Union of Concerned Scientists

Citizens and Scientists for Environmental Solutions

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SUBJECT: REVIEW OF TOSHIBA 4S SODIUM-COOLED NUCLEAR POWER REACTOR PROPOSED FOR GALENA, ALASKA

Dear Gentlemen:

I reviewed publicly available information on the Toshiba 4S sodium-cooled nuclear power reactor being considered for operation in Galena, Alaska. This review is necessarily limited in its scope because no Toshiba 4S reactor has ever operated any where on the planet and the company is still developing the detailed design package for this experimental reactor. The safety questions that I was unable to find answered in the publicly available information are described below.

FIELD EXPERIMENT OF PROTOTYPE REACTOR DESIGN

The publicly available information indicates that the Toshiba 4S reactor would be provided to Galena at an apparent bargain price:

> "*Toshiba has approached the City with the offer to provide the reactor and power plant at no capital cost so that the 4S can have a reference site and operation experience*." [1]

Just like Chuck Yeager did not have to buy a ticket for his X-1 flight in breaking the sound barrier and Alan Shepard did not have to buy a ticket for his Freedom 7 first US manned space flight, it is rare that people pay for prototypes. Once the bugs have been worked out and the risks reduced, companies then market production models to commercial customers.

The proponents of the Toshiba 4S design (and it's worth noting that this design is not the next evolutionary step from a Toshiba 1S, Toshiba 2S, and Toshiba 3S series of proven designs; this design currently exists only on paper and in cyberspace) want to skip some steps in the normal development process for new technology:

> "*Toshiba currently is conducting engineering work to complete the reactor and plant designs. Therefore, if the first operational unit is installed at a site such as Galena it would be considered a "reference" rather than a "prototype" or "demonstration" plant. … The assumption that the 4S would be a reference plant is subject to some question by U.S. National Laboratory staff.*" [2]

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[1] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 7.

[2] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 32.

The US government is unlikely to permit an unproven design to move directly from foreign blueprints to American backyards, particularly without qualifications and conditions such as those acknowledged by the reactor's proponents:

> "*For a first-of-a-kind installation in Galena, licensing requirements may include extensive analysis of the reactor after a short run-time (i.e., 1 to 5 years). In this case the reactor would be changed out at that interval and returned to Toshiba for analysis*." [3]

Even if the US government allowed a foreign company to convert an American city into an experimental reactor laboratory, that government is likely to impose conditions to gauge how well the experiment is progressing. That American city might be inconvenienced by its power plant being unavailable during its Japanese "vacation."

SODIUM-COOLED REACTOR OPERATING EXPERIENCE

The publicly available information on the Toshiba 4S sodium-cooled nuclear reactor – I find it curious that NONE of the 4S's stands for sodium even though it's the most distinguishing aspect of the reactor's design – completely misrepresent actual operating experience worldwide with sodium-cooled reactors. Consider these verbatim statements from two different documents:

> "*Sodium cooled reactors throughout the world have been run for thousands of hours without incidents involving the reactor core*." [4]
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> and
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> "*Liquid metal reactors (LMRs) have been operated successfully worldwide and have been used in the United States at test facilities, with over 300 reactor years of operational experience*." [5]

The first statement is either horribly misinformed or an outright falsehood. The history of sodium-cooled reactors in the United States had very serious incidents involving the reactor core. For example, there were the following two events involving partial meltdown of the reactor cores of sodium-cooled reactors:

- In July 1959, the sodium-cooled nuclear reactor at the Santa Susana facility outside Los Angeles, California, experienced overheating causing damage to roughly one-third of the fuel elements in the reactor core. The design of this reactor was very similar to that proposed for Galena in that it also featured a low-pressure, pool-type, sodium-cooled reactor with a sodium/sodium heat exchanger and a secondary sodium/water steam generator. [6]

- In October 1966, the sodium-cooled nuclear reactor at the Enrico Fermi nuclear plant outside Detroit, Michigan experienced overheating causing damage to several fuel assemblies in the reactor core. [7]

It is true that both of these incidents involving reactor core damage at sodium-cooled reactors occurred more than 40 years ago. But that distant past is explained in large part by proper context for the second misleading statement quoted above. That statement implies that sodium-cooled reactors are tried and proven. The reality is that sodium-cooled reactors are a tried and <u>rejected</u> technology. At the end of 2005,

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[3] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 34.
[4] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 35.
[5] City of Galena, Alaska, 2006. "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility." March 21, page 5.
[6] Atomics International, 1959. "SRE Fuel Element Damage: An Interim Report." November 30.
[7] Power Reactor Development Company, 1968. "Report on the Fuel Melting Incident in the Enrico Fermi Atomic Power Plant on October 5, 1966." December 15.

