Export Possibilities for Small Nuclear Reactors

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ABSTRACT

The worldwide deployment of peaceful nuclear technology is predicated on conformance with the Nuclear Non-Proliferation Treaty of 1972. Under this international treaty, countries have traded away pursuit of nuclear weapons in exchange for access to commercial nuclear technology that could help them grow economically. Realistically, however, most nuclear technology has been beyond the capacity of the NPT developing countries to afford. Even if the capital cost of the plant is managed, the costs of the infrastructure and the operational complexity of most nuclear technology have taken it out of the hands of the nations who need it the most.

Now, a new class of small sodium cooled reactors has been specifically designed to meet the electrical power, water, hydrogen and heat needs of small and remote users. These reactors feature small size, long refueling interval, no onsite fuel storage, and simplified operations. Sized in the 10 MW(e) to 50 MW(e) range these reactors are modularized for factory production and for rapid site assembly. The fuel would be <20% U235 uranium fuel with a 30-year core life.

This new reactor type more appropriately fills the needs of countries for lower power distributed systems that can fill the gap between large developed infrastructure and primitive distributed energy systems.

Looking at UN Resolution 1540 and the impact of other agreements, there is a need to address the issues of nuclear security, fuel, waste, and economic/legal/political-stakeholder concerns. This paper describes the design features of this new reactor type that specifically address these issues in a manner that increases the availability of commercial nuclear technology to the developing nations of the world.

INTRODUCTION

The global market for energy is evolving away from fossil fuels and towards renewable/sustainable sources faster than we are environmentally capable. The accelerating pace of growth however, demands a diversity that includes high density application of distributed power; especially true in 3rd world countries without extensive grid transmission and distribution infrastructure.

Recent geo-political events also highlight the need to plan for chronic future upward pressure on natural gas and oil prices. High-density power needs in remote areas with hostile climatic conditions provides good potential (niche) market application for smaller – e.g. <100 MW(e) nuclear plants. Examples include polar regions (e.g. Alaska) isolated mines (including oil shale, gold, etc.), petro-chemical (including hydrogen production) processing/refining and/or scientific missions, recreation resorts or other specialty government "base operations" applications.

Security concerns become central to maintaining reliable supplies of power, heat, water (e.g. via desalination), hydrogen and other "life giving" outputs provided by a high-density power source. Like a space ship or nuclear submarine the elements of this hostile external environment are as much of a "threat" as any predator, terrorist intruder or other malevolent effects. The same basic design features therefore protect the high-density power source from any "subset" of security concerns – including nuclear proliferation.

This paper explores the practical viability for technology export of suitable small nuclear reactors. A close examination is made of the basic features for this distributed power solution. In general, standard design criteria need to adequately consider impact from the basic "nuclear worries" – fuel type, nuclear waste, threats to physical security and all-in capital/operating & other life cycle cost. The challenge is to properly address these worries in the design in order to make export of nuclear technology become more widely accepted.

SECURITY ISSUES - FULL SPECTRUM INTEGRATED DESIGN AND OPERATIONS

On March 28, 1979 a complex loss of coolant accident occurred at the Three Mile Island-2 Nuclear Power plant near Harrisburg, PA (Ref. 1). Many beneficial safety, operational and process improvements in policy/stakeholder communications have been implemented at the (103) US nuclear plants. (Ref. 2) Then, following the February 1993 WTC attack and security breach/intrusion at TMI-1, in 1994 the US Nuclear Regulatory Commission (NRC) amended 10 CFR Part 73 "Physical Protection of Plant and Materials" to include the use of a four wheel drive land vehicle, by adversaries, for transporting personnel, and their hand-carried equipment, to the proximity of the safe shutdown equipment and structures, and to include a land vehicle bomb. When this rule was implemented, it was generally viewed as excessively conservative by personnel at all levels in the nuclear industry. The terrorist attacks of September 11, 2001 dramatically changed this thinking; (Ref. 3) outlines steps taken by the US NRC (published Sept. 21, 01) to immediately assess the security condition at the US commercial nuclear plants. Other State and Federal level actions (e.g. formation of Department of Homeland Security (DHS) have been positive steps. This "gold standard" is continually being improved.

