99m supply. Further major requirement details are given in (3).

**The construction tender**

The tender procedure originally began in 2007 with a qualification process. Three consortia were qualified: AREVA Ballast Nedam, KAERI-KOPEC-DOOSAN and INVAP-ISOLUX. Following this step, there was a dialogue and consultation phase comprising sessions of several days during which each potential tenderer provided additional information and asked more than 400 formal questions. Only one major requirement had to be adjusted; the fast neutron flux specification had to be reduced by about 30% in order to keep sufficient flexibility in reactor operation.

The tender procedure allowed NRG to produce final employer requirements in summer 2008. The accompanying criteria for granting the tender concentrated on licensability of the design, treatment of safety and health physics aspects, production capacity and quality, investment costs, and cost of operation. After the draft contract was completed in agreement with all parties, NRG received the tenders in May 2009.

In summer 2009 NRG analysed the valid tenders. It was clear that the technical requirements could be met, though the solutions were very different. NRG selected the most economically advantageous tender. However, the contract could not be granted because, in the meantime, the requirements for financing of the reactor design and build changed, affecting the timetable to such a degree that a new tender was inevitable. A new tender procedure, preceded by a qualification stage, is expected in 2011-2012. The Pallas team does expect to change its requirements in the new tender. As before, its selection criteria includes safety, flexibility in operation, ease of operation, acceptable return on investment and economics.

**Funding**

Construction will require an investment of several hundred million Euros. Currently NRG is still actively pursuing the acquisition of funding for the project. The goal is to have the reactor operating within ten years (2020), subject to funding and regulatory approvals. That schedule would include three years for design and licencing, three years for construction and a year for commissioning. The reactor would be expected to have a 40-year lifetime.

Sourcing of assured funding for the total project is still ongoing; it is currently the limiting factor of the project. Public and private sources are being investigated, since Pallas will serve the needs of both communities. Public interests have to do with research for sustainable energy and the guaranteed availability of medical isotopes for the treatment and diagnosis of patients. Private interests are focused on commercial irradiation and the production of isotopes. Construction will rely on:

- Public funding for the pre-competitive research and science development carried out in Pallas.
- Private funding for the investment needed for the commercial production of isotopes.

The ratio of private sector to public sector funding, and the relative importance of Mo-99 production compared to scientific experiments, ranges from 60:40 to 40:60. A recent communication from the European commission states: "The possibility of financing mechanisms to ensure a sustainable supply of radioisotopes in the interest of public health and an equitable share of public expenditure by all member states will be explored together with the council and European Parliament, and the commission will ensure appropriate follow-up to the council conclusions on this matter. The needs will be established on the basis of the conducted technical and economic studies and of a reference scenario for the replacement of reactors of age."(4).

**Organisation**
In the Netherlands, six ministries form the competent authority for the 'kernenergiewet' (Nuclear Energy Law, KEW). In early 2008 the first project information exchange was held between NRG and the coordinating competent authority for the KEW, the ministry of housing, spatial planning and the environment (VROM). VROM takes the IAEA framework as the basis for its safety policy, extended by rules pertinent to the Netherlands' particular circumstances. For research reactors with a thermal power over 30 MW, several safety rules (based on IAEA rules) will be similar to those established for nuclear power reactors in the Netherlands. Some of the preconditions are:

- withstand high internal pressure
- withstand high-speed, heavy aircraft impact
- long 'grace period' in the event of an accident
- Core damage frequency (CDF) 10-6
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In 2009 NRG published an initial memorandum (5), informing the public about its plans for Pallas and how it will analyse and control its environmental impact. The formal submission of the initial memorandum triggers the EIA procedure. The public hearings, organised by VROM, were held in the two candidate locations: the communities of Zijpe and Zeeland. The views of the Dutch public, gathered during and after the meetings, are used by the EIA committee to set the themes for the analyses and report. NRG welcomes the cabinet-council's support (1) for the building of a new reactor and is fortunate in having fast growing public acceptance and support for it too.

The committee gave its final guidelines for the EIA in June 2010. NRG has now started working on the EIA procedure, and expects to complete it by the end of next year. The final reference license basis and the final operational limits and controls need to be agreed with the regulator as soon as possible so that the design and license application can be completed. Construction can only begin after that license has been issued.

