Licensing small modular reactors

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Small modular reactor designs with power levels of less than 300 MWe are being developed in several countries. While there are several potential advantages with these reactors, they are also confronted with multiple challenges. Important among these challenges is to have these new reactor designs licensed by national regulatory bodies. Because of the many novel features incorporated in different SMR (small modular reactor) designs, careful and thorough licensing procedures are critical to maintaining safety of the nuclear fleet. This paper examines how different countries have engaged in the process of licensing new reactor designs, and demonstrates both similarities and differences between countries. In many cases, designers have emphasized the safer design and deployment features of SMRs and attempted to use those features as reasons to get existing licensing requirements diluted. This raises the concern that the promised safety enhancements in SMR designs could be offset by a simultaneous relaxation of licensing requirements.

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1. Introduction

In recent years, there has been widespread interest in SMRs (small modular reactors). These would generate between 10 and 300 MWe of electricity, with power levels much smaller than those of reactor designs that are now standard [1–3]. These reactors are aimed at solving some of the multiple problems plaguing the nuclear industry and allow the possibility of using nuclear power in market niches that have previously been difficult to enter. These market niches include developing countries with smaller electric grids, remote locations, water desalination, and industrial heat supply [4–6].

There are a very wide variety of SMR designs with distinct characteristics that are being developed. Many of them are light water reactors, the leading reactor-type that is currently deployed around the world, but there are also many designs that are radically different (Table 1). Several countries are developing and planning to construct SMRs, including the United States, Russia, China, France, Japan, South Korea, India, and Argentina.

Many expect the SMR market to be large. One widely cited assessment from 2009 concludes that there could be between 43 and 96 small modular reactors (SMRs) in operation around the world by 2030 [8]. In 2006, Advanced Systems Technology and Management, Inc., a management consulting company, projected that SMRs will capture 30 percent of the future market for nuclear reactors, which it estimated at around 1000 GW; assuming “an average SMR size of 300 MWe, this implies some 1000 units by 2050” [9]. For the United States, the Energy Policy Institute in Idaho projected a “moderate case” involving about 150 SMRs and a “disruptive case” involving about 550 units by 2030 [10]. Though these figures are only tentative projections, the belief that there will be a substantial market for SMRs seems to be widely held by policy makers in many countries. There are, of course, many who are skeptical of this proposition [12,13].

Further, the general expectation is that the first movers will have a considerable advantage in capturing the global SMR market and this would help create domestic jobs in the design and manufacture of these technologies. Partly for this reason, many countries have provided substantial government support for the development of such reactors. In the United States, for example, the Department of Energy has offered up to $452 million to support engineering, design certification, and licensing of two SMR designs.

2 The trade organization Nuclear Energy Insider estimates that just in the United States, replacing coal power plants that are to be shut down offers a market opportunity of over $30 billion [11].

3 Michael Dittmar [12] is explicit in his assessment: “During the last years some newspaper reports about future “small” scale wonder nuclear reactors appeared... However, looking at similar claims and plans from past decades one might give them not much more credibility than most people give to snake oil medicine”.

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1 According to the International Atomic Energy Agency’s PRIS database, among the 437 operating power reactors, as of March 2013, there were 354 LWRs (270 Pressurized Water Reactors and 84 Boiling Water Reactors). There are historical, political, and technical reasons responsible for nuclear power being “locked into” light-water technology [7], and this is likely to persist at least for the near-term future.
However, most of these countries also realize that there are multiple vendors offering such products. The U.S. Department of Commerce’s International Trade Administration, for example, sees “intense foreign competition, primarily by state-owned or state-aligned enterprises” as a significant challenge or obstacle [14]. Likewise, South Korea also stresses “export competitiveness” because of “intense competition among nuclear suppliers” [15].

There are multiple challenges that confront vendors of SMRs [16], with an important one being their licensing. While not strictly necessary for exports to other countries, the general expectation is that each SMR design should be licensed in one or more countries, typically their ‘home’ country as the first step to deployment.4 This, in turn, is based on the assumption that countries may be more hesitant to purchase a SMR when the design has not received its originating nation’s regulatory stamp of approval. The International Atomic Energy Agency (IAEA) offers the following recommendation to countries considering their first nuclear power plant: “Choosing a nuclear reactor design that is finalized and frozen, particularly one that has undergone licensing review in other countries, can minimize project uncertainties. While some modifications may be needed due to local regulatory requirements or due to the special characteristics of a site, a complete design helps to ensure that the project will be within budget and schedule” [18].

Many analysts have observed significant differences in the regulation of nuclear power in general [19–21]. Therefore it should not be surprising that the process of licensing new reactor designs varies significantly from country to country. These differences are related to a number of country specific factors, primarily relating to the characteristics of its nuclear energy program, and will affect the pace of deployment of SMRs as well as the kind of SMRs that may be deployed in the near to medium term.

This paper offers a survey on the state of licensing SMRs in different countries. We focus on the United States, Russia, China, India, and South Korea. The United States is arguably the country that has the largest number of SMR designs under development and the country that has the greatest financial investment into SMRs. It is the source of both the PWR (pressurized water reactor) and the country that has the largest number of SMR designs under development [21].