The classic nuclear culture/approach has always been regarded as defense in depth from the 'inside-out' perspective; i.e. lines of functional defense (D) to protect the public with layers moving outward from DI (nuclear fuel cladding) to DII (reactor coolant) to DIII (reactor vessel and systems) to DIV (robust containment building). This was illustrated in the classic Three Mile Island accident, when the last line (the Reactor Building) performed to protect the public. Full-spectrum integrated risk management also involves an evaluation of SWOT-Strengths, Weaknesses, Opportunities and Threats (Ref. 4). These are defined as follows: Strengths (risk resistors) – good points; Weaknesses (risk sources) – areas of vulnerability; Opportunities (upside risks) – positive improvements not currently planned; Threats (downside risks) – anything that might go wrong. In the past, the primary focus with regard to nuclear plants in the area of risk has been on the fear driven or negative W and T of the SWOT formula, which had resulted in the existence of an overall "worry culture". Ever since the 1950s, there have always been people who are extremely doubtful about – indeed, often distrustful towards – nuclear power. Actual safety performance and perception have both improved [actual safety by a factor of 100 since 1978 (Ref. 5)] – while a more positive/confident approach is evident in 21^{st} Century nuclear – with much more emphasis other S&O of SWOT… well over 20 years beyond such negative events demonstrated on the world stage with dramatic accidents at Three Mile Island & Chernobyl. Since the events of September 11, 2001 renewed concerns exist (which are emotionally charged by the media – in the month before September 11 events, there were 57 stories world-wide about nuclear terrorism; the following month there were 1106) (Ref. 6). Therefore, a new more enlightened approach depends even more than ever on highlighting S&O aspects to deal more effectively with terrorist threats – even those such as media manipulation where psychological warfare becomes a real factor. As such, we must supplement classic nuclear planning to also include examination of security defense in depth oriented from the OUTSIDE IN.

Included in the environmental security threats would be weather, animal intrusion and malevolent human intrusion including both economic piracy and para-military or non-government sponsored terrorism. Electronic surveillance and detection systems in combination with engineered physical barriers can provide a high level of protection for high value/high risk assets. Examples of aesthetic physical barriers used at nuclear facilities as well as chemical and petrochemical facilities are shown in Figure 1 and Figure 2. These engineered vehicle barriers possess high kinetic energy absorption capacity capable of stopping very large (high mass) vehicles traveling at high speeds. Figure 3 depicts a more utilitarian type vehicle barrier, which also possesses high kinetic energy absorption capacity. Such barriers are designed to prevent slow push-through as well as high-speed impacts for large (high mass) vehicles.

Figure 1 – Cast-in-place reinforced concrete wall designed to appear as masonry, serving as a high energy capacity vehicle barrier

Figure 2 – Landscape masonry wall backed by a soil berm serving as a high energy capacity vehicle barrier system while allowing for pedestrian traffic

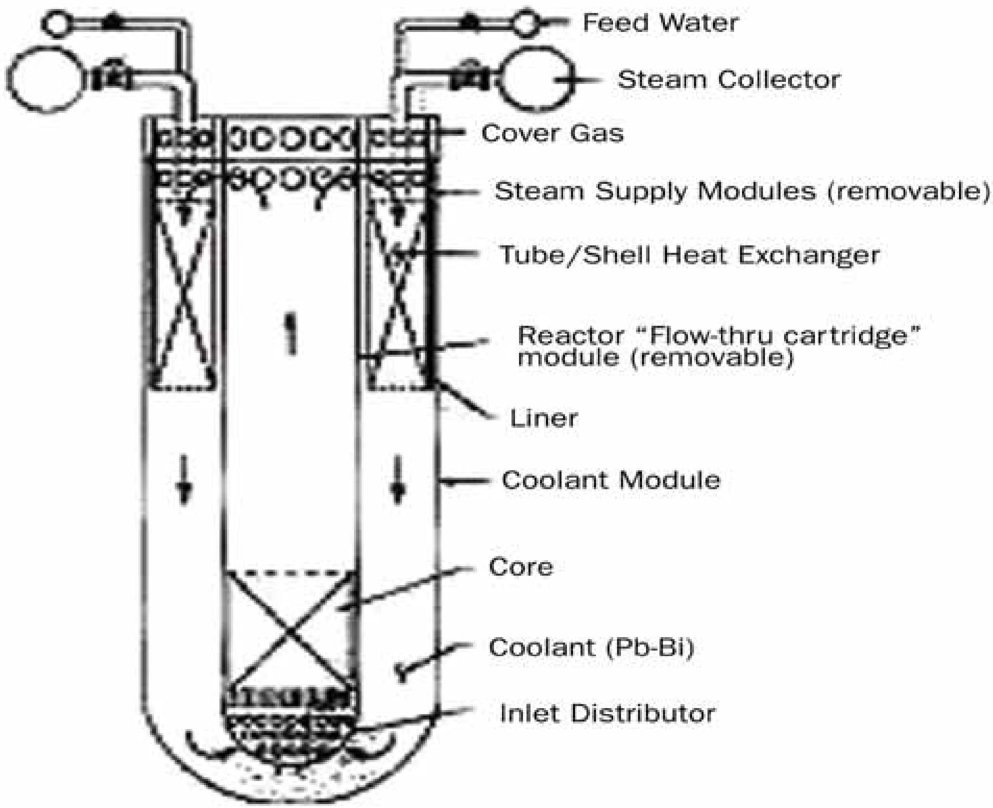
Figure 3 – High energy capacity/high deterrent, surface mounted precast concrete inertia vehicle barrier system

