development in Korea which the designer plans to apply the licensing for construction permit by 2020. The revision and refinement of the draft GSR for SFR will continue further.

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RMB: The New Brazilian Multipurpose Research Reactor

José Augusto Perrotta and Adalberto Jose Soares

1. Introduction

In 2009, pushed by the international Moly-99 supply crisis that occurred in 2008/2009, and that affected significantly the nuclear medicine services in the world, Brazilian government, decided to carry out a sustainability study, to decide about the feasibility to construct a new research reactor in the country. As demonstrated in reference *[2],* the result of the study, which was done following *IAEA's* recommendation presented on reference *[3]*, was favourable to the construction of the new reactor, and Brazilian professionals started analysing its conceptual design.

In 2010, following recommendations of *COBEN (Bi-national Commission on Nuclear Energy),* a committee responsible for a bi-national cooperative agreement between Brazil and Argentina, a decision was taken to adopt, for the new *Research Reactors of Brazil (RMB)* and Argentina (RA10), a conceptual model based on *INVAP* designed *OPAL* research reactor, as a reference for radioisotope production and neutron beams utilization.

For the Brazilian *RMB* research reactor, in addition to radioisotope production and neutron beams utilization, two other requirements were established. The first one was the capability to test fuels and materials for the Brazilian nuclear program, and the second was the requirement to have, around the reactor building, the necessary infrastructure to allow the interim storage, for at least 100 years, of all spent nuclear fuel used in the reactor. Details of these two characteristics will be given in the next sections.

2. Description of the reactor

RMB is a MTR open pool type reactor that uses beryllium and heavy water as reflector, and light water as moderator and cooling fluid. The power of the reactor is 30 MW, and its main requirements, established during the feasibility study, are: radioisotope production, to attend national demand beyond 2020; production of thermal and cold neutron beams for research and application in all areas; development of materials and nuclear fuels for the Brazilian nuclear program; neutron activation analysis; and silicon transmutation doping.

The core of the reactor is a 5 x 5 matrix, containing 23 MTR fuel elements, and leaving 2 positions available for materials irradiation tests. Each fuel element has 21 plates, with a meat made of low enriched (19.75 %) Uranium Silicide-Aluminium dispersion (U_3Si_2-Al) clad with Aluminium. Dimensions of the fuel element are 80.5 mm x 80.5 mm x 1,045 mm, and meat dimensions are 0.61 mm x 65 mm x 615 mm.

Three sides of the core are surrounded by a reflector vessel, filled with heavy water that acts as reflector for the neutrons produced in the core. The reflection on the fourth side is done with the utilization of removable beryllium blocks. These beryllium blocks are needed to allow *RMB* to be used as a tool for the Brazilian nuclear program. **Figure 1** shows a top view of

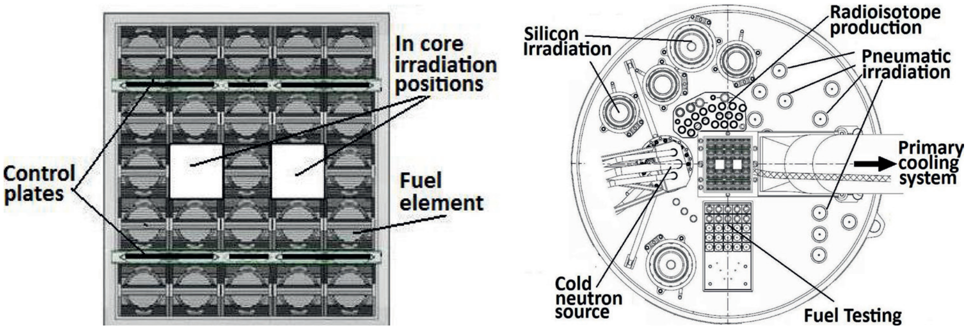

Fig. 1.
Top view of reactor core (left) and reflector vessel (right).

the reactor core and the reflector vessel.

The core is designed to have a cycle length of 28 days. To accomplish with this cycle, the fuel element is poisoned with Cadmium wires which are depleted together with the fuel element. Each fuel element has 42 Cadmium wires, which are placed on the fuel element alongside the fuel plates, one on each side of the plate. The Cadmium wires are 0.4 mm in diameter and 615 mm long. The core has also 6 independent Hafnium control plates, which move parallel to the fuel plates.

