The first stage of Licensing of PBMR in South Africa and Safety Issues

Clapisson G A, Mysen A.

National Nuclear Regulator - Republic of South Africa

1. Introduction

The National Nuclear Regulator (NNR) has received a nuclear installation licence application from Eskom (the South African electricity utility). The Application is made in accordance with the National Nuclear Regulator Act for a nuclear installation licence for the demonstration module of a 110 Mwe Class Pebble Bed Modular Reactor (PBMR) electricity generating power station.

It is proposed to locate the installation on Eskom property within the owner-controlled boundary of Koeberg Nuclear Power Station situated in the Western Cape, subject to *inter alia* a favourable Environmental Impact Assessment (EIA) record of decision, which is currently being undertaken under the requirements of another legislation the Environment Conservation Act.

The PBMR is a graphite moderated helium cooled reactor using a direct gas cycle to convert the heat, generated by nuclear fission in the reactor and transferred to the coolant gas, into electrical energy by means of a helium turbo-generator. By design, provision has been made to accommodate the storage of spent fuel in the buildings for the 40-year design life of the plant and thereafter for a further period if so required. Radioactive material and waste will be managed and disposed of in accordance with Regulatory and Government legal requirements.

2. Licensing process

In terms of the complexity of this Project a multi staged licensing process has been adopted by the NNR. This is to acknowledge the developmental nature of the PBMR Demonstration Unit. The approach adopted entails that, following a satisfactory Regulatory Review of the application by the NNR, an initial Nuclear Installation Licence, (NIL) will be issued to the applicant for the first stage of the process and a Variation to this NIL will be requested by the applicant, and issued by NNR following its satisfactory Regulatory Review, at each of the subsequent agreed Licensing Stages. A programme of staged licensing submissions will coincide with the application for a NIL variation (by means of a NIL Change Request) to proceed to the next phase, which will need to be supported by a comprehensive safety justification e.g. Safety analysis Report to demonstrate compliance with the NNR Regulatory safety requirements.

Each stage of the licensing process will indicate the NNR Hold & Witness Points that will form the prerequisites to proceed to the next licensing stage. The Quality Assurance (QA) Programme will ensure traceability and credibility of results of the previous licensing stage, before issuing the next stage licence variation.

The Licensing Programme currently includes, *inter alia*, the following major licensing stages:

1) Limited construction activities (PBMR NIL issued for the first stage)
2) Construction and manufacturing phase (NIL Variation)
    * Civil works
    * Installation of auxiliary systems
    * Installation of Main Power System
3) Nuclear Fuel on Site/ Commissioning and Start-up (NIL Variation)
    *Cold commissioning testing
    *Fuel Load

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* Initial criticality
* Low Power Testing
* Full Power Testing

4) Operation (NIL Variation)
5) Decommissioning

As indicated above a comprehensive safety justification e.g. Safety Case must accompany and support the application for the initial NIL and for each subsequent applicant for a NIL Variation. The framework of such safety case is presented below under Chapter 3.2.

The first stage of the licensing process, which is currently being undertaken, is the regulatory review towards issuing the initial NIL, which will be issued for limited site construction activities prior to issuance of the licence variation authorising the construction of the civil structures, auxiliary systems and main power system of the Pebble Bed Modular Reactor.

Typical activities authorised under the scope of the first stage of the licensing process, which is being discussed with the applicant, would be as follows:

* Preparation of the site for construction of the facility (including such activities as clearing, grading, and construction of temporary access roads)
* Installation of temporary construction support facilities (including such items as warehouse and shop facilities, utilities, concrete mixing facility, unloading facilities, and construction support buildings)
* Excavation for facility structures
* Construction of service facilities (including such facilities as roadways, paving, fencing, exterior utility and lightning systems, transmission lines, and sanitary sewerage treatment facilities)

The following typical documentation to be submitted in support of the application for authorisation of the above activities of the first stage of the licensing process:

* Approved Safety Case Philosophy
* Updated Site Safety Report
* Environmental Impact Assessment Report (EIR)
* Licensing Programme for the multi licensing stages
* Site Redress Plan
* Safety Case

The Site Redress Plan provides an assurance that the activities performed in the first stage will not result in any significant environmental impact that cannot be redressed.

