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Communication dated 8 July 2021 from the Chairman of the International Nuclear Safety Group (INSAG)

On 8 July 2021 the Director General received a letter from the INSAG Chairman Richard Meserve, providing his perspective on current emerging safety issues. The aforementioned letter is circulated herewith for the information of the General Conference.

CARNEGIE INSTITUTION FOR SCIENCE

Richard A. Meserve
President Emeritus
rmeserve@carnegiescience.edu

July 8, 2021

Director General Rafael Mariana Grossi
International Atomic Energy Agency
Wagramer Strasse 5
A-1400 Vienna
Austria

Dear Director General Grossi:

I am writing in my capacity as Chairman of the International Nuclear Safety Group ("INSAG"). Our terms of reference state that INSAG should provide "recommendations and opinion on current emerging safety issues" to the IAEA and others. During my term as Chairman, I have customarily sought to fulfill this obligation not only through the various INSAG reports, but also with an annual letter. This correspondence constitutes this year's installment of the annual letter. My past letters are available on the INSAG website at http://goto.iaea.org/insag.

This letter will focus on the strong interest in innovative advanced reactor designs and the need for action by those Member States that contemplate their deployment. Nuclear power is an important tool in the response to climate change and advanced reactors may offer advantages over existing plants in providing carbon-free generation at the scale necessary to respond to the existential challenge that climate change presents. The IAEA is aggressively pursuing issues related to the possible transition to advanced reactors. This letter is to urge a redoubling of effort by the Member States to put in place the necessary capabilities to deal with the challenges that they present.

Many countries are responding to threat of climate change by promising to move toward radical reduction of carbon emissions by 2050 or before. This will require a revolution in energy generation and the transition must start many years before the target date. Given that nuclear power plants (NPPs) are long-lived investments that require many years to plan, construct, and incorporate on the grid, there is no time to waste in preparing for that changed world.

There are about 440 nuclear reactors operating in the world, providing about 10 percent of electrical supply and about 30 percent of carbon-free generation. Most of these are light water reactors (LWRs), reactors that use ordinary water as a moderator and coolant. Although there will no doubt be continuing reliance on

Carnegie Institution
of Washington

1530 P Street NW
Washington, DC 20005

202 387 6400 Phone
202 387 8092 Fax

existing and new LWRs in the coming years, there has been a resurgence of interest in innovative advanced reactor designs. Some of these reactors use different coolants (gas, liquid metal, or molten salt), different moderators, and, in many cases, apply simplified, passive, or other innovative means to achieve their essential safety functions. Some utilize a fast neutron spectrum (LWRs have a thermal neutron spectrum). Some of them use fuel of higher enrichment and of different chemical and physical form from LWR fuel. Some promise to operate at higher temperatures, thereby improving thermodynamic efficiency and allowing more extensive process heat applications. Unlike some current LWRs for which security-related elements were an add-on to the plants, security can be improved by incorporating security features in the basic design of these contemplated plants. Moreover, the proposed designs exploit advances in engineering, materials, computer technology, and modern digital instrumentation and control to a greater extent than existing plants.

Although existing LWR power plants of recent vintage typically offer output of about 1 GWe per unit, the advanced reactors are being proposed in a range of sizes. Many of the designs have a power output from 50 MWe to about 300 MWe – these are so-called "small modular reactors" (SMRs)– and a full power plant might incorporate several such modules with a common control room. Some vendors are also pursuing "microreactors" – reactor designs with power outputs of 1-20 MWe – which could provide reliable power in remote locations or in emergency circumstances.

The vendors who are pursuing advanced reactors claim a number of advantages. They are hopeful that the new designs will offer electrical output at lower cost per kWh, thereby making nuclear more competitive with alternatives. Indeed, the achievement of improved economics is likely to be essential if nuclear power is to play a major increased role in the response to climate change. The lower costs are believed to be achievable as a result of serial factory fabrication (thereby minimizing costly on-site construction), modular construction and standardization, advanced construction techniques, and simplified designs. Moreover, because many of the offerings provide much smaller power output, the total capital investment cost may be more manageable for some owners. And the smaller size may be particularly attractive to countries with small regional grids. (As a rule of thumb, no power plant should constitute more than about 10% of the capacity on a grid so as to enable the plant to shut down for refueling or for safety reasons without seriously disrupting power availability.)