Table 1

<table>
<thead>
<tr>
<th>Reactor design</th>
<th>Country</th>
<th>Technology</th>
<th>Status</th>
<th>Additional applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHWR</td>
<td>India</td>
<td>Light water cooled, heavy water</td>
<td>Pre-licensing design safety</td>
<td>Desalination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moderated, helium cooled</td>
<td>review</td>
<td></td>
</tr>
<tr>
<td>HTR-PM</td>
<td>China</td>
<td>Graphite moderated, helium cooled</td>
<td>Preliminary safety analysis</td>
<td>Industrial heat</td>
</tr>
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<td></td>
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<td></td>
<td>report review</td>
<td></td>
</tr>
<tr>
<td>ACP-100</td>
<td>China</td>
<td>Light water moderated and cooled</td>
<td>Under development</td>
<td>Desalination and industrial heat</td>
</tr>
<tr>
<td>SMART</td>
<td>South Korea</td>
<td>Light water moderated and cooled</td>
<td>Standard design approval</td>
<td>Desalination</td>
</tr>
<tr>
<td>KLT-40S</td>
<td>Russia</td>
<td>Light water moderated and cooled</td>
<td>Licensed</td>
<td>Desalination</td>
</tr>
<tr>
<td>SVBR-100</td>
<td>Russia</td>
<td>Lead-bismuth eutectic cooled, no</td>
<td>Under development</td>
<td>Desalination and industrial heat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moderator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mPower</td>
<td>United States</td>
<td>Light water moderated and cooled</td>
<td>Under development</td>
<td>Not currently envisioned</td>
</tr>
<tr>
<td>NuScale</td>
<td>United States</td>
<td>Light water moderated and cooled</td>
<td>Under development</td>
<td>Not currently envisioned</td>
</tr>
<tr>
<td>Westinghouse SMR</td>
<td>United States</td>
<td>Light water moderated and cooled</td>
<td>Under development</td>
<td>Not currently envisioned</td>
</tr>
<tr>
<td>HiSMUR (Holtec)</td>
<td>United States</td>
<td>Light water moderated and cooled</td>
<td>Under development</td>
<td>Not currently envisioned</td>
</tr>
</tbody>
</table>

Table 1 Design and status information for select reactors.

HiSMUR (Holtec) United States Light water moderated and cooled Under development Not currently envisioned
Westinghouse SMR United States Light water moderated and cooled Under development Not currently envisioned

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is a more recent entrant to the nuclear exports world, having secured a contract with the UAE, and China and India have ambitious plans for nuclear expansion and exporting reactors [22–25].

While the SMR design process has advanced to different extents in different countries, and the procedures adopted in licensing them has been different, there have been some similarities. An important similarity is that SMR designers have tried to get credit for various design and deployment features (passive safety, smaller radioactive inventory, underground construction) and sought to get one or more typical licensing requirements for large reactors diluted. One thrust has been to get regulatory authorities to eliminate the requirement for an EPZ (emergency planning zone) or at least reduce the size of such a zone.3 Despite this similarity, as we describe in each of our country studies, there are variations in the way different countries have treated the issue of EPZ size.

We start with a description of the challenges involved in licensing SMRs.

2. The importance and challenges of SMR licensing

The hazards that stem from nuclear accidents have long been recognized and the consequent importance of ensuring safety at all levels has been often emphasized. The centrality of licensing reactors as part of ensuring safety has been emphasized by the International Atomic Energy Agency, which has produced guides on how this is to be carried out [32]. Analysts argue that nuclear power plant licensing plays a dual role and “should: (a) protect interests that may be affected by the new plant; and, at the same time, (b) enable investments that are assessed to be in the overall public interest” [21].

Licensing of SMRs is not likely to be straightforward. To start with, licensing any new nuclear reactor design, especially in the

4 For example, China purchased Westinghouse’s AP1000 reactors after the U.S. NRC (Nuclear Regulatory Commission) certified the design in January 2006.
5 To cite a non-SMR example, when India was preparing to import and construct VVER nuclear reactors from Russia, India’s nuclear regulatory agency stipulated that “the design of such a plant should be licensable by the Federal Nuclear and Radiation Safety Authority of Russia” [17].
6 We do not include two countries that may have been expected in this list: France and Japan. Following the Fukushima accidents Japan’s nuclear policy has been in a state of flux. France, too, has had some questions raised about its future nuclear policy following the election of Francois Hollande [26,27]. Further, its nuclear reactor design organization, Areva, has stated that its priority in the SMR field “has been on markets outside traditional electricity namely the industrial process heat market” [28]. For this reactor, Areva’s focus has been on the United States and HTGR reactor has been selected by Next Generation Nuclear Plant Industry Alliance—a US based group of companies interested in promoting, developing and commercializing HTGR (high temperature gas cooled reactor) technology, with a focus on process heat applications (petrochemicals, oil recovery, synfuel production) as well as power—as “the optimum design for next generation nuclear power plants” [29]. Given the general state of flux that has been apparent in the nuclear energy policies of different countries [30], this state of affairs could well change in the future.
7 The IAEA in fact advertises a “reduced emergency planning zone” as a perceived non-technological advantage for SMRs [31].
United States and Western Europe, has always been time consuming and costly, involving detailed analyses and reviews. Further, in practically all countries, licensing rules that are currently applied for certifying reactors have been developed for relatively large reactors. Therefore, it is likely that in most countries, current licensing procedures will have to be adapted to fit SMRs. Further, many SMR designs are novel with features that have not been deployed in any reactor so far. These unique characteristics are largely unstudied from a regulatory perspective, even in the case of SMR designs that use (light) water as coolant and moderator; examples include the integration of primary system components into the reactor pressure vessel, and the use of passive recirculation modes with low coolant flows under operational and accident situations. Further, because regulatory provisions are not available to deal with some of these novel features, many of these design concepts will have to be justified by designers and accepted by regulators before generic licenses are issued [3]. Historically, the absence of detailed rules and guidelines for alternate reactor designs has been identified as a problem and there have been calls for “licensing revision or reform” [33]. It has resulted in delays in licensing non-light water reactor designs, for example, the Thorium High Temperature Reactor in Germany [34].

