Licensing Framework for the Pebble Bed Modular Reactor and the Lessons Learnt with the Licensing of a New Reactor Technology

Peter Bester
National Nuclear Regulator
+27 (0) 12 674 7100
pbester@nnr.co.za

Abstract
In July 2000, the NNR received a nuclear installation licence application from Eskom, for the prospective siting, construction, operation, decontamination, and decommissioning of a demonstration unit of a 110 MWe Class PBMR electricity generating power station. In order to determine whether such a design is licensable, the NNR developed licensing requirements for such a power reactor and elaborated the processes that must be undertaken to demonstrate compliance with the requirements. The scope of the regulatory assessment for the licensing of the PBMR was based on the licensing requirements and criteria defined by the NNR in regulatory documents that expand on the legislative requirements. In addition guidance is provided on selected issues in regulatory guidance documents and position papers.

With the introduction of the licensing of this reactor technology in South Africa the major challenges faced by the NNR were mainly related to the adjustment of its internal human resources capacity of undertake the licensing review of the PBMR, and the adjustment of the regulatory philosophy and processes to the licensing of a “first of a kind” reactor project.

The paper describes the challenges that were faced by the Regulator, the licensing process that was adopted for the PBMR as well as the lessons learnt with the licensing of a new reactor technology.
## Abbreviations and Definitions

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPP</td>
<td>Demonstration Power Plant</td>
</tr>
<tr>
<td>EPR</td>
<td>European Pressurised Reactor</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>FOAKE</td>
<td>First Of A Kind Engineering</td>
</tr>
<tr>
<td>GOR</td>
<td>General Operating Rules</td>
</tr>
<tr>
<td>HTGR</td>
<td>High Temperature Gas Cooled Reactor</td>
</tr>
<tr>
<td>KLI</td>
<td>Key Licensing Issues</td>
</tr>
<tr>
<td>KNPS</td>
<td>Koeberg Nuclear Power Station</td>
</tr>
<tr>
<td>LWR</td>
<td>Light Water Reactors</td>
</tr>
<tr>
<td>NNR</td>
<td>National Nuclear Regulator</td>
</tr>
<tr>
<td>NNRA</td>
<td>National Nuclear Regulator Act</td>
</tr>
<tr>
<td>PBMR</td>
<td>Pebble Bed Modular Reactor</td>
</tr>
<tr>
<td>PIE</td>
<td>Postulated Initiating Event</td>
</tr>
<tr>
<td>SAR</td>
<td>Safety Analysis Report</td>
</tr>
<tr>
<td>SCP</td>
<td>Safety Case Philosophy</td>
</tr>
</tbody>
</table>

“defence-in-depth” means a hierarchical deployment of different levels of diverse equipment and/or procedures to prevent the escalation of anticipated operational occurrences and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions.

“dose limit” means the value of the effective dose or the equivalent dose to individuals in planned exposure situations that is not to be exceeded.

“good engineering practice” means practices or rules based on demonstrated basic scientific facts or experiences, applied for a purpose by experienced practitioners and verified by frequent successful application in similar situations.

“optimisation of protection and safety” means the process of determining what level of protection and safety would result in the magnitude of individual doses, the number of individuals (workers and members of the public) subject to exposure and the likelihood of exposure being “as low as reasonably achievable, economic and social factors being taken into account” (ALARA).

“source term” means the amount and isotopic composition of material released or postulated to be released from a nuclear facility or action as well as the release characteristics and associated data required for the impact analysis.
Introduction
The National Nuclear Regulator of South Africa (the NNR) started the review of aspects of High Temperature Gas Cooled Reactor (HTGR) technology since 1999, in anticipation of the Pebble Bed Modular Reactor (PBMR) nuclear installation licence application.
In terms of the South African legislation, the NNR Act, Act No 47 of 1999, no person may site, construct, operate, decontaminate or decommission a nuclear installation, except under the authority of a nuclear installation licence, granted by the NNR. Any person wishing to site, construct, operate, decontaminate or decommission a nuclear installation may apply in the prescribed format to the NNR Chief Executive Officer for a nuclear installation licence and must furnish such information as the NNR Board requires.

