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EMERGING REGULATORY REQUIREMENTS FOR SMALL MODULAR NUCLEAR REACTORS IN DISTRIBUTED ELECTRICAL SYSTEMS

P. NAIDOO[1], S. H. CONNELL[1], D. NICHOLLS [2], A. C. CILLIERS [2]
University of Johannesburg [1], Consultant [2]
South Africa

SUMMARY

The development of small modular reactors (SMR's) as a distributed energy source is gaining traction globally. SMR is a type of nuclear reactor that has an inherently different fuel supply and power extraction design as compared to the conventional large scale, pressurized or boiling water reactors. SMRs provide modular construction, scalable size and flexible operation in addition to conventional advantages of nuclear power production.

Safety standards and related licensing regulation make nuclear technology for power generation more expensive than other energy resources. The high fixed overhead costs have caused the power generation plants to become larger such that the safety and regulatory burden per unit cost of power generated, is lower. Today, the market boasts very large units (up to 1750MW) with multiple units on a common site. This causes the current technology to be suitable for large grid deployment such as that of large national or regional power grids.

At a distributed energy source level as in a municipal reticulation grid or a micro-grid, the nuclear regulatory compliance requirement will prevail. The emerging global practice is to develop a number of different classes of nuclear power plant regulations for the different types of nuclear power plants. This approach makes practical and affordable the regulatory requirements for the licensing and operations of small modular nuclear reactors as municipal power stations. This paper reviews the emerging global practice in regulatory requirements and submits recommendations that will accommodate the needs and requirements of all stakeholders.

KEYWORDS

Nuclear Safety and Technology, Nuclear Regulatory, Nuclear License, Nuclear Policy

nicholdr@iburst.co.za

1 INTRODUCTION

The South African Government has policy, regulatory and operational oversight for the South African Nuclear Industry. National Treasury Vote 26, names the Minister of Energy as the Executive Authority and the Director General of the Ministry of Energy as the Accounting Authority for the national budget allocation for fiscal years 2018 to 2021. The purpose of the vote is to "formulate energy policies, regulatory frameworks and legislation, and oversee their implementation, to ensure energy security, the promotion of environmentally friendly energy carriers, and access to affordable and reliable energy for all South Africans". The National Energy Act (2008), the Petroleum Products Act (1977) and the Electricity Regulation Act (2006) regulates South Africa's energy sector and empowers the Ministry to govern the sector using policies.

Table 1 illustrates the budget allocation for nuclear energy and details the destination of the funds. For the 2018/2019 financial years, R 49,5m is for the current payments and R 767.0 m is for transfers and payments to the regulatory agencies for their oversight of national policy. Their mandate is to manage the South African nuclear energy industry and control nuclear materials in terms of international obligations, nuclear legislation and policies that ensures the peaceful use of nuclear energy.

Table 1: Budget Allocation for Nuclear Energy for the three-year period 2018 to 2021

R' Million	2018/2019	2019/2020	2020/2021
Nuclear Energy	816.6	870.3	912.1
Planned Expenditures			
Nuclear Safety and Technology	796.2	850.2	890.9
Nuclear Non Proliferation and Radiation Security	9.1	9.6	10.2
Nuclear Policy	11.4	10.4	11.0
Total	**816.6**	**870.3**	**912.1**

The bulk of the expenditure is for nuclear safety and technology.

2 STRUCTURE OF SOUTH AFRICA'S OVERSIGHT OF NUCLEAR FOR ECONOMY, TRADE AND INDUSTRY

South Africa's administration consists of national, provincial and municipal structures. At all levels, there are five clusters of activities. These are designated as economic and infrastructure development, social services, finance and administration, central administration and justice and protective services. South Africa's Ministry of Energy is a member of the economic and infrastructure development and Ministry of Public Enterprise is a member of the finance and administration cluster. Table 2 presents the national departments and their executing agency for nuclear.