Many countries moving to carbon-free electrical generation are planning to rely on renewables, backed up by nuclear power, storage, and possibly fossil generation with carbon capture and storage. The advanced reactors may be attractive in this changed environment, particularly if they achieve competitive costs per kWh. Some of the advanced designs enable greater load-following capacity, thereby helping to respond to the intermittency of renewable generation. Moreover, at times when there is an abundance of renewable power, the output of the nuclear plant could be diverted to hydrogen generation (for use as a synfuel or as an energy storage medium), desalination, district heating, or industrial process applications. The higher temperature operation of some of the advanced reactors could open up greater opportunities for the exploitation of this versatility.

The IAEA has many activities to confront the various issues that advanced reactors will present, but there is a need for the nuclear community (regulators, operators, vendors, contractors, equipment suppliers, technical support organizations, standards organizations, and architect-engineers) to confront the challenge before it. Indeed, since SMRs may be particularly attractive to new entrant countries, there is a special challenge that they will confront by perhaps being in the first wave of countries who apply these advanced reactor technologies.

Some of those challenges include the following:

Safety. All of the advanced designs claim significant safety advantages over existing designs. Many of the designs have cores with less radionuclide content (and hence a smaller accident source term) and some contemplate the use of advanced fuels that can withstand much higher temperatures before failure when compared to current fuel now used in LWRs. Other designs operate at near atmospheric pressure, avoiding the high pressures of LWR operation that can propel debris and radionuclides in an accident, thereby reducing the need for robust piping, pressure vessels and containment structures. Many of the advanced design rely on passive systems – that is, systems that use gravity, natural convection, or pressure gradients – to achieve safety objectives, rather than pumps, automatic valves, and AC power. It is anticipated that advanced reactors will rely less on operational measures and human intervention to ensure safety than existing reactors, thereby allowing relaxation of a regulatory strategy of overlapping safety provisions to compensate for human failures. If effective, these various changes potentially offer significant safety advantages, as well as a means to simplify the reactor in ways that reduce cost. But careful analyses backed by test data and validated codes and simulation tools will be required to establish that such systems are effective in the variety of circumstances in which there is dependence on them.

Advanced reactors may also present new safety challenges. For example, those designs that rely on multiple modules to achieve the required total power will require careful consideration of possible interactions among modules during transients and accidents. Sodium-cooled fast reactors will require consideration of and protection against effects of sodium-water and sodium-air chemical reactions. Molten salt reactors will require careful consideration of corrosion issues and potential freezing of molten salt in piping. Indeed, innovative designs may have failure modes and accident sequences that may be novel and thus difficult to identify. A regulator must be prepared for a significant challenge in analyzing the safety case for an advanced reactor and in adjusting its regulatory requirements, which are now focused on LWRs, to these different technologies. It will be important at the same time to maintain adequate defense in depth and to assure a balance between accident prevention and accident mitigation.

<u>Security</u>. As noted above, most existing reactors were not designed with security issues as a primary concern, but security was significantly upgraded during operations as the terrorist threat has grown. There is the opportunity and need to incorporate security considerations in the design of a new plant. Many of the modern designs place the core below grade, thereby enhancing the ability to withstand sabotage, such as by an aircraft attack. Passive safety systems, smaller cores, accident-tolerant fuel, and increased use of automation (thereby limiting insider-threat challenges) all hold the promise to improve security. Security considerations in the layout of the plant can similarly reduce the vulnerability of vital areas. The key point is that safety and security should be considered together in evaluating a new design so as to assure that both purposes are served appropriately. A forthcoming report being jointly prepared by INSAG and AdSec (the Advisory Committee on Security) will reinforce the importance for enhancing the coordination between safety and security. *See also* INSAG, "The Interface Between Safety and Security at Nuclear Power Plants" (2010) (INSAG-24).

<u>Safeguards</u>. Many of the advanced reactors are designed to use fuel of up to 20% U-235, considerably higher than the enrichment of about 5% that is now typical. Greater security and safeguards requirements attend this change in enrichment. Of greater significance, several of the advanced reactor designs require reprocessing of used fuel to put it in a stable chemical form for storage and disposal or for recycling through the reactor. Any such processing will require safeguards monitoring to assure that weapons-usable content is not diverted. Again, safeguards should be considered as an aspect of the design along with safety and security.

Fuel. Many of the advanced reactors contemplate the use of novel fuel forms or even, in the case of some molten salt reactors, the use of fuel that is dissolved in the molten salt coolant. All fuels must demonstrate a certain level of accident tolerance while meeting various performance standards, such as retention of fission products and cladding-coolant compatibility. Moreover, some advanced reactors contemplate the use of reprocessed fuel or even thorium-based fuel cycles. There may be limited data on the performance of new fuel types and there is the necessity for such data to support the safety case.