Each licensing stage shall be scoped by making reference to the construction programme, and to the test and commissioning programme, to ensure alignment of the expectations of both the applicant and the Regulator.

3. Licensing requirements for the PBMR and the PBMR Safety Case

3.1 Licensing requirements for the PBMR

The "Basic Licensing Requirements for the PBMR" [1] describes the fundamental safety standards adopted by the National Nuclear Regulator and provides some insight into their basis and establishment. It presents the derived standards in terms of design and operational principle and in terms of quantitative risk criteria both of with which the design must comply. The document then describes the processes that the licensee must undertake in demonstrating compliance with the standards, essentially the requirements for licensing of the reactor.

The licensing requirements defined by the NNR for the PBMR cover all general safety requirements needed to protect individuals, society and the environment from radiological hazard. In this sense for the purpose of this workshop, licensing requirements and safety requirements should be considered as synonyms.

The philosophical basis for the current safety standards set down by the National Nuclear Regulator for licensing any nuclear installation or activity involving radioactive materials is presented in a set of fundamental principles referred to as the fundamental safety standards. From these standards, quantitative criteria and qualitative requirements are derived for a particular installation or activity and the licence applicant must demonstrate that the installation or activity in question will comply with these regulatory requirements.

In order for the applicant to demonstrate that the reactor will be acceptably safe, it is required that he demonstrate that the design and operation of the plant:

* respects good nuclear safety design practise,
* that it will make use of appropriate internationally recognised design and operational rules, and
* will comply with the risk and radiation dose limitation criteria.

With regard to good nuclear safety design practice, of prime consideration are the principles of defence in depth and of ensuring that risks and radiation doses to members of the public and workers will be maintained as low as reasonably achievable (ALARA) below laid down radiation dose limits.

The "Basic Licensing Requirements for the PBMR" and the licensing process adopted requires the applicant to identify all events that will be associated with the normal operation of the reactor (referred to as category A events with a frequency up to 10^{-2} /y), which will or could give rise to radiation exposure to workers or members of the public. The design of the plant must be demonstrated to ensure that such exposures will not give rise to the applicable dose limits being exceeded and will be maintained as far below these limits as reasonably achievable by optimal provision of engineered and operational safety features. In undertaking the assessment to demonstrate compliance with dose limits, conservative assumptions must be used.

The applicant is also required to identify all those events associated with the design which could reasonable be anticipated to be possible and which may give rise to accidental exposure of workers or members of the public (referred to as category B events with a frequency from 10^{-2} to 10^{-6} /y). The applicant must demonstrate that such events will either be prevented from occurring or that the design will mitigate the consequences such that radiation doses will not exceed laid down criteria and will not give rise to any serious off site radiation hazard. Again conservative assumptions must be made in this assessment.

According to the NNR requirements all events even with very low probability of occurrence or complex events of equally small likelihood, which could give rise to accidental exposure (referred to as category C events) must also be identified. A probabilistic risk assessment must be conducted which includes these and the other events (identified in categories A and B) and a demonstration provided that the risk from the reactor will comply with the criteria laid down for workers and members of the public. It is acceptable for best estimate assumptions to be made for this assessment

For this analysis a cut off criteria for the consideration and analysis of low probability events also needs to be established.

In addition to demonstrating that the reactor will be safe in terms of meeting good design and operational requirements and will comply with the risk and radiation dose criteria, the applicant must also demonstrate that the radioactive waste arising from operation and decommissioning of the reactor will be safely managed. This requires all sources of waste to be identified and characterised and that the design makes provision for collection and treatment of the waste, for control over effluent discharges and for safe storage of waste at the facility. The adequacy of these proposals will be evaluated against prevailing internationally endorsed standards for radioactive waste management and Governmental policies in terms of radioactive waste management in South Africa.

The applicant must also demonstrate that arrangements will be in place to deal with any accident that may occur. The arrangements must enable the operator to recognise the occurrence of an accident or incident, which may degrade levels of safety. Accident management procedures will be required to minimise the consequences of any accident and arrangements in place to ensure that the public and workers will be adequately protected.