Regulatory Standards
In July 2000, the NNR received a nuclear installation licence application from Eskom, for the prospective siting, construction, operation, decontamination, and decommissioning of a demonstration unit of a 110 MWₑ (electrical) Class PBMR (equivalent to an output of 268 MW thermal) electricity generating power station. In order to determine whether such a design is licensable, the NNR developed requirements for licensing of a HTGR (LG-1037) and elaborated the processes that must be undertaken to demonstrate compliance with the requirements. Unlike Light Water Reactors (LWRs), for which well-researched and documented design criteria and rules are readily available, broad international consensus on general design criteria and design rules for the PBMR was not available at the initiation of the PBMR licensing process.
The principal nuclear and radiation safety requirements now formulated in the Regulations in terms of section 36 of the NNR Act, on Safety Standards and Regulatory Practices form the basis for the stipulation of the licensing requirements for the PBMR which are elaborated further in a number of regulatory documents as listed in Table 1. Most of the documents listed were developed subsequent to the initiation of the licensing process.

Table 1: NNR licensing documents applicable to PBMR

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD 0018, Rev 1¹</td>
<td>Requirements</td>
<td>Basic licensing requirements for Pebble Bed Modular Reactor</td>
</tr>
<tr>
<td>RD-0024, Rev 0</td>
<td>Requirements</td>
<td>Requirements on the risk assessment and compliance with principal safety criteria for nuclear installations</td>
</tr>
<tr>
<td>RD-0034, Rev 0²</td>
<td>Requirements</td>
<td>Quality and Safety Management Requirements for Nuclear Installations</td>
</tr>
</tbody>
</table>

¹ RD-0018, Rev 0 superseded LG-1037
² Superseded LD-1094 that was issued in 2001
The scope of regulatory assessment for licensing of the PBMR is based on the licensing requirements and safety criteria defined by the NNR in the requirements documents as listed in Table 1. In addition, guidance is provided on selected issues in regulatory guidance documents.

The principal licensing requirements comprise, besides the general requirements to respect good engineering practice, optimisation of protection and safety and defence-in-depth, specific radiation dose limits. These are categorised for normal operation and operational occurrences as well as for design basis events for workers and the public. The safety criteria also stipulate occupational risk limits for the workers as well as risk limits for the public for all possible events that could lead to radioactive exposure. The radiological dose and risk limits for the public and workers relate directly to the objectives of nuclear and radiation safety, and are therefore considered the most fundamental yardsticks against which to assess nuclear safety, contributing towards a more consistent and transparent basis for regulatory decision making. The dose limits are consistent with the International Atomic Energy Agency (IAEA) Basic Safety Standards. The risk limits were established in the 1970s in relation to other industrial and man-made hazards.

The dual nature of the NNR safety criteria implies that the safety analyses for demonstration of compliance of the safety case with the licensing criteria for the PBMR have to comprise both deterministic and probabilistic analyses.

---

3 Superseded LG-1038 that was issued in 2001
4 LD-1097 was revised in 2010 and a final draft of the revised document was finalised as RD-0036 but not submitted for approval.
The dose and risk limits for the various categories of events for plant personnel and the public are listed in Table 2.

### Table 2: Dose and Risk Limits

<table>
<thead>
<tr>
<th>Initiating Event Frequency</th>
<th>Limits</th>
</tr>
</thead>
</table>
| **Category A**             | **Plant Personnel:**
|                            | • annual individual accumulated design dose limit of 20 mSv |
|                            | **Members of the Public (critical group):**
|                            | • annual individual design dose limit of 250 μSv (per site) |
| **Category B**             | **Plant Personnel (outside of exclusion areas):**
|                            | • 50 mSv individual design dose limit for the total accumulated exposure after one single event |
|                            | **Members of the Public (critical group):**
|                            | • 50 mSv individual design dose limit for the total accumulated exposure after one single event |
| **Category C**             | **Plant Personnel:**
| (Limitation of risk to the values set by the risk criteria) | • \(5 \times 10^{-5}\) y\(^{-1}\) peak individual risk due to all nuclear installations, and \(10^{-5}\) y\(^{-1}\) average risk due to all nuclear installations |
|                            | **Members of the Public:**
|                            | • \(5 \times 10^{-6}\) y\(^{-1}\) peak individual risk due to all nuclear installations, and \(10^{-8}\) y\(^{-1}\) average risk per site |

### Multi stage licensing approach

The siting, design, manufacturing and construction stages (as well as the operation and decommissioning) have to be done under the regulatory control of the NNR. The applicant has two options, viz:

(i) A multi-stage approach to licensing for the various stages or combinations of stages of the nuclear authorisation may be adopted. Each stage requires a safety case to address the aspects that have an impact on the safety for the proposed installation as an entity and holistically. Depending on the scope and rigor of the safety case, the NNR may grant a licence with conditions attached to it for activities commensurate with those adequately addressed in the safety case. These conditions may be varied at later stages when the safety case basis is fully developed.