The IAEA’s Nuclear Power Technology Development Section has identified a number of “key issues in licensing and design certification” for SMRs [35] that still need to be resolved. These critical issues include dealing with first of a kind engineering, the viability of multiple-modules per site, proliferation resistance and physical security, control room staffing, choice of emergency planning zone size, the use of a mechanistic source term in modeling of accident consequences, the use of risk-informed licensing methods, and technology transfer and proprietary design protection. To give a flavor of the complexities underlying these issues, we briefly describe the case of control room staffing within the U.S. regulatory context. Current U.S. NRC (Nuclear Regulatory Commission) regulations permit at most two reactors to be controlled from a single control room [36]. However, some SMR plant designs site more than two reactors at a plant. In these instances, the number of personnel required in a control room and the number of control rooms required for the entire plant by current regulations might affect an SMR design’s economic viability because the cost of plant maintenance and operations is directly tied to the number of staff required. There are further questions regarding the growth of staffing requirements as additional reactors are brought on site (as is the case for some SMR designs which call for increasing the number of reactors in response to local power demand).

At the same time, monitoring multiple reactors from a common control room poses risks. In the case of current LWRs (light water reactors), a typical control room has “a large overview display, several operator workstations, a supervisor’s workstation, and supplemental workstations for engineering and maintenance” and “is managed by a crew of three or more people” [37]. Likewise, SMRs require multiple displays. Some SMR designs require up to eight monitors to show the alarms, displays, procedures, and controls for a single unit, and, by implication, 32 monitors could be needed for four units. The ability of a single operator to monitor so much information may be problematic, and, compared with current NPPs (nuclear power plants), the likelihood of missing important information might well increase [37]. Further, operators might also have new tasks, such as moving reactors for refueling, and new missions, such as hydrogen production or desalination.

These could increase the operator’s workload and complicate navigation through the information screens [37].

3. The emergency planning zone

We now turn to the main regulatory issue that we discuss for each country: the reduction in size of the EPZ. Emergency planning, i.e., planning for actions to be undertaken in the event of a severe accident, is among the important tasks of the regulatory body. This planning has typically taken the form of listing the set of emergency measures to be followed within areas that are close to the reactor or nuclear facility. The EPZ, also known as the urgent protective action planning zone, is the area where “preparations are made to promptly implement urgent protective action based on environmental monitoring data and assessment of facility conditions, the goal being to avert doses specified in international standards” [38]. Such measures provide one of the necessary protection levels in the defense-in-depth strategy adopted for nuclear safety [3].

For reactors with thermal power levels of between 100 and 1000 MWth, the IAEA suggests an EPZ radius of 5–25 km [38]. Establishing emergency planning zones around a reactor enables the undertaking of effective protective actions to reduce the radiation exposure to the public in the event of an accident. Even if such accidents might be very unlikely, given the history of Chernobyl and Fukushima, prudence requires planning for such extreme scenarios. This may be one reason motivating some countries, such as South Korea and China, to continue with adherence to traditional requirements. Even the lower distance figure of 5 km that is suggested by the IAEA, while smaller than the EPZ size typically chosen for current standard sized reactors, is not acceptable to most SMR developers and potential operators. Many SMR vendors have advertised much smaller EPZ radii, arguing that the improved safety of SMRs is sufficient reason to lower the size of an EPZ. For example, Babcock and Wilcox lists a “small EPZ radius, down to 1000 feet”, as one of the ten “game-changers” offered by its mPower reactor [40]. Likewise, NuScale’s website announces that the design of the whole power plant “will support a reduced Emergency Planning Zone based on small core size and use of the mechanistic source term methodology” [41].

For vendors as well as operators of SMRs, there are clear motivations to advocate a smaller EPZ. As the EPZ radius increases, the set of potential sites where the reactor can be constructed comes down. Further, if SMRs are to serve as sources of desalinated water or industrial heat, they would have to be constructed closer to population centers [42]. Thus, a smaller EPZ enlarges the market of potential customers for SMRs.

Potential operators of SMRs, namely electric utilities, are also interested in a smaller EPZ. The size of the EPZ directly impacts the overall emergency plan complexity [43]. Utilities have to pay for the various activities associated with the emergency plan to be implemented within the EPZ. These include the installation and maintenance of sirens, coordination with various local and state government offices during drill exercises, and the size of the staff associated with various emergency preparedness activities. Because utilities expect the profits of the facility to be lower for a SMR compared to a traditional size nuclear unit, they seek to lower the cost and complexity of managing the emergency plan by reducing the size of the EPZ. In the United States, a particular concern is that without a reduction in the size of the EPZ, SMRs

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[38] Light water reactors are the most widely deployed reactor type.