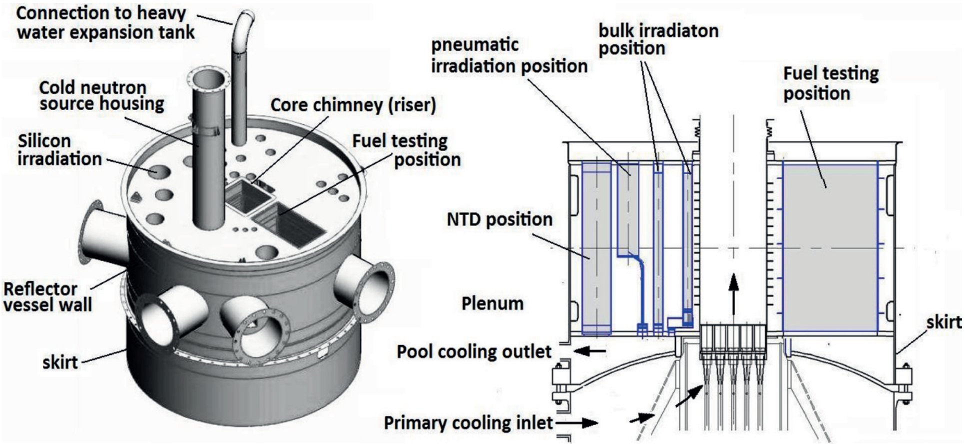

Fig. 2.
Perspective (left) and cutaway (right) views of the reflector vessel.

3. Reflector vessel

The reflector vessel is made of zircaloy, and it is installed in the bottom of the reactor pool, about 10.5 meters below water surface level. Filled with heavy water, it has an internal diameter equal to 2.6 meters and an internal height equal to 1.0 meter. It has 5 positions for neutron transmutation doping; 14 positions for pneumatic irradiation (9 with 3 vertical positions each and 5 with 2 vertical positions each); about 20 positions for bulk irradiation; one cold neutron source; 2 cold neutron beams; 2 thermal beams, 1 neutrongraphy beam and one position for fuel irradiation testing, where up to 2 rigs can be installed simultaneously. As explained before this fuel irradiation position constitutes one of the main differences between *RMB* and the reference reactor. The position has a 5 x 5 grid where beryllium blocks are placed to reflect the neutrons produced in the core when there is no fuel being tested. When used, the fuel irradiation position allows testing of fuel prototypes, simulating steady state and dynamic conditions (ramp tests and load following).

At least 10 of the bulk irradiation positions in the reflector vessel can be used to irradiate rigs with low enriched fuel miniplates, to produce Mo-99. Each rig is designed to produce, after 7 days irradiation, between 2,400 and ,3000 Ci of Mo-99, which will correspond to 400 and 500 Ci, respectively, after 6 days calibration.

On the lower part of the reflector vessel there is a skirt, whose interior is divided into two parts. The central part is used as water inlet for the primary reactor cooling system, and the outer section, between the central part and the wall of the skirt, is used as water outlet for the reactor pool cooling system. **Figure 2** shows a perspective and a cutaway view of the reflector vessel.

4. Reactor and service pools

The reactor pool is a 5.1 meters diameter, 14 meters high cylindrical tank made of stainless steel, filled with water up to the 12.6 meters level. It houses the reflector vessel, a small spent fuel storage rack, with capacity to store up to 32 fuel elements; the bundles of tubes used for pneumatic irradiation; the internal piping that form the inlet and outlet of the primary and pool cooling systems; nuclear and process instrumentation; auxiliary support and mechanical structures, and the water inventory, required for the pool cooling system to perform its functions. The tank is embedded in a concrete block, anchored to the concrete by a set of reinforcement rings and clamps at the bottom. The bottom of the pool has 5 penetrations, one for the control plates driving mechanisms, and four for the heavy water system. One of the heavy water connections is used for drainage of the reflector vessel, two are used as inlet and outlet of the heavy water cooling system; and the forth connection is used as an alternative system to shut down the reactor. This connection has a set of valves that once open, removes about 50 % of the heavy water in less than 15 seconds, assuring that the reactor is kept shutdown, even after returning to normal temperature.