(ii) An authorisation for a combined licence covering siting, construction and operation may be obtained. For this the safety case submitted in support of the application has to cover the full scope of design, siting, construction, manufacturing, operation and decommissioning stages.

In view of the complexity of the project and acknowledging the developmental nature of the PBMR DPP, a multi-staged licensing process was adopted. The multi-staged licensing process provides a logical link between the various steps of the design
process, the safety assessment and the development of operational support programmes.

A programme of staged licensing submissions will coincide with the application for a nuclear installation licence variation to proceed to the next stage, which will need to be supported by a comprehensive safety case to demonstrate compliance with the NNR regulatory safety requirements at a level appropriate for the stage of licensing at hand. The licensing programme adopted for the PBMR licensing included the following major licensing stages:

**Stages 1&2: Site preparation, construction and manufacturing phase**

The first phase of the licensing process was for the granting of a construction licence. For a construction licence it is nevertheless important that the NNR is provided with sufficient information, in the safety case, to assess whether the proposed site and design will meet the licensing requirements and that all safety issues identified during the safety case review will be satisfactorily addressed.

Typical activities will include:
- site access, excavation, etc.;
- component manufacturing;
- civil works;
- installation of auxiliary systems;
- installation of main power system; and
- cold commissioning testing up to and including non-nuclear integrated test.

**Stage 3: Nuclear Fuel on Site/ Commissioning and Start-up**

Typical activities will include:
- nuclear fuel on site;
- nuclear fuel load;
- initial criticality;
- low power testing; and
- full power testing.

**Stage 4: Plant operation (commercialization)**

The safety case for operation must consider the results of the commissioning testing and should address all outstanding issues. Subject to the NNR review, the conditions of the licence will be amended to allow for the operation of the nuclear installation and a variation of the licence will be issued to the applicant.

Although nuclear authorisations may be different for different types of nuclear installations typical conditions of authorisations will be related to:
- A valid description of the installation
- Modification control procedure of safety related aspects
- Maintaining a valid and up-to-date safety case.
- Limits on operation and use (such as dose or discharge limits or limits on the duration of the authorization)
- Establishment and compliance with operating technical specifications
- Maintenance and inspection program
- Operational radiation protection program
- Waste management program
- Transport of radioactive material
Stage 5: Eventual decommissioning

At the end of its operating lifetime, the nuclear installation should enter post-operational decontamination and reduction of hazards to move towards a more passively safe state. A decommissioning strategy and plan must be included in the safety case for construction.

Challenges faced with the licensing of the PBMR

The main challenges faced by the NNR are mainly related to the adjustment of the regulatory philosophy and processes to the licensing of a “first of a kind” reactor project and to its internal human resources capacity to undertake the licensing review of the PBMR.

Regulatory philosophy and licensing process adopted for the PBMR

Broadly speaking, the NNR licensing process requires the applicant to present a safety case to the NNR which is a structured presentation of documented information, analyses and intellectual arguments to demonstrate that the proposed design can and will comply with the NNR licensing requirements. The licensing philosophy is non-prescriptive concerning the adoption of codes and standards for design and operation. However, the applicant has to use internationally acceptable codes and standards, and has to justify that he selected codes and standards are sufficient to support the safety case.

The regulatory approach applied to the licensing of the Koeberg Nuclear Power Station (KNPS) (twins 930 MWe PWRs) presented challenges to the NNR in terms of its applicability to the PBMR. One of the major aspects of the PBMR licensing process, which must be thoroughly considered as an integral part of the development (by the applicant) and review (by the regulator) of the safety case, is the credibility of the PBMR licensing basis. Unlike Light Water Reactors (LWRs), for which well-researched and documented design criteria and rules are readily available, broad international consensus has not been developed on general design criteria and design rules for high temperature gas reactors. Although these type of reactors have been licensed and operated elsewhere in the world, no international “off the shelf” package was available for defining the design basis and the safety case for the PBMR. As part of the safety case the establishment, documentation and assessment of the PBMR design basis is therefore an important step in the licensing process and received significant attention by the designers, applicant and the NNR.