there were 444 nuclear power reactors operating worldwide. Only two (2) of these hundreds of reactors were sodium-cooled.[8] History has repeatedly shown sodium-cooled reactors to be unsafe, unreliable, and/or uneconomical. An abridged list of sodium-cooled reactors permanently shutdown years before their projected ends of lifetime:

Name	Country	Output	Started	Shutdown
Creys-Malville	France	1200 Mwe	01/1986	12/1998
Aktau	Kazakhstan	135 Mwe	07/1973	04/1999
Dounreay	United Kingdom	250 Mwe	08/1976	03/1994
EBR-II	United States	20 Mwe	08/1964	09/1994
Fermi	United States	61 Mwe	08/1966	11/1972
Hallam	United States	75 Mwe	11/1963	09/1964

Sodium-cooled nuclear reactors may have compiled more than 300 years of operational experience, but that history has been so troubled that country after country abandoned the technology as unviable. More than 99.5 percent of the nuclear power reactors operating in the world today are NOT sodium-cooled. There's a reason for that – sodium-cooled reactor technology failed in the commercial marketplace.

REACTIVITY CONTROL

The Toshiba 4S design would produce energy from a sustained nuclear chain reaction within the reactor core. The splitting, or fissioning, of atoms releases energy and also nuclear particles that can interact with other atoms to cause more splitting. "Reactivity control" is the term of art applied to the regulation of the rate of fissioning in the reactor core. According to the publicly available information, the Toshiba 4S reactor features:

> "*A single control rod has absolute control on reactivity and power. … The core can be maintained in the cold shutdown condition with the control rod inserted. The control rod also scrams the reactor by either of two diverse actuators when rapid shutdown is required*." [9]

It's highly questionable that a design with this feature can be licensed in the United States. In January 1961, the withdrawal of a single control rod at the SL-1 nuclear reactor in Idaho resulted in an uncontrolled nuclear reaction and steam explosion that killed every single person at the plant site.[10] One of the many lessons from this tragic accident was to NOT design and operate production reactors such that a single control rod is capable of so much reactivity control. When this lesson is properly applied, a single operator error or equipment malfunction cannot trigger an uncontrolled nuclear chain reaction.

The Toshiba 4S design also features fine-tuning reactivity control:

> "*A cylindrical steel reflector shield rising from the bottom [of the reactor vessel] at a rate of around 5 cm/yr by means of an electromagnetic drive mechanism maintains the proper reaction rate by reflecting neutrons back into the core. The reflectors are moving upward slowly in order to compensate the reactivity loss during 30 years burn-up*." [11]

and

[8] American Nuclear Society, 2006. "World List of Nuclear Power Plants." *Nuclear News.* March, page 62.
[9] City of Galena, Alaska, 2006. "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility." March 21, page 18.
[10] United States Atomic Energy Commission, 1962. "IDO Report on the Nuclear Incident at the SL-1 Reactor January 3, 1961 at the National Reactor Testing Station," January.
[11] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 33.

> "*The radial reflectors are movable and creep upward slowly during the service life of the core to maintain neutron flux and power levels. In case of electrical power loss or failure of the reflector drive, the assembly is designed to fall to the bottom of the core. Reflector bottoming will reduce reactivity and thus slow or stop the nuclear reaction depending on the operational age of the core*." [12]

The Toshiba 4S design is so conceptual at this stage that it is impossible to assess whether the reflector(s) could be mis-positioned or could malfunction to get higher than desired. The conceptual design refers to the reactivity control provided by negative temperature feedback (i.e., as fuel temperature rises, "brakes" are inherently applied on the nuclear chain reaction rate), but nothing in the publicly available information addressed what would happen if the reflector(s) moved to their vertical limit.

FLAW-FREE OPERATION EXPECTATION

The Toshiba "*4S design introduces a small liquid metal nuclear reactor to the commercial power industry in the United States*." [13] As described in the Sodium-Cooled Reactor Operating Experience section, the worldwide experience with liquid metal nuclear reactors – regardless of size – contradicts an assumption of flaw-free operation. Yet such an unfounded, unjustified assumption is part of the marketing campaign:

> "*In all cases, the nuclear system will provide the lowest cost power to the consumer. … The economic analysis reveals that the 4S option will provide the lowest cost power if the assumptions hold. … If this technology is successfully deployed in Galena, its economic viability in other Alaska villages and elsewhere depends on the actual life cycle costs yet to be quantified*." [14]
>
> and
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> "*Annual supplies and expenses are in addition to labor. Toshiba estimates about $1 million for this line item for their 50-MW plant. Since the reactor is sealed these expenses probably relate almost exclusively to the steam piping and turbine/generator systems. … Lacking specific data on this point, we have assumed that annual supplies and expenses are one-half the amount estimated by Toshiba for the 50-MW design*." [15]