3.2 PBMR safety case

The licensing process requires the licensee to present a safety case to the National Nuclear Regulator which is a structured and documented presentation of information, analysis and intellectual argument to demonstrate that the proposed design can and will comply with the licensing requirements. In order to demonstrate that the PBMR design will meet the licensing requirements, Eskom has, in consultation with the NNR, developed and implemented a structured process to develop the PBMR safety case. 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 two main components of the Safety Case are 1) the Safety Case Philosophy (SCP) and 2) the Safety Analysis Report (SAR) and Development/Support Documents.
The Safety Case Philosophy provides the high level intellectual safety argument, and demonstrate the linkage between the various elements of the licensing basis, clearly linking the Licensing requirements, the plant design basis, the plant safety assessment and the plant General Operating Rules (GORs) while the SAR provides the detailed justification for the demonstration of safety as presented in the safety case philosophy.

The PBMR Safety Case development framework is illustrated in Table 1.

As indicated in the table the following nine main elements, briefly explained below, have been identified for the development of the PBMR safety case.

A) Fundamental Safety Design Philosophy - The key safety objectives and fundamental safety principles on which the PBMR will be designed, constructed, commissioned, operated and ultimately decommissioned are defined.

B) Quality Management Programme - Over its entire lifecycle the PBMR must be supported by a quality management system.

C) Technical Description & Key Safety Characteristics - presentation of the PBMR plant technical description and key safety characteristics

D) Identification & Classification of Events - Licensing basis events. Identification and classification of all potential challenges (events) to the plant which could give rise to radiation exposure to workers or members of the public.

E) General Design Criteria (GDC)- Identification and development of the General Design Criteria against which the plant will be designed to prevent/mitigate the consequences associated with the identified events.

F) SSC Classification - Classification of Systems Structures and Components (SSCs). Present the safety classification of the plant SSCs, which provides the rationale for determining the relative stringency of design requirements and rules applicable to the SSCs as derived from the above GDC.

G) Design rules - Development of the set of rules, codes and standards which will be applied to the PBMR design, construction (including manufacturing), commissioning, operation and maintenance.

H) Safety Assessment - an appropriate safety assessment must demonstrate that the PBMR design is in line with the PBMR fundamental safety design philosophy and meets the associated regulatory requirements.

I) Support Programmes -As derived from the safety assessment a set operational programmes e.g General Operating Rules (GORs) is developed to support the operation of the PBMR.

For the development and review/assessment of each of these nine elements the following approach has been implemented:

* **Column a: Safety Case Philosophy** - the philosophical approach of each element is presented

* **Column b: Safety Case Route Map** – This basically provides the link between the Safety Case Philosophy (SCP) and the SAR. The Safety Case Route Map defines the following:
HOW will the assumptions and assertions made in the SCP be substantiated
WHERE they will be substantiated e.g. in the main body of the SAR or/and in supporting documentation
WHEN will they be substantiated in the licensing process and to what level of detail and completeness.

* **Column c: Development documentation** - giving additional detailed information e.g. safety analyses, in depth design calculations etc. Development/Support Documents are required to provide further details to the information submitted in the SAR.

* **Column d: Safety Analysis Report** - the Safety Analysis Report (SAR) documents the output of a, b and c in presenting the safety demonstration of the PBMR. Compliance with the NNR licensing requirements and safety criteria must be demonstrated by way of formalized safety analyses. These safety analyses shall be presented in a Safety Analysis Report (SAR), which shall substantiate the statements, made in the Safety Case Philosophy and be carried out in an auditable fashion under the appropriate QA regime. The SAR is the principle document submitted with the various licence variation applications as part of the staged licensing process. Specific licensing issues may require addressing by means of focused supporting licensing submissions, but these will be the exception rather than the rule.

This systematic "matrix" type process provides a framework for efficient project management and reporting mechanisms for both Eskom and the NNR.