[42] As sociologist Lee Clarke argues, disasters, even worst-case ones, are a part of life and deserve to be taken seriously [39].
cannot be sited at those locations where old coal plants are being retired.

The suggestion that EPZ sizes can be reduced substantially is not new. Indeed, in the United States, ever since the Three Mile accident of 1979, the size of the EPZ has long been a source of conflict between the nuclear industry and the federal government on the one hand, and local governments on the other [44]. The reasons given by nuclear vendors and operators for decreasing the emergency planning zone area have been countered by analysts highlighting the erosion of any potential safety advantages that SMR designs might possess [45].

We now turn to the country studies.

4. United States of America

In the United States, the Nuclear Regulatory Commission (NRC) is the primary authorizing body for an applicant intending to conduct activities involving nuclear materials. These activities include the siting, design, construction, operation, or decommissioning of commercial reactors, fuel cycle facilities, and waste disposal sites, as well as the possession, use, processing, export, or import of nuclear materials and waste and certain aspects of these materials’ transportation not handled by the U.S. Department of Transportation.

To receive, amend, or renew a license for these activities, an application is submitted to the NRC and reviewed to ensure that the assumptions are technically correct and that the activities will not adversely affect the environment. The applicant pays both for the preparation of the application as well as a fee after application submission to cover the NRC resources expended in the application review process.

The NRC develops specific review schedules for each application based on the application’s completeness and quality. An acceptance review is performed in 60 days, followed by a nominal 30-month detailed review for an application that references a certified design. Non-certified designs typically require 48–60 months to review. Many factors impact this review schedule, including NRC requests for additional information and the availability of that information.[10]

Before 1989, the NRC licensed nuclear power plants under a two-step process described in 10 CFR (Title 10 of the Code of Federal Regulations) Part 50, “Domestic Licensing of Production and Utilization Facilities.” This process required separate reviews for a construction permit and for an operating license. Under this process, the NRC reviews an application for a construction permit. If the construction permit is granted, the NRC subsequently reviews a second application for an operating license when plant construction nears completion.[11] All of the currently operating US reactors were licensed under this process, and the process is still a valid approach for licensing a new nuclear power plant.[12]

The two-step process was developed in the earlier phase of nuclear reactor construction, when designs were being evolved rapidly. A plant’s detailed design often underwent changes even during construction. However, as reactor designs matured, designs were often more stable. In an effort to improve regulatory efficiency and increase the predictability of the process, the NRC established alternative licensing processes in 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants”. This newer process allows an applicant to seek an early site permit, limited work authorization, and a combined license for construction authorization and operation. For the combined license, rather than reviewing a second application, the NRC authorizes the operation of the plant after construction is complete and the required inspections, tests, and analyses are performed. The newer regulations also allow the NRC to issue ESP (Early Site Permits), through which an applicant addresses site safety issues, environmental protection, and emergency planning independent of a review of a specific nuclear plant design to be located at the site. In addition to siting specific reactors, the NRC can also grant non-site specific design approvals, design certifications, and manufacturing licenses. These would be issued to the reactor vendor for a specific plant unrelated to plant siting.

Although the NRC process can be complex, time-consuming, and expensive, many vendors seek NRC certification as an effective “gold standard” or “seal of approval” in order to enter the export market.[13] Several SMR vendors have begun exploring NRC licensing. However, none has submitted a license application to date. Though there is far more regulatory experience with LWRs, and it is generally expected that the first SMRs to be developed and constructed will be scaled-down LWRs (especially after the announcement in November 2012 by the Department of Energy that it would support Babcock and Wilcox’s mPower reactor for technology development and design certification), the NRC has stated that it would like to be “technology-neutral” in its licensing.[14]

The NRC’s list of what it considers “critical policy issues” involved in licensing SMRs has a large overlap with the issues identified by others, including the IAEA. These include control room staffing, emergency planning, mechanistic source term, security requirements, multi-module licensing, issuing manufacturing licenses, and various economic issues such as annual fees, decommissioning funding, and insurance and liability[51]. The NRC has been issuing a series of papers focused on some of these.

As mentioned, the size of the EPZ for SMRs has been under debate. According to the NRC, the objective of setting aside a specified area as an emergency planning zone is to “ensure that the nuclear power plant operator is capable of implementing adequate measures to protect public health and safety in the event of a radiological emergency”[52]. The SMR industry recommends a “scalable” EPZ definition so that the smaller radiological source terms and passive safety features of SMRs can be taken into consideration. The same issue had come up in the early 1990s, when the NRC was considering advanced LWR designs with passive safety features. At that time, NRC had noted that “the promulgation of emergency planning requirements following the TMI-2 [Three
Mile Island] accident was not premised on any specific assumptions about severe accident probability. Hence, as a policy matter, it may be that even very low calculated probability values should not be considered a sufficient basis for changes to emergency planning requirements” [53]. Now again, there is concern about proposed changes to licensing policy and it has been argued that “weakening regulatory requirements for SMRs could erode any inherent safety features provided by their design” [54].