Table 2: National Departments and Executing Entity for Nuclear

National Department	Executing Entity for Nuclear	Purpose
Ministry of Energy	National Energy Regulator of South Africa (NERSA)	Electricity Price Regulation
	National Nuclear Regulator (NNR)	Nuclear Safety Regulation
	South African National Nuclear Energy Corporation (NECSA)	Research and Development of Nuclear Science, Engineering and Technology
Ministry of Public Enterprises	Eskom	Nuclear Power Plant Operations and Maintenance

The mandate of each is as follows:

Department of Energy:

The mission of the Department of Energy is to regulate and transform the sector for the provision of secure, sustainable and affordable energy. The Department's mandate is to ensure secure and sustainable provision of energy for socio-economic development. The strategic objective derives from the NDP, which envisages that, by 2030, South Africa will have an energy sector that promotes economic growth and development, social equity and environmental sustainability.

The Department's Energy Policy is based on the following key objectives: attaining universal access to energy; accessible, affordable and reliable energy, especially for the poor; diversifying primary energy sources and reducing dependency on coal; good governance, which must also facilitate and encourage private sector investments in the energy sector; and environmentally responsible energy provision. This mandate is from the White Paper on Energy Policy, 1998, the White Paper on Renewable Energy, 2003, and the National Energy Efficiency Strategy.

National Energy Regulator of South Africa (NERSA)

The mission of the National Energy Regulator of South Africa (NERSA) is to regulate the energy industry in accordance with government laws, policies, standards and international best practices in support of sustainable development.

National Nuclear Regulator (NNR)

The mission of the National Nuclear Regulator (NNR) is to provide and maintain an effective and efficient national regulatory framework for the protection of people, property and the environment against nuclear damage. The NNR must monitor and enforce regulatory safety standards for the achievement of safe operating conditions, prevention of nuclear accidents or mitigation of nuclear accident consequences, resulting in the protection of workers, the public, property and the environment against the potential harmful effects of ionizing radiation or radioactive material. To fulfil its mandate, the NNR advocates the development and maintenance of appropriate regulatory frameworks for enforcing regulatory radiation safety standards that are consistent with the recommendations of the International Commission on Radiation Protection (ICRP) and the International Atomic Energy Agency (IAEA). The NNR's approach to regulatory functions is commensurate with the radiation risks associated with a specific facility or activity. These include functions such as safety case reviews and assessments, authorisations, compliance assurance inspections, enforcement, drafting of regulatory documents, and overseeing emergency planning and preparedness.

South African Nuclear Energy Corporation (NECSA)

The mission of the South African Nuclear Energy Corporation SOC Ltd (NECSA) is to develop, utilise and manage nuclear technology for national and regional socio-economic development. This is effected through: applied research and development; commercial application of nuclear and associated technology; fulfilling the state's nuclear obligations; contributing to the development of skills in science and technology; total commitment to health, safety and care for the environment; developing and empowering its human resource base; and satisfying stakeholder expectations.

Eskom Holdings SOC Limited (Eskom)

Eskom Holdings SOC Ltd is South Africa’s primary electricity supplier, generating approximately 90% of the electricity used in South Africa and approximately 40% of the electricity generated on the African continent. Eskom's strategic role remains to assist in lowering the cost of doing business in South Africa, enabling economic growth, and providing a stable electricity supply in an efficient and sustainable manner. It also contributes to job creation, skills development, transformation and broad-based black economic empowerment, in support of the National Development Plan (NDP) and other country initiatives. Eskom owns and operates the Koeberg Nuclear Power Station.

3 PROPOSAL FOR GENERATION IV - SMALL MODULAR REACTORS

While small modular nuclear reactors (SMRs) theoretically offer the potential to provide support to modern distributed grids, the dominant limitation is that of safety standards and related licensing regulation. This requires the utility to maintain its own engineering and safety analysis organization, along with external technical oversight on the reactor operation. The cost overheads this induces in the plants is very large and this has driven nuclear power stations to bigger and bigger sizes to minimize the relative impact on the economics. This leads to very large units (up to 1750MW) with multiple units on a site, with many countries optimizing at four units per site. Even with this approach, the cost of regulation is still a substantial part of the costs involved. This essentially makes current technology only suitable for regional level deployment. As an example of this burden on nuclear power plants, the US Nuclear Regulatory Commission (NRC) levies a flat fee on all current nuclear reactors, with an average of $8.6 million in regulatory costs and $22 million in fees per plant [1]. While this level of administrative costs, amortization on a large (1000+MW plant) makes individual SMRs non-viable.