4. Major safety issues/concerns identified

At this stage of the licensing process the NNR has not carried out an in depth review of the design and safety analysis of the PBMR. However the following concerns and issues important to safety have been identified

- **Application of Defence in Depth in the PBMR**

As indicated above one of the main consideration in the NNR safety requirements is the application of Defence in depth. As an internationally adopted principle defence-in-depth requires that there should be multiple layers (structures, components, systems, procedures, or a combination thereof) of overlapping safety provisions. Accident prevention and accident mitigation are natural consequences of the defence-in-depth principle.
The application of defence-in-depth for High Temperature Gas cooled Reactors (HTGR) is currently not supported by international guidelines and therefore there are some views amongst the PBMR designers that the PBMR fuel balls will provide sufficient levels of defence in depth. The NNR does not accept this kind of approach and considers that defence in depth principles are generally applicable and required in assuring the safety of any Nuclear Power Plants. In this respect the NNR recommended to the applicant to use, as a guideline, the approach developed in the draft document prepared by the IAEA Consultancies on "Safety and Licensing Aspects of the Modular HTGR". The applicant has taking cognisance of the NNR recommendation and has subsequently accordingly updating their Safety Case Philosophy to reflect the application of the 5 levels of Defence in Depth (as per IAEA INSAG 10) to the PBMR.
Completion of the IAEA document, mentioned above, is seen as an important milestone in the process of establishing and harmonizing international safety standards for advanced Modular HTGR reactors.

- **PBMR design basis**

One of the major safety requirements is the credibility of the PBMR design basis. Unlike for Pressurised light Water Reactors (PWRs) such as the Koeberg Nuclear power Station design, for which well-researched and documented design criteria and rules are readily available, broad international consensus has not been developed in terms of general design criteria and design rules for the PBMR. No international "off the shelf" package is available for defining the design basis of the PBMR. The establishment and documentation of a credible PBMR design basis is thus an important issue, which shall be resolved during the licensing process.

- **Requirements for the confinement structure**

Internationally there are many philosophical discussions around the acceptability of building a new reactor without having a conventional type of PWR containment. The approach of the NNR in this regard is that the design requirements of the confinement structure will be defined by the capability of the structure towards accident mitigation. Should the results of the accident analyses, demonstrate with adequate safety margins, that the PBMR design has low radiological consequences during accidental conditions, the PBMR may not require a conventional PWR type containment when considering plant faults, and therefore a conventional type of confinement structure designed to withstand external events e.g. earthquake, aircraft crash etc. might be adequate; the detailed analyses will have to support this conclusion.

In terms of these external events taking into account the recent events, which happened on 11 September 2001 in the USA, consideration is being given in terms of the criteria for the analysis of the aircraft crash.

- **Use of passive safety features and systems in the PBMR design**

A main feature of the PBMR design is the elimination of most of complex active systems that rely on a large number of safety grade support systems as for example used in PWR type reactors and the extensive use of passive safety features and systems to perform the required safety functions. This "new" approach requires the applicant, as part of the safety case, to demonstrate the capability and the reliability of these passive safety features and systems in particular for the long time response required during some transient or accident scenarios. This extensive use of passive components, could lead to the case that by sound design the safety of the PBMR is determined by initiating events of very low probability. Therefore taking into account the advanced reactor type of the PBMR and its expected inherent safety characteristics, the main change which has been made in the NNR licensing requirements in comparison with the existing requirements for PWR (as based on ANSI/ANS-51.1-1983) is in area of event categorization. As indicated above in 3.1 all design basis events have been combined into two categories A and B up to a frequency of 10^{-6} /y.

- **The PBMR annual core**

One of the new design features of the PBMR compared to the previous HTGR design e.g. the German AVR is that to reduce the peak fuel temperatures the PBMR has an annular core design with a central graphite balls column. There is currently limited experimental data, which supports this core geometry. At this stage this data is however deemed to be insufficient to give confidence that the assumed annular core geometry would remain uniform during the life cycle of the power plant, especially taking into account that the current proposed PBMR design does not cater for an instrumentation monitoring system, which could provide an on line verification of the annual core geometry. The following options could be considered to address this issue:

- establishment of an experimental program to verify that under the PBMR operational condition the core geometry can be maintained uniform; this may however prove to be quite difficult to achieve with a high level of confidence.

- Consideration for deviating from the assumed annular core geometry. Two scenarios can be envisaged: the first implies that no credit is given in the accident analyses for the annular core; this option could most probably impose some restriction on the thermal power that can be generated by the core and the second is to consider this deviation as a design basis accident in the PBMR design.