Although the KNPS reactors were subjected to licensing requirements developed in the 1970’s the first challenge faced by the NNR was to develop licensing requirements for this “new” type of reactor taking cognizance of reactor operating experience, developments in international safety standards and application of these in the design of new generation of reactors such as for example the European Pressurised Reactor (EPR). Recognizing these factors the NNR developed and
published the first revision of the “Basic licensing requirements for the PBMR” in 2000 (LG-1037). These requirements are essentially “technology neutral” safety requirements according to which defence-in-depth is enforced in a graded approach based on the scale of the hazard in terms of the risk and dose criteria referred to above.

This was followed by the progressive development of many specific regulatory requirements and guidance documents in support of these Basic Licensing Requirements that would have formed the basis for the NNR review of the safety case as presented by the applicant (See Table 1).

The next challenge faced by the NNR was to provide guidance to the applicant and the designer on the processes that will need to be undertaken to demonstrate compliance with these requirements. In order to demonstrate that the PBMR design will meet the above licensing requirements Eskom has, in consultation with the NNR, developed and implemented a structured process to develop the PBMR safety case which takes account of the absence of well-researched and documented design criteria and rules. This process also provides a logical link between the various steps of the design process, the safety assessment and the development of operational support programmes. The main components for the development and review of the PBMR safety case are:

(a) The PBMR Safety Case Philosophy (SCP)

The SCP provides the intellectual and philosophical arguments of how PBMR safety will be demonstrated to meet the safety requirements set by the NNR. These refer to the broad safety objectives of the PBMR.

The process for developing the SCP also involved the systematic identification of Key Licensing Issues, applicable to this type of reactor technology, which will need to be addressed as part of the demonstration of the PBMR safety objectives in the Safety Analysis Report.

(b) The PBMR Safety Analysis Report (SAR)

The Safety Analysis Report (SAR) for the PBMR, and other supporting documents are to provide a detailed justification of how the safety arguments/objectives presented in the safety case philosophy are or will be demonstrated.

(c) The General Operating Rules (GOR)

The General Operating Rules (GOR) refers collectively to safety related practices or programmes that are applicable during the operational phase of the plant and may also be applicable during interim licensing stages.

The NNR acknowledged that the production of a safety case, particularly for the Demonstration Power Plant of a novel type of reactor, is a difficult undertaking especially taking into account that international well-researched and documented design criteria and rules are not readily available and was confident that, following the systematic approach summarised above, a considerable amount of thought has been put into the strategy to be employed in the development of a credible safety case and its review against international norms and standards, which ultimately must demonstrate the safety of the PBMR.
**Human resources capacity**

At the onset of the PBMR project (1998-99) it became evident that in order to undertake the necessary licensing work associated with the PBMR reactor technology it will clearly be necessary to supplement the NNR staff, who were more experienced in the licensing of Pressurized Water Reactors, and to develop in-house expertise in gas/graphite reactor technology.

A campaign of identifying potential local and international technical support organizations in this reactor technology was initiated. It was concluded that at that time there were no local institutions that could provide such specialized services. Contact was established with various international organisations that could possibly provide the NNR with the necessary consultancy services and the necessary expertise and experience with this type of reactor technology. The organisations were selected on the basis of advice solicited from international contacts and the involvement the NNR have had with the IAEA group on high temperature gas cooled reactors.

Two international companies provided technical services to the NNR for the review of the PBMR safety submissions and internal capacity building of the organisation. The support of these two international companies to the NNR has proved very successful and beneficial to the progress of the licensing process, preparing for the assessment of the safety case, and also to the capacity building of the regulator. The participation of these technical support organisations however also introduced challenges with the interpretation and implementation of the NNR licensing requirements which had to be carefully managed especially in the absence of well-defined regulatory requirements at the initiation of the project.

**Lessons learnt from the licensing of the PBMR**

**Evolution of the licensing process**

In response to the licence application in July 2000, the NNR developed requirements for licensing of a HTGR (LG-1037) and elaborated the processes that must be undertaken to demonstrate compliance with the requirements.

The applicant submitted in November 2001 a safety case to the NNR for stage 1, which was only for site preparation, of the licensing process. The NNR review identified many short comings in the safety case even for a stage 1 licensing and defined pre-conditions and conditions for licensing.

The NNR review of the safety case philosophy, SAR Rev1a and other relevant supporting documents identified 25 Key Licensing Issues (KLIs) and specific safety issues underpinning these KLIs, which required resolutions at various stages of the licensing of the PBMR. A process was put in place between the applicant (Eskom), the designer (PBMR Company) and the NNR for the resolution of the KLIs that involved the use of 10 working groups of experts. Most of these issues needed to be addressed in SAR Rev 2 in support of stages 1&2 of licensing.