Emergency Planning/Siting. Existing LWR nuclear plants are often sited in remote locations to protect the public from exposure to radionuclides in the event of an accident. The vendors of some of the advanced reactors believe that their designs can justify relaxation of such siting requirements. They assert that their designs are sufficiently safe or that the consequences of an accident are sufficiently small that a modification of the current siting approach can be justified. Indeed, such relaxation is absolutely essential if some of the proposed uses of the reactors are to be realized. For example, some of the vendors anticipate that their designs will be used to provide high-temperature process heat for industrial applications, which requires the reactor to be in the vicinity of the facility that uses the process heat (perhaps, for example, a chemical plant). It must be demonstrated that an event or accident in the adjacent facility does not compromise the safety of the reactor. Some vendors of SMRs also contemplate that their designs might be deployed as replacements for similarly sized fossil plants, thereby benefiting from existing transmission facilities and nearby cooling water. Many such fossil plants are near to or in the middle of urban areas. Careful and early examination of siting and emergency response issues, taking into account the promised safety characteristics of advanced reactors, will be necessary to define the future range of economic opportunities that are available for such reactors.

International Trade. Many of the vendors clearly are hopeful of international sales. Indeed, given the anticipated efficiencies that may result from serial production, substantial foreign sales may be an essential part of their business plans. It is expected, for example, that SMRs may be particularly attractive to developing countries because their total cost should be more manageable than that of a GWe-scale LWR reactor and the electrical output may be more appropriate for smaller grids, in addition to the promised safety advantages, faster construction, and reduced operational costs. There is a danger, however, that adaptations or modifications may need to be made to satisfy licensing requirements in each country in which a plant is sold. This obviously could increase cost and diminish the prospects for international deployment.

Although there are important efforts by the IAEA and the NEA to harmonize licensing requirements, continuing attention to this issue may be essential to enable the promise of advanced reactors to be realized. There also should be a close technical and regulatory relationship between the vendor country and the receiving country. *See* INSAG, "Licensing the First Nuclear Power Plant," (2012) (INSAG-26).

Waste. Many of the advanced reactors promise to have extended fuel cycles and to produce less used fuel than existing LWRs. However, as noted in a recent annual letter, progress in the disposal of spent fuel has been extraordinarily slow and most existing nuclear countries have no disposal path in place. *See* INSAG Annual Letter of Assessment, 2019. The disposal challenge will only grow larger as there are more reactors in more places. The failure to grapple with the problem serves to undermine the prospects for the usage of nuclear power at a time when it is most needed because those concerned about nuclear power can justifiably point to the waste situation as a reason to reject nuclear power. The accumulation of spent fuel (and high level waste) must eventually be confronted and there is no justification for delay.

Materials. Some of the advanced reactors may present materials challenges because of the harsh chemical environment, high temperatures, or the fast neutron bombardment of structures. There is an opportunity for the application of new materials – new claddings, new alloys, and the like – to overcome these challenges. But new materials must be tested to ensure their performance. There is a need to move swiftly to provide the necessary testing data that will allow these materials to be used.

Digital Instrumentation and Control. Many of the advanced reactor designs incorporate extensive usage of automation to improve safety by using technology to diminish the demands on operators and the potential for human error, and to allow reduced control-room staffing. The regulatory issues associated with assuring the reliability of such systems must be confronted, along with the technical issues associated with new coolants, fuels, and safety systems. Moreover, as more reliance is placed on digital systems and artificial intelligence, recent events have reinforced the importance of heightened cybersecurity.

Public acceptance. In many countries the public is hesitant to accept reliance on nuclear power because of fears of the technology. This reality must be recognized and confronted if the role of nuclear power is to be realized. The nuclear industry has an obligation to discuss nuclear safety issues in an open and comprehensible way and to respond to legitimate questions and challenges. The establishment of public trust will require the candid and transparent acknowledgment of the issues associated with nuclear power and a balanced appraisal of its costs and benefits.

In sum, there are many difficult challenges that must be overcome if advanced reactors are to play an important role in the response to climate change. The IAEA is doing its part. Because the designs of innovative advanced reactors are technologically diverse, the IAEA is working on the establishment of a technology-neutral framework for safety, security and safeguards to facilitate the development of harmonized safety standards. But, as indicated by this letter, there is much work to be undertaken by all those in the nuclear community and any delay in confronting the challenges will serve to limit the opportunity for nuclear technology to contribute in a timely way to the threat of climate change.

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INSAG will continue to monitor the many activities surrounding the prospects for advanced reactors and intends to offer its advice from time to time as the circumstances warrant. In the meantime, please feel free to contact me if INSAG can offer assistance on this or other matters.

Best regards.

Very truly yours,

Richard A. Meserve

cc: DDG Lydie Evrard
INSAG Members