Adjacent to the reactor pool there is the service pool, a 9.0 meters high rectangular stainless steel structure, with maximum water level equal to 7.6 meters. The service pool houses a spent fuel storage rack with capacity to 600 spent fuel elements, the equivalent to 10 years of operation; some containers specially designed to store damaged fuel assemblies; a basket for solid waste storage; a transport cask platform; a structure to store the reactor isolation gate; internal piping of the pool cooling system; pool lighting supports; and racks used for decay of materials irradiated in the reactor and that needs further processing, like Silicon, the miniplates for Mo-99 production, etc., The service pool also is the entrance of an elevator, which connects the service pool to a hot cell, named Moly Hot Cell, which is part of a system used to transfer the miniplates to a transport cask. The service pool is connected to the reactor pool by a transfer channel. The transfer channel, also made of stainless steel, has a 5.0 meters layer of water, which works as biological shielding when the spent fuel, or any material irradiated in the core, is transferred from the reactor pool to the service pool. A sliding gate, when installed in a

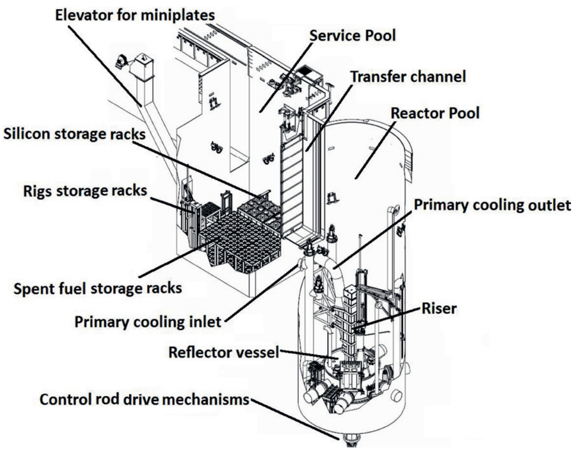

Fig. 3.
Perspective view of the reactor and service pools.

groove of the transfer channel, allows maintenance of one pool without the need to empty the other pool. **Figure 3** shows a perspective view of the reactor and service pools.

5. Reactor and pools cooling systems

Light water is used for cooling the reactor core and the internals of the reactor and service pools. The water used in the reactor primary cooling system enters the reactor pool through two pipes installed about one meter below the transfer channel, and flows down to enter in the lower part of the reflector vessel, then flows upward through the reactor core, and through a riser installed on top of the reflector vessel, leaving the reactor pool through a single pipe also installed below the transfer channel, as shown in **Figure 3.** The volume of water that flows through the core represents 90 % or the total flow in primary cooling system. The other 10 % comes from the top of the reactor pool. It enters the top of the raiser and flows down to the outlet piping. By using this design, all N-16 produced in the water, when it passes through the reactor core, goes directly to the N-16 decay tank, installed below the service pool.

The primary cooling system has 3 circuits. Each circuit has a pump, with inertia flywheel, and a plate type heat exchanger with capacity to remove 50 % of the heat generated in the reactor core. One of the circuits remains in standby during normal operation.

In addition to the 10 % of water that flows in the primary cooling system, the reactor pool has another equivalent volume of coolant that flows downward in the reactor pool, passes through the radioisotope production and silicon irradiation rigs, and enters a plenum between the primary cooling inlet region and the external wall of the skirt installed on the lower part of the reflector vessel, as shown in **Figure 2.** The water leaves the plenum through a pipe that goes upward, leaving the reactor pool close to the transfer channel. The inlet and outlet pipes of both cooling systems, the primary cooling system and the pools cooling system, have siphon brake and flap valves on their top positions. The siphon brake valves are installed to prevent the accidental loss of water as a consequence of a siphon effect following the unlikely rupture of a pipe outside the pool, and the flap valves are installed to allow the establishment of the natural circulation process, to cool the reactor core, following the reactor shutdown.

A 1.5 m thick hot layer on top or the reactor and service pools, provides a non-activated stable water layer over the pools. It prevents active particles from reaching the surface of the pools, reducing significantly the radiation dose to reactor operators. The hot layer temperature is 8 °C higher than the pool water temperature.

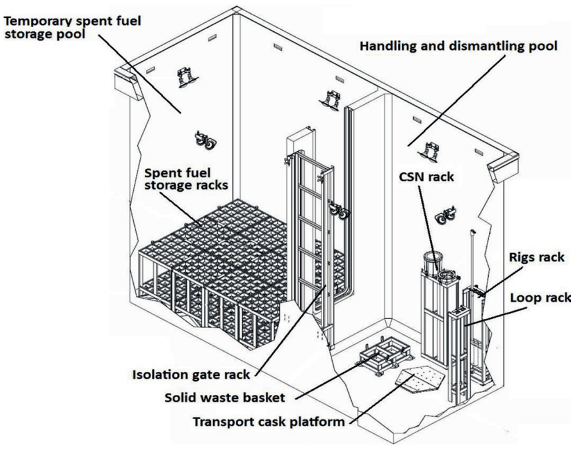

Fig. 4.
The temporary spent fuel storage and the handling and dismantling pools.