5. Russia

In the aftermath of Fukushima, Russia has emerged as a leader in nuclear reactor exports. It reportedly had 21 deals to build reactors in China, Vietnam, India, Iran and Turkey as of January 2012, and, according to the head of Russia’s state-owned Rosatom, has secured over $50 billion worth of reactor contracts, both domestic and export, to be delivered over a 10-year horizon [55]. Russia has several domestic designs of standard-size reactors including the VVER-1000 and its successors, and these have been the main design it has offered for export. However, Russia is also pursuing designs for SMRs including the KLT-40S, the ABV-6M, the VBER-150 and VBER-300, and the SVBR-100.17

Russian civilian nuclear regulatory authority has gone through several organizational changes in the past decade, transferring the authority to issue rules and regulations between various federal services and ministries. The primary regulatory agency that is responsible for nuclear licensing is the Federal Environmental, Industrial and Nuclear Supervision Service (Rosnedzhdoradz); the Ministry of Natural Resources and Environment is authorized to issue national requirements and regulatory provisions on the safety of nuclear facilities [58].

The procedure for obtaining a nuclear license includes: a review of applications and preliminary appraisal of submitted documents, including analysis reports on nuclear and radiation safety and conclusions of a state environmental expert assessment; a decision to issue or refuse a license; issuance of the license and establishment of terms and conditions; follow-up inspections to verify compliance; and extension, suspension, or termination of license as needed [59]. Once issued, licenses are valid for the engineered life span of the reactor (approximately 30 years), although the precedent has been established to provide lifetime extensions of 15–25 years [60].

Among the SMRs that Russia is developing, the KLT-40S will likely be the first one to be deployed since it has already been licensed and is under construction. The KLT-40S is to be deployed on a ship and therefore called the FPU (Floating Point Unit) design. It is aimed at supplying electricity, and possibly water desalination capabilities, to developing countries and remote areas. In October 2002, the power module for this design was approved by a joint decision of Russia Minatom, “Rosenergoatom” Concern, and Russian Shipbuilding Agency. The state ecological review has also been successfully completed. Russian Gosatomnadzor has issued licenses for the ATES-MM (siting and FPU construction), a complex of buildings and structures including the FPU itself, the hydraulic engineering facilities (special berth and piers for FPU docking, underwater pit, enclosed sea area), and the facilities that transfer the electricity and heat from the FPU to the coastal communities, and also perform certain auxiliary, servicing and protective functions [61]. The construction of two such reactors was completed in 2009 [62]. The Akademik Lomonosov, the first prototype ship based on the FPU design, was launched on June 30, 2010, and construction of the onshore infrastructure in Vilyuysk started in September 2010 [63].

Two larger Russian factory-built and barge-mounted designs are the VBER-150 (350 MWT, 110 MWe) and the VBER-300 (295 MWe). In 2006, a joint venture was set up between Atomstroyexport and Kazatomprom of Kazakhstan to construct these in the latter country and then export these reactors. The first two-unit VBER-300 plant is planned to be built in Aktuy city, western Kazakhstan, with completion of the first two units envisaged in 2016 and 2017 [8]. A smaller barge mounted SMR is the ABV with a power output level of 8.5 MWe. Russia is also developing a small modular fast reactor cooled by lead-bismuth eutectic, the SVBR-100. This reactor is based on experience with AFA-class nuclear submarines [64]. The SVBR-100 design is still under development and a 100 MWe demonstration plant is proposed to be built by the end of 2017 at the Research Institute of Atomic Reactors at Dimitrovgrad. The reactor’s designers expect that the preliminary safety analysis report will be completed and a construction license obtained by 2013 [65]. Even though some key issues regarding the SVBR design are yet to be resolved, including operation staff requirements, emergency planning zone size, safeguards requirements, and liability insurance, its developers state that the Russian Federation’s requirements are flexible enough to support its “innovative features” [66].

6. South Korea

South Korea has been emerging as an international vendor of nuclear reactors and related technology. Since 1997, the Korean government has prepared a CNEPP (comprehensive nuclear energy promotion plan) every five years [15]. One of the objectives of the 3rd CNEPP was “Pursuing exportation by achieving international competitiveness” and this was achieved through exporting a research reactor to Jordan and entering into a contract with the United Arab Emirates to construct four APR1000 reactors. The 4th CNEPP called on South Korea to become a global leader in nuclear technology and industry.

South Korea’s contender in the SMR race is the SMART (System-Integrated Modular Advanced Reactor), an integral type pressurized water reactor (PWR) with a rated thermal power of 330 MWe (electric power of 90–100 MWe) and capable of desalinating water to produce 40,000 tons of fresh water every day. The project to develop an SMR was launched by the KAERI (Korea Atomic Energy Research Institute) in 1996 [68]. The reactor has been promoted by the Korean government as part of its fostering of the nuclear power industry and completion of its basic design was achieved as part of the 2nd CNEPP. There has been extensive industry support and in