REACTOR DESIGN – CRITERIA TO ADDRESS THE FUEL, WASTE AND COST ISSUES

Past efforts (References 7, 8, 9 and 10) illustrate specific examples of promising smaller (e.g. <100 MW(e) reactors that are also fast or actinide burners. Such prominent firms and laboratories as (Toshiba/Japan [Galena Alaska-4S project]) and Argonne National Laboratory (Chicago USA) have built experience for 30 years (+) with research and developmental hands-on demonstration of small fast reactors (SFR).

These smaller reactors are based upon many years of government and private research and development programs. Examples of these early efforts include Experimental Breeder Reactor-II

(EBR-II) (Ref. 11)US Department of Energy, PRISM US DOE (Ref. 12) and SPRISM (Ref. 13) General Electric, Argonne National Laboratory STAR (see Figure 1 below and Ref. 14).



Star-LM Simplified, Modular, Small Reactor featuring Flow-thru Fuel Cartridge

The Secure Transportable Autonomous Reactor (STAR) project is an example of the type of reactor that could address the needs of developing countries and independent power producers for small, multi-purpose energy systems, which operate nearly autonomously for very long term.

As opposed to large PWR or BWR 1000 MW(e) (+) light water reactor these liquid metal cooled reactors can be designed with life cores (e.g. 20 – 30 years), which feature no need for refueling during life; thus a "cartridge or battery" bounce back feature where the fuel core integrity remains pristine (untouched) for the entire useful life. Also, for remote regions likely to be arid or dry, there is no need for cooling water in large quantities such as for light water reactors because they are small enough to use dry cooling towers.

Technical features of the liquid metal fast reactor reactors actively discourage malevolent or terrorist objectives as follows:

MAINTENANCE WINDOW / REPLACEMENT OF COMPONENTS ARE OPTIMIZED

Using a liquid metal coolant (such as sodium) in a well sealed system should result in a non-corrosive overall feature that minimizes deleterious effects on mechanical components; thus enabling less down time and exposure of reactor internals.

OPTIMAL FUEL ENRICHMENT CONFIGURATION WITH IMPROVEMENT OVER LIFETIME

At start of core life, attractive actinide laden fuel [that is therefore NOT suitable for use to develop a nuclear weapon] presents a low value target for nuclear terrorists. This feature becomes more prominent over 20-30 year life since the core becomes more radioactive while enrichment levels drop.

NO NEED FOR FUEL HANDLING – ELIMINATES WASTE WORRY WITH SEALED 30 YEAR REACTOR CORE

This feature lowers risk of malevolent terrorist intervention to be near deminimus. The reactor is welded closed and is sealed in a welded closed guard vessel, inside massive concrete structures. A large lift crane, huge metal cutters and robots? (e.g. terrorists would certainly die trying!) would be required and would yield a poor prize for all the trouble. When shut down and hot, the coolant is too radioactive to permit people to safely approach the vessel, and when shut down and cold, the reactor coolant hardens and seals the fuel within a solid metal blob inside the reactor vessel precluding easy removal. Therefore, by eliminating the need to refuel, spent fuel handling and storage any non-authorized fissile material diversion can be precluded.

COST IS NOT PROHIBITIVE

Compared to the current cost being paid for remote power in locations such as Galena, Alaska. (see Ref. #3) of over 30¢/ kWh, a new SFR can be operated at or near 10¢ / kWh with a capital cost of approx 10% of a larger light water reactor.