6. Reactor control and shutdown systems

Six independent Hafnium control plates are used to control the fission process in the *RMB* research rector. Each control plate has an extension which has a magnetic disc at the end, and is driven by an independent mechanism installed in a sealed compartment below the reactor pool. The driving mechanism is based on a system known as “rack-pinion”, having on its extremity an electromagnetic assembly. When active, an electric current passes through the electromagnetic assembly and engages the magnetic disc, allowing the movement of the respective control plate. The movement is upwards for removal from the core, and downwards for insertion. Once the electric current is interrupted, the magnetic disc automatically disengages from the eelectromagnetic assembly, and the control plate falls by gravity. Compressed air, from a pneumatic cylinder, helps to accelerate the introduction of the control plate into the reactor core.

The negative reactivity inserted by any combination of five control plates is enough to keep the reactor shutdown, and if for some reason, following a “scram signal” it is detected that two control plates have not reached to bottom position, a second “scram signal” is generated. This second “scram signal” is used to open a series of valves that result in the removal of about 50 % of the heavy water from the reflector vessel; quantity enough to assure keeping the reactor shutdown even when it returns to ambient temperature.

7. The spent fuel storage building

To comply with the requirement to allow the interim storage, for at least 100 years of all spent nuclear fuel used in the reactor; a building, named “Spent Fuel Storage Building”, was designed adjacent to the reactor building. This building, which can be accessed directly from the reactor building, will have two additional pools, one for temporary wet storage of the spent fuel used in the reactor, and the other for handling and dismantling rigs that were used for material and fuel irradiation tests.

The temporary spent fuel storage pool is a stainless steel structure, similar to the service pool. The pool has only three items, the spent fuel storage rack, the inlet piping from the pool cooling system, and the pool lighting system. The spent fuel storage rack has a capacity to store 1,200 spent fuel elements, the equivalent to 20 years of reactor operation. In order to improve water distribution injection and water circulation through the fuel assemblies, the diffuser of the pool cooling system is placed below the storage rack. The pool cooling system has a derivation that is used to continuously purify the water, before it returns to the pool.

The handling and dismantling pool is also a stainless steel structure. It houses several racks, with capacity to store 4 in-core irradiation rigs, 2 used cold neutron sources, 1 fuel irradiation loop, and 2 isolation gates, one for the temporary storage pool and the other to isolate the pools from a “delivery transfer channel”, that connects the two pools with the service pool, located in the reactor building. The pool has also the pool lighting system, the piping of the cooling and purification system, and a transport cask platform, needed to receive a cask that will be used to transfer the spent fuel to a dry storage position. **Figure 4** shows the temporary spent fuel storage pool and the handling and dismantling pool.

The two pools of the spent fuel storage building plus the reactor pool and the service pool, these last two located in the reactor building, form a stainless steel structure embedded in a concrete block, as shown in **Figure 5.** Three hot cells located in the reactor building and one hot cell in the spent fuel storage building complement the concrete block.

According to the conceptual design of the spent fuel storage building, after 20 year of decay, the spent nuclear fuel shall be transferred from the storage pool to a dry storage position, located in the level -6,00 of the building. For this operation, a dual purpose cask (for transport and storage) is lowered in the transport cask platform, installed in the handling and dismantling pool. After being filled with spent fuel assemblies, the cask is taken to an area where it will be properly dried, and then transferred to level -6,00 of the building, where 150 dual purpose casks can be stored for at least 100 years.

A system comprising two ante cameras and two isolation gates, maintain the physical and environmental separation between the reactor and the spent fuel storage buildings.

8. The research and production nucleus

The reactor and spent fuel storage buildings are the centre of what is called the "research and production nucleus", which includes a radioisotope production facility and three laboratories, one for research utilizing neutron beams, one for neutron activation analysis and the third one for post irradiation analysis of irradiated materials and nuclear fuels.

The radioisotope production facility will have two lines of hot cells, the first one for production of radioisotopes, like Mo-99 and I-131, and the second one for "sealed sources", like Ir-192 and I-125, for industrial and medical applications. According to the established requirement, it will have the capacity to produce radioisotopes and sealed sources to attend the national needs beyond 2020.

The neutron beams laboratory will have lines of thermal neutrons, for experiments like high resolution diffractometry, high intensity diffractometry, Laue diffractometry, residual stress diffractometry, and neutrongraphy; and lines of cold neutrons, for experiments like small angle neutron scattering (SANS), reflectometry, prompt gamma analysis and others that are under analysis.