[15] This is, of course, only a claim and how many reactors actually get constructed remains to be seen.
[16] A smaller version of the latter design is the VVER-300, which has a lower power level (300 MW electric) as compared to the VVER-1000 design [56]. There is also a 600 MW version of the VVER.
[17] Russia is also planning to construct the BREST-300, a lead cooled fast reactor with 300 MW capacity that could technically qualify as a SMR, but this seems to be intended as a prototype for a larger 1200 MW lead cooled fast reactor [57].
[19] KAERI has been granted an SDA for a single unit construction, although the SMART can reportedly also be built in a two-unit plant site [67].
The primary organizations involved in the regulation of nuclear safety in Korea are the MEST (Ministry of Education, Science and Technology), the NSSC (Nuclear Safety and Security Commission), which acts as a safety regulatory authority, and the KINS (Korea Institute of Nuclear Safety), which plays the role of a safety regulatory expert body. The process of obtaining a license for constructing a nuclear facility involves the vendor first submitting an application for a SDA (Standard Design Approval) to NSSC [70]. NSSC then requests KINS to conduct the technical review of the proposal. As part of this review, KINS could request the industry for additional information. Following review of the results of the KINS review, NSSC could issue the license. A similar process is involved in obtaining a CP (construction permit) and an OL (operating license). After the first construction permit (CP) application has been approved, those parts of the nuclear power plant that are approved as being of standard design will be excluded in the process of safety review for further CP applications for a period of ten years from the time the SDA is issued [71].

In July 2012, SMART was granted an SDA, which makes it the first licensed land based SMR of LWR design (not including the designs from the 1950s and 1960s). Despite being the first, it may be worth mentioning that this is much delayed from earlier expectations. In 1998, for example, KAERI projected that licensing activities will be done by 2004, on the basis of “close cooperation between the licensing body and the reactor developer” [72]. But this did not proceed smoothly and in 2002, KINS started a research project to develop safety requirements and related regulatory technologies for the prototype integral reactor [73]. The work “surveyed domestic and overseas licensing procedures for nuclear reactors, developed a draft of licensing procedures for a prototype reactor to demonstrate safety and performance of new commercial reactors, and revised a draft for supplementation and amendment of the current regulation for nuclear reactor facilities” [73]. Safety review started in 2010 [74].

As in other countries, the question of what size EPZ is appropriate to SMART was raised during the license reviewing, but it was decided that the EPZ of SMART must be the same as that of a commercial power reactor [75,76]. However, SMART’s designers would like its EPZ to have a radius of 1.5 km and the LPP (low population zone) radius to be 2 km [77]. According to KAERI, the area needed for two units of SMART is about 126,000 square meters including an EAB (Exclusionary Area Boundary) [78].

The SMART is yet to apply for a CP or an OL [78]. However, the pre-application review was completed in 2010 [77]. A feasibility study on domestic construction, jointly sponsored by MEST and MKE (Ministry of Knowledge Economy), is under way [80]. Looking further ahead, KAERI expects to complete the site survey between 2013 and 2015, and begin constructing the first SMART plant in 2015, which is projected to be completed in 2019 [77].

7. China

China plans a large expansion of nuclear power and has aggressively expanded construction of reactors and other fuel cycle facilities [23]. It has also been eying the possibility of entering the nuclear reactor market as a vendor in a major fashion. Thus far, China has exported reactors only to Pakistan; these reactors have been 300 MW pressurized water reactors (CNP-300) based on the design of the Qinshan-1 reactor. But in the future, Chinese officials hope to export larger reactor designs such as the CAP-1400, a modified version of the AP-1000. In parallel, there is an ongoing program of improvements of the CNP-300 aimed at potential exports to developing countries [84]. It is not clear if this program will be continued in the aftermath of Fukushima since the CNP300 is a Generation II design.

China has largely pursued two SMR designs [23]. As with giga-watt scale light water reactors [86], different institutions have promoted their own favored reactor designs.

The first of these is the High Temperature Reactor that China has developed since the 1970s. In turn, the Chinese design was based on the prior failed German effort to commercialize the technology [87]. The HTR-PM (high-temperature gas cooled reactor pebble-bed module) builds on the experience with the pilot scale HTR-10 reactor that was developed by the Institute of Nuclear and New Energy Technology of Tsinghua University; HTR-10 reached its criticality in 2000, achieved full power operation, and began to supply power to the grid in 2003 [23]. Soon after the HTR-10 attained criticality, in 2001, the HTR-PM project was launched so as to develop a full-scale high temperature reactor [88]. The development of this reactor became a high priority under the “Chinese Science and Technology Plan” for the period 2006–2020. In February 2008, the implementation plan and the budget for the HTR-PM project was approved by the State Council of China. The HTR-PM received final approval from China’s cabinet and its national energy bureau around two weeks before the Fukushima accidents [89]. However, in the aftermath of Fukushima, all nuclear construction was frozen. In December 2012, construction of HTR-PM commenced in China’s eastern Shandong province [90,91].

The primary organization involved in the regulation of nuclear safety in China NNSA (National Nuclear Safety Administration), which is under the authority of the Ministry of Environmental Protection [92]. NNSA is responsible for developing relevant guidelines and regulations for nuclear safety, licensing and supervising reactors’ operation, drafting emergency response plans, and overseeing nuclear facility safety. Project proponents suggest that “by licensing the HTR-10, the NNSA [had] acquired large experience and knowledge of HTGRs” [88]. The HTR-PM has gone through a
number of steps towards licensing, including submission of the PSAR (Preliminary Safety Analysis Report), review of PSAR, and the Safety advisory committee’s identification of issues that need testing and resolution before the PSAR (Final Safety Analysis Report) can be issued [93].