This issue is currently being discussed with the applicant in terms of which options (or mix of options) will be most appropriate.

- **Use of computer codes in safety analyses**

The design and safety calculations are performed using evolutional models incorporated in complex computer codes that simulate many different phenomena.
One of the safety rules requires that the licensee demonstrates in the safety case that the safety analysis performed for the PBMR design is comprehensive and sufficient and that all models used are robust and benchmarked against experimental data. The NNR licensing guide LG 1038[2] presents the NNR requirements for licensing submissions involving computer codes and evaluation models for safety calculations. The document defines the following specific requirements:

* A complete description of each evaluation model which is sufficient to permit technical review of the analytical approach, empirical correlations, the equations used, their approximations in difference form, the assumptions made and included in the programs, procedure for treating program input and output information, specification of those portion of analysis not included in computer programs, values of parameters, and all other information necessary to specify the calculational procedure.

* Solution convergence shall be demonstrated for each computer program, by studies of system modelling or nodalization and calculational time steps.

* Sensitivity studies shall be performed for each evaluation model, to evaluate the effect on the calculated results of variations in nodalization, time step size and phenomena assumed in the calculation to predominate. For items for which results are shown to be sensitive, the choices made shall be justified.

* The empirical models and correlations used in the evaluation model shall be compared with relevant data. Predictions of the entire evaluation model shall be compared with applicable experimental information. If an evaluational model for evaluating the behaviour of the reactor system during a postulated accident includes one or more computer programs and other

information, overall code behaviour must be checked against results from standard problems or benchmarks.

There are two main approaches used in evaluational models: Conservative and Best-estimate.

The Conservative approach is a well-known traditional one that provides assurance that calculational results and values of the critical parameters are conservative from the safety point of view. The approach has to be used carefully because in some cases the conservatism that was incorporated for calculating one critical safety parameter could introduce non-conservatism with regard to the other.

The Best-estimate approach requires the use of phenomenological models for realistic calculations of processes and systems behaviour. This kind of evaluation model must include sufficient supporting justification to show that the analytical technique realistically describes the behaviour of the reactor system during postulated accidents. Comparison with applicable experimental data must be made and uncertainties in the analysis method and inputs must be identified and assessed so that the uncertainty in the calculated results can be estimated. This uncertainty must be accounted for, so that when acceptance criteria are satisfied, there is a high level of probability that the criteria will not be exceeded.

As indicated in 3.1 above, the NNR requires to use conservative approach for the design basis accidents (category A+B) and best-estimate approach could be used for category C or risk analysis.

At this stage, it is evident that the validity of models and data used for the PBMR is not adequate to provide the safety evaluation of accident conditions which is comparable to for example what is currently available in terms of the safety evaluations of existing reactor designs e.g. PWR's.

In this respect an important part of the licensing process will be the validation and assessment of code quality and uncertainties of the results. An insufficient validation and verification of the codes may be compensated by extra margins, limitation of power etc.

There are many examples of computer codes verification and validation around the world. The approach used by US NRC for its Camp agreement to validate the Relap5 code is a good example of international cooperation, which could be applied in principle for the verification and validation of the PBMR computer codes.

Important experimental data needed for computer codes validation will need to be obtained during plant testing. Therefore the demonstration plant will be subjected to a comprehensive step by step testing and commissioning programme for the acquisition of such. The expected major testing areas are: fuel design, reactor physics, in-vessel-flow distribution and flow-induced vibration, the reactor vessel, the passive heat removal system, and the safety analysis.

The main objectives of this test programme will be:

* to resolve safety questions in order to proceed to the next licensing stage;
* decrease and justify uncertainties in the design and safety analysis;
* validate evaluation models and computer codes;
* demonstrate and validate expected inherent safety features of the PBMR design.

To fulfil these objectives a comprehensive testing programme must be prepared and justified. Each step of the testing programmes shall be supported by a safety assessment. As part of this safety justification reactor transient response shall be investigated and assessed over the maximum practical range without significant challenging the NNR safety requirements.