The Pallas project team in Petten will direct the development of Pallas on NRG's behalf. It will review and assess the design and construction processes provided by the vendor, and it will have primary responsibility for defining the employer's requirements, the licensing and the commissioning of Pallas, with the supporting design and safety systems supplied by the vendor. The major projects the team will have to manage are:

- Control and supervision tasks for the design & licensing phase
- Evaluation and verification of nuclear design codes of the vendor
- Netherlands Environmental Impact Assessment
- Netherlands Nuclear Law: construction and operation license
- Preparation for operation and commissioning
- Experimental irradiation device design, and emplacement in the reactor core
- Isotope irradiation device design and emplacement in the reactor core
- Site layout
- Infrastructure, including power, gas, water, sewerage, data supply, and so on
- Cooling water supply, including licenses.
- Remnant heat processing and disposal.

Studies to use (and sell) the remnant heat in the cooling water are underway. The continuity of heat delivery during outages requires heat buffers that are quite costly. Heat buffers might include ground-source heat from sand layers 100m below the dunes. Although there is market potential, finding sufficient numbers of customers to justify the extra investments needed for the delivery of the heat is not simple in such a sparsely-populated area.

The project team has a director and project manager leading the lead engineers of the major projects. The core team now consists of 10 members. They will be supported by experts from NRG and some third parties. Subcontractors will supply the design and hardware needed to accomplish the goals of the projects. The Pallas team will detail the scope and planning for the design and construction for the infrastructure needed and will control the contract management.

**Pallas and the EU**

Over the past years the nuclear industry and politicians (European and Dutch) have produced an extensive set of future strategies to strengthen the nuclear research infrastructure and security of supply of medical isotopes. Below there are some important conclusions concerning Pallas.

The thematic network "Future European Union Needs in Materials Research Reactors", FEUNMARR, already stated in 2001 that "given the age of current Materials Test Reactors (MTR) there is a strategic need to renew Materials Test Reactors in Europe". (6).

The European Strategy Forum on Research Infrastructures (ESFRI) followed in 2006 with a note that the next prominent nuclear facilities such as the Reacteur Jules Horowitz (JHR) in France are primarily designed for research projects that serve scientific, industrial and public needs. Pallas and JHR will be complementary (7).

In 2008, the Committee for Netherlands' Roadmap for Large-Scale Research Facilities (Commissie van Velzen) of the Ministry of Education, Culture and Science carried out an international peer review of Pallas resulting in very positive advice for the go-ahead of the project. In early 2009 Pallas was added to the list of the Netherlands' National Roadmap Large Scale Research Facilities (8).

The Sustainable Nuclear Energy Platform's (SNETP) Strategic Research Agenda (May 2009) makes the need for Pallas clear with statements such as "To hold on to its leadership in reactor technology, Europe must maintain its efforts towards the realization of a European Research Infrastructure Area"[9).

In a letter for the Dutch Parliament issued 16 October 2009, the Netherlands government clearly expressed their positive vision on the building of Pallas (1). The letter stipulates that the replacement of the HFR by a state-of-the-art reactor will satisfy both the need for nuclear research, and the security of radiopharmacological supply.

CEA (French Atomic Energy Commission), SCK-CEN (Belgium Nuclear Research Centre), TUM (Technical University, Munich) and NRG have recently written a position paper called 'Scenario for sustainable Mo-99 production in Europe' (10]. This position paper has been positively referenced by the EC DG Energy in recent advice to the European Parliament.

In September 2010 OECD-NEA published an important study called 'An Economic Study of the Molybdenum-99m Supply Chain' (11). This study highlights the current absence of "sufficient financial incentives for new Mo-99 production infrastructure without government assistance."

**Conclusion**

The role of Pallas in the EU's future research and isotope utilization is well established. The tender process has lead to offers that technically seem feasible. The competition and dialogue procedure for the tender was most effective in arriving at stable requirements and clear offers. The tender process will be continued later this year/early next year. Although progress has been made, only limited funds are available at the moment. The financial arrangements for the design and construction phase of the project have not yet been concluded. The licensing path has been started with an environmental impact assessment, based on the results of public hearings following Netherlands practices. The project organisation for the Pallas project is ready for the next phase: the design and license preparation, followed by construction and commissioning as soon as the construction and operating license has been awarded.