The radiochemistry laboratory will have two pneumatic connections to receive long life irradiated samples, plus five pneumatic tubes connected directly to the reflector vessel, for cyclic irradiations of short life products and delayed neutron activation analysis.

The post irradiation laboratory is the facility that, together with the reactor, allows irradiation tests of materials and fuels needed for the Brazilian nuclear program.

Seven more facilities complement the research and production nucleus, the reactor auxiliary building, the cooling tower complex, the electrical supply and distribution building, a radioactive waste management facility, a workshop, an operator's support building, and a researcher's building. **Figure 6** shows the main facilities of the research and production nucleus.

9. The RMB nuclear research and production centre

RMB is a new nuclear research and production centre that will be built in a city about 100 kilometres from Sao Paulo city, in the southern part of Brazil. The centre will have, in addition to the research and production nucleus, an administrative centre and an infrastructure centre to attend all the needs of the centre. The administrative centre will have a library, an administration building, a hotel, a restaurant, an ambulatory, and a training centre. The infrastructure centre will have a water treatment plant, a warehouse, a workshop, a facility for the fire brigade, a garage, a sewage treatment station, a chemical treatment plant, a meteorological station, the main gate, and the electrical substation. Shown in **Figure 7,** RMB Centre has an area of about 2 millions square meters.

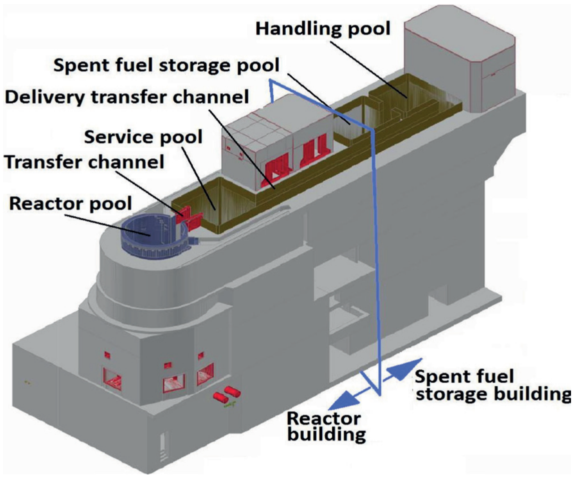

Fig. 5.
Pools embedded in the concrete block.

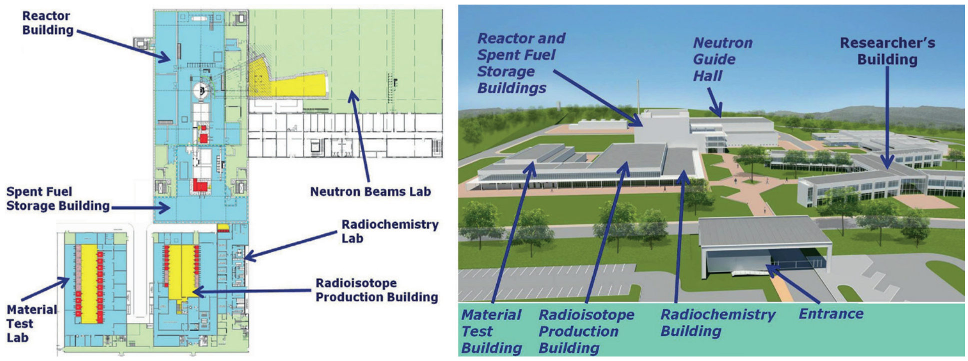

Fig. 6.
Plant (left) and perspective view (right) of the RMB research and production nucleus.

10. Status of the project

In 2011, the *Ministry of Science Technology and Innovation* allocated R$ 50 Mill. (about US$ 25 Mill.) for the conceptual and basic designs of the complex. It allowed, in 2012, the signature of a contract, with a Brazilian company, to develop the engineering work for the conceptual and basic design phases of all buildings and facilities of the centre, excluding the reactor and connected systems; and in 2013 the signature of the contract with *INVAP* for the work related to the preliminary engineering of the reactor and connected systems. Conclusion of both contracts is planned for the middle of 2014.

Also in 2012, a contract was signed, with a Brazilian company with tradition in environmental studies, to perform environmental and site studies. The report was finished by middle 2013, allowing the starting of environmental and nuclear licensing processes, with presentation of site and local reports, requirements for first license. They were also the basis for the three public hearings, done in October 2013.