The compilation of the SAR Rev 2 involved early intervention workshops with the NNR with the objective to familiarise the NNR with the contents of the revised SAR and also provide opportunities for the NNR to intervene at an early stage in the process to provide guidance in terms of the adequacy of the document in terms of overall scope and content being developed. It was hoped that this process would maximise the quality of the final document and optimise the review period once the SAR Rev 2 is officially submitted to the NNR.
An updated version of the entire SAR was made available to the NNR in 2006. Both the applicant and the NNR screening reviews assessed that almost all of the SAR chapters, whilst demonstrating significant progress, were still incomplete and/or inadequate and lacking in consistency between each other and did not demonstrate evidence that some of the important KLI’s can be resolved with some degree of reliability. In view of the lack of sufficient progress with the development of the SAR and the changes to the PBMR design, the NNR suspended further workshop activities at the end of 2006 pending a basis for discussions acceptable to the applicant (Eskom) and the NNR.

The resolution of licensing and design issues parallel to the development and review of the SAR chapters as part of the early intervention process demonstrated to be problematic invalidating certain KLI resolution strategies already agreed upon and impacting the quality and consistency of licensing submittals.

Considering the improvements and progress in some areas with the resolution of technical issues evident from submissions, the NNR lifted the suspension on early intervention workshops in December 2008.

**Evolution of the PBMR design**

The application in July 2000 was for a 110 MWe (electrical) class PBMR (equivalent to an output of 268 MW thermal) electricity generating power station.

In November 2002, the applicant informed the NNR of its intention to construct a PBMR demonstration module with design features and safety characteristics that evolved from the 268 MWth (thermal) design that formed the basis of the PBMR Safety Analysis Report SAR Rev 1a. In June 2003 the applicant confirmed that the preferred option will be to retain the licence application for the PBMR, but with an increased thermal power output of 302 MWth. This was followed by consideration of a 400 MWth design due to commercial reasons. The safety case would however be for a reduced power and temperature level.

Further, to address the uncertainties on fuel performance, Eskom communicated to NNR in February 2008 its intention to submit a safety case for operating at a reduced power and hot gas temperature. Whilst this strategy would improve the safety margins on the source term, it did not resolve the other outstanding issues that were identified as part of the KLI resolution and SAR early intervention process. In March 2009 the applicant informed the NNR of a change in the business strategy of PBMR Company who considered a standardised Nuclear Heat Supply System capable of producing electricity and/or process heat application options. The design solution would involve an indirect cycle, involving a Rankine cycle for electricity production, amenable for process heat generation, co-generation or combined cycle generation. PBMR Company approached the NNR to engage in a Design Assessment Process for the new design.

Eskom indicated that the DPP licensing process will be brought to a logical conclusion. This included concluding the resolution strategies on the outstanding key licensing issues not impacted by design changes and the finalisation of some (design neutral) parts of the safety case. The manufacturing activities and reviews will be suspended in a way that further use of the items is not compromised.

During the years the design evolved from a 3 vertical turbine shaft, solid centre column direct Brayton cycle to an indirect Rankine cycle impacting negatively on the development of the safety case and related documentation.
**Evolution of Regulatory standards**

The NNR regulatory approach is to set overall safety standards and requirements the applicant to provide a comprehensive safety case that justifies the application of relevant standards and demonstrate compliance with the safety criteria as discussed in the paper.

The NNR developed and published the first revision of the “Basic licensing requirements for the PBMR” in 2000 (LG-1037) as there were no internationally recognised standards for the licensing of a novel reactor type such as the PBMR. During the years LG-1037 was followed by a number of NNR requirements and guidance documents which were developed when a need was identified based on a request from industry or where the NNR was of the opinion that further intervention is needed.

The regulatory standards should ideally be in place in advance of a licence application and should inform the licensing process and the development of the safety case.

**Manufacturing of long lead items**

The NNR is mandated to provide for the protection of persons (the public and workers), property and the environment against nuclear damage and to “Exercise control over the siting, design, construction, operation, manufacturing of component parts, decontamination .... through the granting of a nuclear authorisation” [1].

The primary requirements document which defines quality and safety management processes that must be complied with is RD-0034. Requirements in this document must be complied with by all organisations involved in the life cycle of the PBMR (owner, designer, suppliers and sub suppliers) which could have a direct or indirect influence on the nuclear or radiation safety of the plant. The approach adopted considers the developmental nature of the PBMR project, the fact that many aspects of the plant design involves first of a kind engineering, as well the absence of international accepted standards for this type of technology.