To allow much simpler licensing for SMR deployment at city level, the regulatory burden on the operator must reduce. The current system makes the operator liable for all aspects of the design and construction of their nuclear plant. This is like requiring every airline to be fully accountable for all aspects of the design and manufacture of their aircraft (such as a Boeing 787 or an Airbus A380). The result will be a few national airlines.

The proposal is to develop a number of classes of nuclear power plant regulation. Class 1 is the current approach for large complex designs (such as Koeberg) where the license is unique to the specific plant. Class 2 is for plants with more constraining safety limits and defined simplicity, which is a fully standardized design license for use by an organization such as a town power company. Class 3 is for a constrained, standardized license, and customised design for an industrial facility, such as water reclamation from wastewater resources or for a deep underground mine.

While any regulator has not adopted this concept, there are several moving in this direction. The Canadian regulator having different licensing criteria for plants below a given thermal size [2] and the US regulator considering different emergency planning requirements for SMRs [3].

The rationale for such draconian nuclear regulation on the operator is both the degree of damage to society from a major nuclear accident, such as Chernobyl, along with the inherent obligation on the state to provide the ultimate societal recompense. What most countries with nuclear operators require is a state determined level of insurance for nuclear damage to society linked to an obligation for the state to recompense affected parties beyond this insurance limit. The regulations ensure that the design is appropriate by technical evaluation and that the actual plant configuration, maintenance and operation respects the design intent. Clearly, this is similar to the aviation industry but, unlike airliners, there is no formal system to ensure that all the aircraft of a given design (such as a Boeing 747-400) are to the manufacturer's latest update and maintained correctly.

This paper therefore proposes that for effective roll out of SMRs to a town (distribution) level requires a fundamental change in how design, construction, operation, surveillance, maintenance and, therefore, regulation is done on SMRs as against the current approach.

The first issue is to relate the type of license to the potential impact of the reactor having any technically possible accident. This tends towards technologies that considered "inherently safe", such as High Temperature Gas-cooled Reactors (HTGRs) with **Tri**structural-**iso**tropic (TRISO) coated particle fuel or molten salt reactors with dissolved thorium based fuel.

The second issue is to have a fully standardized design with absolute vendor control of the configuration. Such a design would need to demonstrate meeting the very stringent release criteria that an urban placement would require. It would also have to demonstrate that even gross errors in the operation of the plant (such as were involved with the Chernobyl accident) would not lead to significant release. The vendor control would mean that the “sign off” of any changes to the design, maintenance and the vendor would approve operating of the plant. Even with this, it would require vendor certification of the operators and maintainers.

The regulation of this kind of plant would therefore require a similar approach to that of the US NRC Design Certification being applied to the AP1000 at Vogtle Units 3 and 4, but even more severe. In the US Design Certification approach, the vendor of the design, as the design authority, submits the design to the US Nuclear Regulatory Commission for review and approval. On approval, the future owner/operator of the actual units submits a license application to the NRC and the Design Certification removes the requirement to justify the design of the plant, with the NRC only supposedly considering the site-specific issues and the Quality Assurance (QA) of the construction.

The difference between the approach in the US NRC Design Certification and that proposed in this paper is that the Design Certification only assists the owner/operator in the licensing process; the vendor still bears no legal obligation on the plant safety and the safety standards. The design is assessed against regulations, standards and margins that are no different to that used for current designs. In the revised approach, the proposed the design would have far greater safety margins and the vendor would remain an integral part of ensuring that the safety of the plant was maintained.

In terms of the insurance requirements demanded by the state, for example, the vendor as part of his support would probably take it out to the operators of all the reactors sold, with each operator proportionally reimbursing the vendor. Clearly, the classic strict liability for all nuclear damages on the operator is between the operator and the vendor, in the same way that liability for any aircraft crash is apportioned between various parties according to the actual causes. In the case of this new licensing approach, it would still be limited to only the vendor and the operator.

To introduce the concept, the paper will consider its application to a Generation IV technology, being the HTGR. The same principles apply to other nuclear technologies. Table 3 presents the results.

In terms of the requirements of a nuclear regulator on a facility, it needs definition in terms of the risk to the public and environment by the design, operation and maintenance of the facility as well as the issues relating to nuclear proliferation risks. For each of the three classes of license discussed above there would be various constraints for each primary aspect of the plant, being design, operation and maintenance.