Site topography was already surveyed; geological sampling completed, and a meteorological tower was installed and it is operational since 2012.

Next steps are: conclusion of the basic and preliminary engineering, development of detailed design, manu-

Fig 7.
Artist view of the RMB nuclear research centre.

Paper presented at the RRFM 2014

facturing, construction, assembling and management. These phases will be carried out by national and international companies, and for these activities, a provision was made in the national budget, but not yet confirmed.

Total project remaining time span is estimated in 5 years after contract signature and subject to availability of funds.

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45th Annual Meeting on Nuclear Technology: Key Topic | Reactor Operation, Safety – Report Part 3

The following reports summarise the presentations of the Technical Sessions **"Reactor Operation, Safety: Radiation Protection"**, **"Competence, Innovation, Regulation: Fusion Technology"** and **"Competence, Innovation, Regulation: Education, Expert Knowledge, Knowledge Transfer"** presented at the 45th AMNT 2014, Frankfurt, 6 to 8 May 2014.

The other Key Topics and Technical Sessions have been covered in previous issues of *atw* and will be covered in further issues of atw.

Reactor Operation, Safety: Radiation Protection

Angelika Bohnstedt

Due to different circumstances the amount of presentations in the technical session **"Radiation Protection"** was at the Annual Meeting actually reduced to three lectures. But this gave the audience with about 23 to 27 participants the opportunity to have a lively discussion after each presentation, not only with the lecturer but also with other colleagues in the public. So the whole session was a fruitful exchange of interesting information and knowledge.

The session was chaired by *Dr. Angelika Bohnstedt, Karlsruhe Institute of Technology (KIT)*.

The first presentation **"Optimisation of Clearance Measurements According to DIN 25457 Taking Account of Type A and Type B Uncertainties"** was hold by *S. Thierfeld* (co-author: *S. Wörlen;* both *Brenk Systemplanung GmbH*). In the beginning *S. Thierfeld* gave an overview of the DIN 25457, the widely applied standard for clearance measurements. He showed the evolvement from the fundamentals in 1993 via the Part 4 about contaminated and activated metal scrap, to the Part 6 of building rubbles and the latest Part 7 of the DIN about nuclear sites. And he emphasized that the primary aim is to get a reliable yes/no decision about the compliance with clearance levels. At the next step *S. Thierfeld* explained the incorporation of DIN ISO 11929, the standard for dealing with uncertainties in measurements, into DIN 25457. The consideration of Type A and Type B uncertainties for measurements and their calibrations was discussed. For different factors, influencing measurement and calibration, a conservative approach, taking only Type A uncertainties into account, and a realistic approach, combining Type A and Type B uncertainties, is possible. *S. Thierfeld* elucidated how to check step by step in the measurement and the calibration procedure which approach of uncertainty determination will be more reasonable for each respective factor. He concluded that finally a combination of all conservative and realistic approaches has to be done in a way to reach clearance measurements as precisely as necessary. At the end *S. Thierfeld* pointed out that the higher effort to reduce uncertainties will bring a decreased effort for decontamination work.

The following presentation **"Optimization of Handling Components and Large Scale Shielding Calculations with the Deterministic Code ATTILA"** was given by *S. Boehlke* (co-author: *M. Mielisch;* both *STEAG Energy Services GmbH*), who started with the statement that in general shielding components are designed with conservative assumptions and boundary conditions which cover all possibly occurring situations. This can result in an overestimated shielding and the goal of an optimization procedure is to decrease on one hand the radiation level in accessible areas but on the other hand to decrease the amount of avoidable shielding material. *S. Boehlke* noted that for this optimization the calculation of the shielding geometry as well as the calculation of the dose rate distribution was done with the code ATTILA. He explained the different features of ATTILA, e.g. intuitive graphical user interface and the possibility to integrate simplified CAD geometries etc., and demonstrated in the following the use of ATTILA with 2 examples: a large scale dose rate mapping and the optimization of the shielding material of a handling machine for canisters of vitrified glass. For the large scale model (situation in a storage building) several aspects like superposition of all sources, the scattering of walls etc. and the scattering through openings was taken into account. As result *S. Boehlke* showed an overview about the shielding situation in the whole building. The second example was the calculation of the dose rate at the surface of a handling machine for canisters. Here S. Boehlke could demonstrate as consequence of the calculations a change in the design of the machine with the success that regions where the dose rate limit was exceeded before vanished and on the material site the reduction of used lead was about 30 % and the overall mass reduction of the machine was of about 10 %.