A second, more recent, Chinese SMR design is the ACP100 being promoted by CNNC (China National Nuclear Corporation). According to one account, CNNC proposed a SMR that could “meet the increasing demand of energy in different areas and fields” in July 2010 [94]. The ACP100 is a pressurized water reactor designed to produce 100 MWe of electrical energy as well as 120,000 tons/day of desalinated water and 420 tons/hour of steam at 250 °C. It can be built in units of one to eight modules [95].

Though CNNC has been working on a LWR based SMR design for some years [96], it is only in the aftermath of the Fukushima accident that the ACP100 has been aggressively promoted by CNNC. The CNNC New Energy Corporation was established in April 2011 and charged with development of the ACP100 [97]. In November 2011, CNNC New Energy and the Zhangzhou municipal government entered into an agreement to construct two small, modular nuclear power reactors at a cost of RMB5 billion or $787 million [98]. According to an announcement from March 2012, Putian in Fujian province is to be the first ACP-100 [99]. CNNC New Energy has entered into cooperation agreements with other cities as well. In some cases, the ACP-100 is designed to produce both electricity and process heat, whereas in one coastal site, it is supposed to co-produce desalinated water and electricity.

In addition to these electricity-generating reactors, China has also had a long-term interest in using nuclear reactors for heating. Nuclear heating reactor technology has been included in the National Industrial Restructuring Guidance Catalogue [97]. A 5 MW experimental nuclear heating reactor started operating in 1989 [100]. In 2003, it was reported that a NHR200 (nuclear heating reactor) had been designed for Shenyang city in Liaoning province [101]. The NHR200 is an integral pressurized water reactor that has a power capacity of 200 MW thermal. It includes no electrical generation equipment within its standard configuration and is a dedicated district heating reactor but it could supply heat for seawater desalination. Though no construction has been initiated, it is not expected to pose any licensing issues in China if a particular deployment project is negotiated [3].

As elsewhere, SMR developers have tried to reduce the size of the emergency planning zone, perhaps in the hope of eliminating it altogether in the future. In the case of the HTR-PM, project proponents note that technically “off-site emergency planning measures can be simplified remarkably” [93]. Likewise, one of the aims of the ACP100 is “to eliminate the emergency evacuation zone of a nuclear plant” so that in “the near future, nuclear plants can be built right next to cities” [99]. Project proponents do advertise the reactor as requiring a “smaller emergency off-site area” [95].

When it comes to deploying the first set of HTR-PMs, its designers have adopted a different strategy. While talking about “the technical possibility that HTR-PM can eliminate [the need for] offsite emergency planning”, they have chosen to co-locate these reactors with large light water reactors (LWRs) so that the latter’s EPZ requirements would dominate [102]. The obvious result of this strategy is that there would be no need for the developers of the HTR-PM to enter into a debate over whether the EPZ for the HTR-PM should be reduced.

8. India

India has a long history of interest in nuclear power and has ambitious plans for a large expansion of nuclear generating capacity. For over three decades since its 1974 nuclear weapon test, India was not allowed to participate in international nuclear commerce, but this state of affairs changed following the 2008 decision by the Nuclear Suppliers Group to allow the country to re-engage in nuclear trade. Since then, India has been trying to enter the reactor market as a vendor. The majority of the reactors deployed in India are 220 MW pressurized heavy water reactors based on the Canadian design imported in the 1970s. It has therefore tried to position itself as a potential exporter of small and medium sized reactors, which Indian nuclear officials have advertised as being an “optimum solution for the countries where medium size electricity grids are in operation, and are keen on expanding their power base” and having a “capital cost much lower than other reactors in the international market” [103].

The main new SMR design that India is interested in marketing is the AHWR (Advanced Heavy Water Reactor), which Indian officials have described as an “innovative” reactor with “several new features” including “utilization of thorium on a large scale and inclusion of several passive safety features” [104]. The design that had been developed since the 1990s involved the use of large quantities of plutonium as fuel [105]. In 2009, the Chairman of the Atomic Energy Commission announced that India had made an export version of this design called the AHWR-LEU, which will dispense with plutonium use as input and use LEU (low enriched uranium) instead [106]. This modified design is advertised as possessing “intrinsic proliferation resistant features” [107]. The DAE (Department of Atomic Energy) is aiming this reactor for a specific “market space”: “developing countries” which may only have “modest industrial infrastructure” [25].

Civilian nuclear installations in India come under the regulatory purview of the AERB (Atomic Energy Regulatory Board). The AERB is tasked with “laying down necessary rules and regulations and ensuring that all the safety criteria thus laid down are adequately met” by nuclear operators [17]. Safety review of new designs is carried out by the AERB’s Nuclear Projects Safety Division.

The AERB started the pre-licensing safety review of the original AHWR design (with plutonium fuel) in 2005 “to identify specific areas that need to be resolved before the formal licensing process of the reactor” [108]. This resulted in a list of issues that had to be resolved before licensing of the AHWR design. However, in the interpretation of the BARC (Bhabha Atomic Research Center) that is developing the reactor design, the pre-licensing design safety committee “concluded that there was no potential issue that could preclude the licensing of AHWR” [109].