CONCLUSION

PROLIFERATION ISSUES - SOLUTIONS EXIST TO THE WORRIES

In conclusion when considering government policy applications for commercial export of nuclear technology, such agreements as (Ref. 16) UN Resolution 1540) and the basic (Ref.17) NPT of 1972 must be considered and complied with. Actions, contracts and long term commercial commitments should also dictate a very conservative approach to security aspects - especially post 9/11. However, a proper export of peaceful nuclear technology is a reasonable expectation for the many countries that fully comply with these agreements.

With large (mostly light water) 1000 MW(e) + reactors limited to the 2--3 dozen heavily industrialized countries, it can be postulated that distributed power using small nuclear reactors needs to help fill the gap during future growth for the rest of the world.

The most conservative and reliable technology that is currently deployable in this range of application most likely needed (50 to 100 MW(e)) is postulated to be a metal cooled fast reactor. Conservative design criteria include a safe fuel mix, passive safety during operation, very low terrorist appeal and desirable lifetime maintenance and waste handling features. These factors create a most favorable product option when considering the international proliferation of nuclear technologies.

REFERENCES

1) NEI – Nuclear Energy Institute (NEI) Nuclear Facts Section, various topical as basic source on www.nei.org (November 2000 – May 2002). [Ref: TMI more than 20 years later]

2) M. Campagna and P. Nurden "A Global approach to Reactor Plant D&D and it's Potential Importance on Future Nuclear Renaissance" November 2001 as presented to US DOE Technology Information Exchange (TIE) Conference, Albuquerque, New Mexico

3) NRC Reaction to Terrorist Attacks – No. 01-112 dated September 21, 2001

4) SWOT concept as presented in the context of nuclear facility security by W. SAWRUK, M. CAMPAGNA in "Protection of Nuclear Plants against Vehicular Bombs via Full Spectrum Risk Assessment: for INMM 44th Annual Meeting July 13 – 17, 2003 Phoenix, Arizona

5) Theodor Krauthammer (Editor) – "Structures for Enhanced Safety and Physical Security", Proceedings of the Specialty Conference sponsored by the Structural Division of the American Society of Civil Engineers (MARCH 8 – 10, 1989). Part 1: Threat Environment and Facility Planning: [p. 61 – 72; "Physical Security Requirements" by Curtis P. Betts, USACE]

6) "Reducing the Nuclear Threat in the 21st Century" – Charles B. Curtis – Nuclear Threat Initiative, Washington DC (2001)

7) Galena Nuclear Power Plant - Source: http://en.wikinpedia.org/wiki/Galena

8) Alaska Journal article (http://www.alaskajournal.com/stories/122604/loc_20041226003.shtml)

9) Galena Electric Power – a Situational Analysis, Robert E. Chaney, SAIC Corporation**,** Stephen G. Colt, University of Alaska Anchorage, Ronald A. Johnson, University of Alaska Fairbanks, Richard W. Wies, University of Alaska Fairbanks, Gregory J. White, Idaho National Engineering & Environmental Laboratory - Prepared for the U.S. Department of Energy, National Energy Technology Laboratory, Arctic Energy Office Contract, DE-AM26-99FT40575

10) A Case for Small Modular Fast Reactor, Yoon I. CHANG[1], Mamoru KONOMURA[2], and Pierre LO PINTO[3], [1]Argonne National Laboratory, Argonne, IL 60439, USA, Tel. +1-630-252-4856, Fax. +1-630-252-7923, E-mail: ychang@anl.gov, [2]Japan Nuclear Cycle

Development Institute, O-arai, Ibaraki 311-1393, Japan, [3]Commissariat a l'Energie Atomique, Cadarache center, Saint-Paul-lez-Durance Cedex, France

11) The Experimental Breeder Reactor-II (EBR-II), http://www.anlw.anl.gov/anlw_history/reactors/ebr_ii.html

12) Introduction to the ALMR/PRISM, http://www.nuc.berkeley,edu/~gav/almr/01.intro.html

13) SPRISM – Boardman, C.E., Fanning A., Carroll D., Dubberley A., Hui M., 1999, "A Description of the S-PRISM Plant", Proceedings of the 8th International Conference on Nuclear Engineering (ICONE-8), Baltimore, MD USA

14) Argonne National Laboratory , Heavy Liquid Metal Reactor Development Lead-Bismuth and Lead Cooled Reactors (STAR), http://www.ne.anl.gov/research/ardt/hlmr/index.html