In order to capture the relevant data required, during the commissioning phase, the PBMR demonstration plant will be fitted with additional instrumentation and controls and other systems important to safety as identified in the safety assessment supporting the proposed testing programme, which will not necessarily be required in subsequent plants. The test programme should be directed towards internal events and conducted step by step from lower power and low decay heat to higher power and decay heat conditions.

This type of testing for the demonstration module, outline above, is one the most important part of the concept in some circles referred as " licensing by test", which will very likely be applied for the licensing of the PBMR demonstration plant should the NNR assessment concludes that the qualification and verification of computer codes as well as plant equipment in the safety case is not adequate. As indicated above as part of this concept additional margins will need to be built in the safety assessment at each step of the testing programme and additional plant hardware will be required, at least on the first demonstration module under review. This concept, which is being discussed between the NNR and the applicant, is relatively new and it requires serious consideration both from a philosophical and practical development point of view.

- **PBMR fuel issues**

The Fundamental Safety Design Philosophy of PBMR is based on the premise that the fuel adequately retains its integrity to contain radioactive fission products for all normal operating and design basis accident conditions, thereby allowing radiological safety to be assured. This is achieved by relying on fuel, whose performance has been demonstrated under simulated operating and accident conditions, and whose integrity, therefore, is not compromised even under accident conditions.

Fuel design limits are required to be established since one of the key safety features of the PBMR is based on the fuel design and performance.

The limiting value of about 1600° C for the coated fuel particles is widely accepted by the HTGR international community, and since this limit plays an important role in the safety analyses, it must be adequately justified for the current fuel design by the applicant.
To justify the fuel design limits, the applicant is required to address fuel system damage mechanisms and provide justification for limiting values for important parameters such that damage and radioactive fission product release be limited to acceptable levels.

Considering aspects of PWR fuel, related to the re-evaluation of Reactivity Insertion Accident following the CABRI REP-Na tests in France, it seems that there is insufficient experimental data currently available to justify the PBMR enthalpy limit for severe reactivity accidents, which could result in the PBMR fuel fragmentation.

Taking the above points into consideration the fuel characteristics and its quality is one of the main factor defining safety characteristics of the PBMR, therefore information concerning fuel requires very serious consideration and the NNR has identified the following issues which need to be addressed:

- The local manufacturing process and associated quality system to confirm the equivalence of locally manufactured fuel with the referenced German one and to ensure that the process will deliver fuel of a quality standard, at least equal to that of the German reference fuel, with a high confidence level.
- Level of applicability of German fuel results to the PBMR fuel to be substantiated as the conditions in the PBMR core are sufficiently different in terms of power density, power gradients, etc.
- Detailed fuel manufacturing and qualification programme must address qualification of referenced German fuel including reliability and auditability of data used for this qualification.
- The requirements for further test regime must be determined and justified. The relevance of earlier Proof Tests to in-core performance in practice is in need of clarification. It is felt that although Proof Test irradiations can test certain important parameters, it can never be fully representative of in-core conditions, particularly regarding variable mechanical and presumably thermal stresses to which fuel elements are exposed.

- Justification of enthalpy limit for severe reactivity accidents which could result in the PBMR fuel fragmentation
- Define other fuel design limits, and address fuel system damage mechanisms.

With reference to the above issues raised it is also difficult at this stage to see how the extreme fuel parameters in the PBMR core can be calculated when the dynamics of fuel element flow through the core and the extent of mixing zones have not yet been satisfactorily proven.

5. Conclusion

As presented above the PBMR licensing process is currently at the first stage of the process. The NNR has accepted the Safety Case Philosophy as being an acceptable basis to review the Safety Analysis Report, against the NNR licensing requirements, which have been formulated for the PBMR. The NNR is currently undertaking the review of the first SAR. As indicated above although the NNR has not, at this stage carried out an in depth review of the PBMR design and safety analyses, which will still require a substantial amount of work from both the applicant Eskom and the NNR (in terms of review), there are a few very important safety issues/concerns, which have been discussed above, which need to be resolved not only for South Africa but also to a certain extent for the international nuclear community as well.