Certain components which require long lead times were in the process of being manufactured. The designer commenced with the manufacturing of major components prematurely without the necessary regulatory oversight. These activities were suspended by the NNR resulting in major delays and rework.

According to the regulatory requirements, the applicant (and its designer) is responsible for definition and implementation of quality and safety management systems and quality assurance processes to ensure the quality of the components and products. To support this, transparent processes consistent with international standards and practices for monitoring the quality of the components and products are required to be in place and implemented.

The procurement process requires that interventions are identified by the applicant, designer, independent inspector (if the code or standard requires the involvement of an independent inspector) and the NNR. The manufacturing activities were released following the assessment of quality related and technical documents, and the identification of intervention points.

The NNR oversight activities are to ensure that the characteristics of the product being produced are consistent with the material and design specifications. The appropriateness/correctness of the material and design specification will, and can only be assessed as part of the review of the safety case. Therefore all products being produced prior to approval of the safety case are being manufactured at risk as
the assessment of the safety case may conclude that certain material and/or design specifications are inappropriate for whatever reason.

**Summary**

Many lessons were learned through the years with PBMR licensing which amongst others include:

- Understanding the role of Regulator, applicant and designer;
- Premature manufacturing of components; and
- Need for well-defined licensing framework in advance of licensing engagement.

The design adopted had many innovative design features departing from previous operating plants and the assumed experience base lacking a rigorous test and qualification programme.

The designer, applicant and the Regulator did initially not have the required nuclear experience and skills for the licensing of this novel technology. PBMR Company further pursued an aggressive and unrealistic project schedule and focused initially on demonstrating the business case rather than focusing on the safety demonstration of the plant which is evident by the frequent changes in and optimization of the design of the plant.

Lack of safety culture and safety management was observed by the NNR during audits on the designer at the early stages of the project and required interventions that should have been implemented at the beginning of the project.

Lessons relating to the licensing process and design assessment have been captured in the NNR position paper on “Design Engagement Framework”, (PP-0008). These specifically relate to:

- The engagement framework should allow for direct engagement with the designer/architect engineer;
- Identification and agreement on key safety issues and the proposed technical resolution;
- Adequately developed and stable design before development of the safety case and licensing engagements;
- Agreement on safety concept considering safety principles such as defence in depth, redundancy, safety and quality classification (reliability), etc.
- Application of sound system engineering principles and past experience with the aim of demonstrating through robust research, test and qualification that the design will survive all postulated transient and accident conditions.

The position paper provides for regulatory decision-making process that is credible, transparent and which carries credit in subsequent licensing stages as the safety evaluation report that is issued will document the NNR position and the issues that may need to be addressed fully.
**Conclusion**

Many lessons have been learnt by the Regulator, designer and applicant and many improvements have been made over the years. The Regulatory framework has been elaborated through the years. PBMR company as a design organisation matured, learnt the necessary lessons and implemented a management system recognising safety first. It further changed its business strategy and design in 2008 to make provision for process heat application. The design change considered the technical issues associated with the direct Brayton cycle design and would have been in line with existing operating and testing experience.

In conclusion, safety has to be demonstrated through a rigorous test and qualification programme through the application of sound system engineering principles and past experience. All this should be performed in an environment where safety is recognised as a priority, incorporated in the management system and implemented and lived throughout all organisations involved in the development, licensing and operation of a nuclear installation.
References

1. NNR Act, National Nuclear Regulator Act, Act No 47 of 1999

2. NNR Regulations, Safety Standards and Regulatory Practices, Regulations in terms of section 36, read with Section 47 of the NNR Act, April 2006

3. NNR Requirements Document, RD-0034 Rev 0, Quality and Safety Management Requirements for Nuclear Installations, September 2008

Biography

Mr. Bester graduated in 1992 obtaining his M.Sc. in Nuclear Physics from the University of Western Cape, South Africa. His professional career started in in 1992 at the university being employed as a Senior Laboratory Technician. In 1994 he started his career in the nuclear industry at the Koeberg Nuclear Power station near Cape Town and served as a Reactor and Project Physicist from 1995 to 1999 where he was involved with the spent fuel reracking and improved fuel management projects. In 1999 he joined the National Nuclear Regulator and fulfilled various functions to this day. His responsibilities included being the PBMR Project Manager from 2005 till the end of the project. He is currently coordinating various projects at the NNR including the safety reassessment reviews following Fukushima and the regulatory framework project.