Table 3: Licensing for Generation IV HTGR Technology

Category	Full Utility License	Municipality License	Industrial License
Design Authority	Operating Company	Vendor	Vendor
Mechanical Design	Allows up to Active Protection Systems with operator intervention in 30 minutes	Fully passive systems for at least 72 hours	No mechanical moving parts required for the first 14 days
Electrical Design	Credit allowed for backup electrical power supplies on and off site.	Credit allowed for power supplies up to initiation of all safety functions.	No credit for power supplies.
Reactivity Control	Core criticality is safeguarded by diverse active systems i.e. US NRC 10CFR50	Core criticality has shutdown systems but can tolerate “failure to insert” for 4 hours	Maintain Core criticality by inherent system and no intervention for 14 days.
Fuel Management	Fuel movement is managed by operator and used fuel is transferred to interim storage by operator	Automated fuel management. Vendor controls core physics. No fuel recycling is used (“Once Thru Then Out” - OTTO only)	No operator involvement in fuel activities and no transfer of used fuel outside reactor system except at controlled intervals.
Fuel Accident Temp limits	1800°C with full release modelling	1600°C	1400°C
Operating Fuel Temp limits	1400°C	1200°C	1000°C
Core Thermal Power	Not constrained	250MWth	50MWth
Maintenance	Normal Maintenance program developed and undertaken by Operator.	Maintenance program fully specified by vendor with vendor certified staff undertaking work. Vendor confirms all work done to schedule	No maintenance related to safety undertaken by site staff. Specific maintenance interventions undertaken by vendor.

For noting, tests on various TRISO fuels have confirmed that there is virtually no fuel failure at 1600°C and only delayed fuel failure and limited release at 1800°C. Similarly, operating temperatures of 1200°C cause no in-service issues with qualified fuel. By design, the approach would clearly provide far greater margins for the Municipal and Industrial plant designs, therefore much reduced public risk. This allows for such less intrusive and expensive activities by the operator. It would also allow an industrial vendor to be able to take on the responsibilities and liabilities.

If the current regulation of nuclear power plants, irrespective of actual safety margins, is the only route to construct SMRs, it is virtually impossible to manage the high costs involved over the small capacity of a single SMR. Under current regulation, the only credible deployment of SMRs is as a cluster of reactors on a single site. This was the approach taken for the proposed deployment of SMRs by virtually all the major project developers. In the case of the South African Pebble Bed Modular Reactor (PBMR) it was planned to be integrated blocks of 8 reactors in one building with a total electrical capacity of 8 x 165MWe or 1320MWe [4]. Similarly, the Chinese are proposing to link six of their HTGR modules (the HTR-PM of 250MWth each) to a single 600MWe steam turbine, with several such sets on a single site [5]. In the US one of the leading SMR projects is the NuScale, which is a 50MWe integral Pressurised Water Reactor (PWR) design, is planned to be deployed in sets of 12, or 600MWe [6].

While these proposals promise some significant advantages for utility level generation they are very much at the upper size that a distributed grid would require.

Clearly one of the key issues for any such deployment is the cost. The dominant cost element for any nuclear plant is the overnight capital costs, with early units costing some more than the series production. At present there is clearly limited real cost numbers available but two of the leading SMRs have stated their expected capital costs. The NuScale has estimated its first plant will have an overnight capital cost of $5,078/kWe [7]. This number is similar to the $5,000/kWe that is the cost of the first Chinese HTR-PM that is due to start-up this year in Shidaowan, while the cost of series produced plants is estimated at $2,000/kWe to $2,500/kWe [8]

While the HTR-PM series production costs could be seen to be optimistic they must be compared with the current export cost of nuclear reactors, such as the two VVER1200 reactors the Russians are building for Belarus at the Ostrovets Power Plant with a total capacity of 2,400MW and a project cost of $11bn, or some $4,600/kWe. This project is seen to be a competitive option and therefore indicates that if SMRs can come close to the numbers they are currently discussing they could, with an appropriate regulatory regime, be a very disruptive low-carbon technology.

4 CONCLUSION

If this approach were to be followed it would allow SMRs to make a significant impact in the viability of the return of the municipal level, distributed, electrical system with far less dependence on the large national, interconnected, grid system.

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