Many things can go wrong, yet the feasibility studies ignore rather than discount this possibility. The cost and impact of things going wrong can be extremely significant. For example, consider this feature of the Toshiba 4s design:

> "*There is no design capability to open the reactor vessel, for any purpose other than at the factory*." [16]

The history of nuclear power is filled with "surprises" that required retrofitting to correct. Many of these "surprises" involved design errors or material degradation inside the reactor vessel. A few examples:

- Turbulent coolant flows inside the fuel assemblies in reactor cores of boiling water reactors necessitated the plugging of existing bypass flow paths in the lower core plates and the drilling of new holes for bypass flow paths. [17]

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[12] City of Galena, Alaska, 2006. "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility." March 21, page 18.
[13] City of Galena, Alaska, 2006. "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility." March 21, page 5.
[14] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 13.
[15] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 64.
[16] U.S. Department of Energy, 2004. "Galena Electric Power – a Situational Analysis," Draft Final Report. December 15, page 33.

- Unexpected thermal stresses caused cracking and failure of the hold-down brackets for the non-moving, non-mechanical jet pumps inside the reactor vessel of boiling water reactors prompting inspections and replacements. [18]

- Unanticipated intra-granular stress corrosion cracking degraded the horizontal welds holding the core shrouds inside the reactor vessels of boiling water reactors together and necessitating repairs.[19]

Each of these, and many similar, "surprises" required costly and time-consuming repairs – repairs that were conducted by opening the reactor vessel at the plants and performing repairs in the field. Obviously, comparable problems within the Toshiba 4S reactor vessel will be complicated if their repair requires the thing to be dug up and shipped back to the factory.

The Toshiba 4S design is far from tried and true, yet its 30-year life at Galena relies on the extremely uncertain – and most likely false – assumption that the longstanding string of nuclear power "surprises" will magically end.

BLACKSTART CAPABILITY

There are 104 nuclear power reactors currently licensed by the Nuclear Regulatory Commission to operate in the United States. Among the many things they have in common is the lack of blackstart capability. While each of these nuclear power reactors is at a plant that generates electricity, NONE can startup without the power provided by the electrical grid. The nuclear power reactors have onsite emergency diesel generators to provide backup power in event the electrical grid is unavailable, but the output of the diesel generators is limited to the safety equipment needed to protect the reactor cores from damage. The emergency diesel generators cannot also power the equipment needed to startup the nuclear reactors.

These US nuclear power reactors are like gasoline-powered motor vehicles with automatic transmissions. When the gasoline engine is running, it makes enough power to move the vehicle while also generating electrical power for the radio and other equipment. But these vehicles need power from a battery to start up the gasoline engine, just as US nuclear plants need power from an electrical grid to start up the nuclear reactors.

Galena has no connection to an outside power grid. [20] The publicly available information does not indicate whether the Toshiba 4S design has blackstart capability. The publicly available information does imply the need for electrical power to startup the Toshiba 4S reactor. For example:

> "*Sodium receiving and transfer subsystems consist of equipment and piping to melt the contents of sodium drums and transfer the molten sodium to the respective heat transfer systems. The primary sodium process subsystem provides purification of sodium contained in the reactor vessel. It also provides the capability to transfer and purify fresh sodium prior to plant start up*." [21]

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[17] United States Nuclear Regulatory Commission, 1976. "Safety Evaluation Report on the Reactor Modification to Eliminate Significant In-Core Vibration in Browns Ferry Unit 1 and Unit 2." March 3.
[18] United States Nuclear Regulatory Commission, 1980. "BWR Jet Pump Assembly Failure." April 4.
[19] United States Nuclear Regulatory Commission, 1993. "Operating Reactors Events Briefing 93-34." September 8.
[20] City of Galena, Alaska, 2006. "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility." March 21, page 3.
[21] City of Galena, Alaska, 2006. "Overview of Galena's Proposed Approach to Licensing a 4S Nuclear Reactor Based Power Generation Facility." March 21, page 20.

The diesel generators which the Toshiba 4S reactor would replace, have blackstart capability. The diesel generators do not require a backup nuclear reactor to enable them to startup. But the nuclear reactor may require backup diesel generators, or other means, to enable them to startup. It's not apparent that the cost of providing blackstart capability was factored into the economic analysis of the "free" reactor.

CONCLUSION

Very little detailed information is publicly available on the experimental Toshiba 4S sodium-cooled nuclear power reactor design at this time. No reactor like it has ever operated and the company still has considerable homework left to do on the reactor's engineering. From the information that is publicly available, it appears that operation of the experimental Toshiba 4S sodium-cooled nuclear power reactor would have to totally contradict more than four decades of actual experience for it to pose minimal risk to the community. While "perfect operation" of the first unit off the assembly line is theoretically possible, no reasonable person would take that bet.

Sincerely,

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Washington Officer