Despite this description, the issue of the emergency planning zone has yet to be resolved. According to the AERB’s sitting rules for nuclear reactors, the EPZ extends to a radius of 16 km (10 miles) without any reference to the power level of the reactor [110].

25 CNNC New Energy Corporation is a joint venture between China National Nuclear Corporation (51%) and China Guodian Corporation (49%) [98].
26 India is also interested in the development of “technologies for hydrogen production by splitting water, utilizing high temperature process heat produced by high temperature nuclear reactors… Under its high temperature reactor program, currently India is developing a Compact High Temperature Reactor as a technology demonstrator for associated technologies. In addition, several design options for a 600 MW with Innovative High Temperature Reactor for commercial hydrogen production are also being evaluated” [105]. Both of these programs are still in the early stages.
28 The AERB is to be replaced by the NSRA (Nuclear Safety Regulatory Authority) once it has cleared the parliament.
However, Indian nuclear officials have stated that the AHWR is so safe that “even in the worst of the accidents, there would be no long-term impact on the people near the plant” and thus “nuclear plants can be constructed anywhere—even in the heart of densely populated cities” [111]. Indeed, the developers of the AHWR would like to construct the reactor in Vishakapatnam [112], a city on the eastern coast of India with a population of 1.7 million (according to the 2011 census). But, they may not be able to do so because the AERB’s “siting criteria being followed now cannot be fulfilled” [112]. Though there is evidently the expectation that the AERB will revise these criteria for the AHWR, because it “has a multitude of advanced, passive safety features that rule out any impact in the public domain”, the first AHWR “will be operated in a demonstration mode and so no exemption from the existing AERB criteria has been sought” and so BARC is looking for a different location for the first AHWR before approaching AERB “for design safety reviews”.

9. Discussion

SMR vendors are confronted with intense market competition and inherent economic challenges, and argue that current regulations impact SMRs (compared to current gigawatt-scale reactors) disproportionally. In countries like the United States, vendors and potential customers, such as utilities, are unlikely to proceed with commercializing SMRs without some or all of these changes. Because of the perceived importance of being the first SMR to be marketed internationally, and the strong commitment on the part of national governments in countries developing SMR designs, it is likely that there would be pressure on regulators to approve these changes.

At the same time, these changes raise the concern that advanced safety features that some SMR designs might be able to demonstrate could be “offset” by a simultaneous relaxation of licensing requirements, e.g., by siting SMRs closer to urban areas. Because of the many novel features incorporated in different SMR designs, careful and thorough licensing procedures are critical to maintaining safety of the nuclear fleet.

Further, one challenge that confronts the expansion of nuclear power has been adverse public opinion [113]. Modifying licensing requirements in order to make SMRs more economically competitive will likely impact how the public perceives these new reactor types and their deployment. If there are questions about the economic viability of SMRs, then it may be more advisable to address those through technological and manufacturing innovation.

10. Conclusion

In our survey of licensing SMRs around the world, we observe both differences in approach and similarities. At one extreme is the United States, where there is a substantial emphasis on light water reactor (LWR) based SMRs primarily because the NRC has the most experience with licensing large LWRs, and where the SMR industry appears to be most interested in obtaining exemptions from several current rules. Regulatory authorities in several other countries seem to be more open to novel designs or deployment modes (Russia to lead-cooled fast reactors and floating power plants, India to thorium based heavy water reactors, and China to gas cooled high temperature reactors) and appear to be proceeding faster with licensing. In South Korea, on the other hand, the vendor of the SMART was apparently less concerned with the size of the EPZ.

The primary similarity in the licensing of SMRs has been the effort by vendors in all countries, albeit to varied extents, to change various existing requirements for nuclear reactor licensing. These include security requirements, insurance and liability arrangements, annual fees, and the size of the emergency planning zone.

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References

[17] Koley J, Harikumar S, Ashraf SA, Chande SK, Sharma SK. Regulatory practices and inherent economic challenges, and argue that current regulations impact SMRs (compared to current gigawatt-scale reactors) disproportionally. In countries like the United States, vendors and potential customers, such as utilities, are unlikely to proceed with commercializing SMRs without some or all of these changes. Because of the perceived importance of being the first SMR to be marketed internationally, and the strong commitment on the part of national governments in countries developing SMR designs, it is likely that there would be pressure on regulators to approve these changes.

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References


Wiwel M. Personal email, 12 February, 2013.


Wiwel M. Personal email, 12 February, 2013.


Wiwel M. Personal email, 12 February, 2013.


Feigenbaum T. Generation mPower. Columbia, South Carolina, USA; 2012.


Tu KJ. Nuclear crisis in Japan: preliminary policy implications for China/32b.


Mayfield M. Advanced reactor program overview of small modular reactor licensing; 2012.


NRC. Policy, technical, and licensing issues pertaining to evolutionary and advanced light-water reactor (ALWR) designs. Washington, D.C: Nuclear Regulatory Commission; 1993 Apr. Report No.: SECY-93


[107] Ramkumar KL. Th-LEU Fuel in AHWR to enhance proliferation resistance characteristics. Vienna, Austria; 2011.