From NNR point of view the following are to be addressed:

1) Completion of the draft document prepared by IAEA Consultancies on "Safety and Licensing Aspects of the Modular HTGR" is an important milestone in the process of establishing and harmonizing international safety standards for advanced HTGR reactors;
2) Containment or confinement issue taking into account heavy aircraft crash.
3) The establishment and documentation of the PBMR design basis including classification of structures, systems and components and General Operating Rules;
4) Licensing Basis Events selection and classification;
5) Reliability of passive systems in particular for the long time response;
6) Probabilistic Safety Assessment (PSA) for advanced reactors with extensive use of passive components and events of very low probability.
7) Cut off criteria for selecting and analysing low probability events;
8) PBMR annual core and core geometry
9) Computer codes, used in safety analyses, validation and verification
10) Testing and commissioning programme for the first demonstration module e.g. "Licence by test" philosophy and acceptance criteria.
11) Fuel qualification program including Reactivity Insertion Accident and fuel design limits;
12) Develop and qualify fuel system damage mechanisms.

This preliminary list of safety issues is currently receiving some serious attention in South Africa and new issues might be identified as the licensing process progresses.

References:

[1] National Nuclear Regulator document "LG 1037 Rev 1 - Basic Licensing Requirements for the Pebble Bed Modular Reactor."

[2] National Nuclear Regulator document "LG 1038 Requirements for licensing submissions involving computer codes and evaluation models for safety calculations. "

TABLE 1 SAFETY CASE DEVELOPMENT FRAMEWORK

	a	b	c	d
Sect	Safety Case Philosophy		Developmental Documentation	SAR
A	**Fundamental Safety Design Philosophy**	SAFETY CASE ROUTE MAP	Non derived numbers ❒ Good Engineering Judgement ❒ "Customer parameter file"	Link to safety case
B	**Quality Management Programme** ❒ Quality Management Philosophy and Approach		❒ PBMR QA Policy Manual ❒ PBMR QA Procedures & WIs ❒ QA of computer codes	QA Programme description and demonstration of adequacy
C	**Technical Description & Key Safety Characteristics** ❒ High level explanation of how it works ❒ Identification of Key Safety Characteristics of design ❒ Explanation of how safety design philosophy is followed		❒ Incremental development of Technical Package & Supporting Design Documentation	Technical description and demonstration of adequacy of safety design characteristics
D	**Identification & Classification of Events** ❒ Basis for identification ❒ Classification and grouping of events & link to Aa ❒ Basis for establishing Initial list of LBEs		❒ Procedure for identification & Classification of LBEs ❒ Initial List of LBEs. Final List & Classification of LBEs analysed	Identified, fully analysed set of LBEs
E	**General Design Criteria** ❒ Purpose & Application ❒ Establishment of GDCs & Preliminary listing ❒ Grouping to provide links to Aa		❒ Procedures for development & application of GDCs ❒ List of GDCs) ❒ Basis for each GDC i.e. why selected	Demonstration of compliance to GDCs
F	**SSC Classification** ❒ Classification philosophy ❒ Process of classification ❒ Links to Da, Ea &Ha		❒ Definition of classifications ❒ Procedures for classifying SSCs Definition of corresponding QA levels, & design requirements (environmental, seismic) ❒ Classification Listing	Demonstration of design compliance with classification system
G	**Design Rules** ❒ Philosophy ❒ Design process ❒ Scope		❒ PIDP procedure ❒ Selection of Codes, Standards & Rules ❒ SSC loading catalogue	Demonstration of compliance with Design Rules
H	**Safety Assessment** ❒ Philosophy ❒ Principles and Approach ❒ Deterministic & probabilistic analysis ❒ Qualification, Test & Commissioning ❒ Computer codes		❒ Justification of analysis techniques ❒ List of Assumptions ❒ Test & Commissioning Plan ❒ Ongoing assessment during procurement, construction and commissioning	PRA Event analysis & demonstration of compliance to licensing criteria. Design evaluation. Commissioning & Test Results
I	**Support Programmes** ❒ Philosophy ❒ Scope ❒ Process to establish		❒ Rules and basis for establishing Operating Programmes ❒ Operational Support Programme procedures	Description of Operating Programmes and their technical bases and link to design & safety bases.