The Reactor Is Not the System

What Civilian Nuclear Power Can Learn from the U.S. Nuclear Navy

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I have always found the American nuclear Navy easier to admire than to explain. In 2025, the United States Navy and Marine Corps marked their 250th anniversaries, and the celebration invited the usual inventory of ships, battles, aircraft, and traditions. The achievement that interests me most is quieter. Every active U.S. submarine and aircraft carrier is nuclear-powered. Across thousands of reactor-years and more than six decades of fleet operation, the Naval Nuclear Propulsion Program reports no reactor accidents and no release of radioactivity that adversely affected public health or the environment.[1] The impressive part is not simply that a reactor can power a ship. It is that an institution can make an extraordinary machine behave routinely.

That record often gets turned into a very simple argument: the Navy can do nuclear safely, so America should deregulate, copy the technology, and build. The first half of the sentence is substantially true. The conclusion does not follow.

What the record shows, at least to me, is not that one reactor design is magically safe. It shows that safety is produced by a sociotechnical system: an institution that controls design, procurement, training, operation, maintenance, oversight, fuel stewardship, and disposal across the full life of the technology. The reactor matters. The system around it decides whether those safety features still mean anything at three in the morning, during maintenance, under schedule pressure, after staff turnover, or when several weak signals arrive at once.

Civilian nuclear power should learn from that system without pretending it can copy the whole thing. Military command, classified technology, public finance, strategic necessity, and a tightly controlled workforce create conditions a civilian utility neither has nor should have. The useful work is translation: identify what makes the naval program reliable, separate those mechanisms from military authority, and rebuild the transferable principles inside democratic, transparent, independently regulated institutions.

That means beginning with Admiral Hyman G. Rickover, but not with the mythology. Rickover is conventionally called the father of the nuclear Navy. He did not invent the nuclear reactor. He did something institutionally more difficult: he led the effort that turned reactor physics into an operational fleet capability. From the late 1940s until his retirement in 1982, he shaped an organization with unusually concentrated technical authority and unusually long memory.[2]

USS Nautilus, commissioned in 1954 and underway on nuclear power in 1955, demonstrated that a submarine could remain submerged for periods impossible under diesel-electric propulsion. The pressurized-water reactor work behind the naval program also influenced the Shippingport Atomic Power Station, which began commercial operation in Pennsylvania in 1957. Shippingport was not a naval reactor placed beside a city, but it was a direct institutional bridge between naval reactor development and civilian power.[3]

Rickover's legacy is often flattened into folklore: one brilliant authoritarian, a few uncompromising rules, and perfect hardware. That version is attractive because it makes reliability look like a personality trait. It is also too simple. Rickover mattered because he built durable arrangements for responsibility, testing, qualification, configuration control, and feedback. The program survived him because those arrangements stopped being biographical and became institutional.

That distinction matters. A country cannot scale charisma. It can scale standards, training systems, interfaces, audit trails, and accountable ownership.

The most useful part of that legacy is what the Naval Nuclear Propulsion Program calls "cradle to grave" responsibility. The same joint Navy-Department of Energy organization remains responsible from reactor research and ship design through construction, operation, maintenance, defueling, spent-fuel management, and disposal.[4] That continuity closes a familiar gap in complex projects: each contractor, operator, and regulator sees one segment, while nobody owns the consequences that emerge between segments.

Civilian nuclear power is necessarily more distributed. Vendors design components. Utilities own plants. Contractors conduct outages. State authorities regulate electricity markets. The Nuclear Regulatory Commission oversees radiological safety. Local communities host facilities and waste. Federal agencies fund research. Investors judge schedules. No single actor can or should dominate this entire landscape.

Fragmented authority does not have to mean fragmented accountability. Every civilian project should have an identifiable technical integrator responsible for the integrity of the complete plant across its life, while an independent regulator remains outside the owner's chain of command. Ownership changes should not erase design knowledge. Contracts should preserve configuration data, failure histories, and supplier traceability. Decommissioning and waste obligations should be funded while the plant is earning revenue, not handed to a future public after the profitable years end. In other words, the reactor cannot be treated as a product that becomes somebody else's problem at commissioning.

Continuity alone is not enough; the naval program also learns by repetition. It benefits from a bounded design family and a fleet that accumulates experience. New technologies are tested in dedicated research and prototype facilities before deployment. Sailors train on systems closely related to those they will operate. Design authorities receive feedback from the fleet and can propagate lessons across ships.[5]

Civilian nuclear construction in the United States has often moved in the opposite direction. One-off designs, site-specific changes, shifting requirements, interrupted supply chains, and long gaps between projects make every plant partly a first-of-a-kind project. A drawing may be standardized while the actual organization has forgotten how to build it. The lost knowledge then reappears as delay, rework, cost escalation, and risk.[6]

The lesson is not that every reactor in America must be identical. It is that learning requires repetition. Stable modules, interfaces, suppliers, and change-control practices let the tenth project benefit from the first. A credible advanced-reactor strategy therefore needs a sequence of builds, not a parade of isolated demonstrations. It needs a workforce and supply chain that stay intact between units, and a way to share operational lessons without forcing every company to rediscover the same failure privately.

Standardization can itself become dangerous if it turns one hidden defect into a fleet-wide defect. That is why common design must be paired with independent review, adversarial testing, and the ability to halt deployment when evidence changes. Repetition should accelerate learning, not obedience.

Nuclear discussions often divide the world into reliable machines and fallible humans. The division is false. People specify requirements, route cables, interpret alarms, write procedures, approve maintenance, select what automation displays, decide which deviations are normal, and determine whether bad news travels upward. Human action is not an external disturbance applied to a technical system. It is one of the system's operating materials.

The naval program invests heavily in selection, classroom education, prototype training, qualification, recurring examination, and watch-team discipline. That investment does more than teach operators which valve to move. It constructs a shared mental model of how the plant behaves, what must never be assumed, and when uncertainty requires escalation.

The International Atomic Energy Agency now describes nuclear operations as complex and dynamic sociotechnical systems in which safety emerges from interactions among people, technology, organizations, suppliers, regulators, and governments.[7] That framing should change how civilian plants are designed. Control rooms are not decorative shells around the reactor. Alarm architecture, display hierarchy, procedure format, automation behavior, staffing, shift handover, and maintenance interfaces are safety systems.

This is where human-computer interaction becomes central. An operator should be able to understand not only what the automation is doing, but why, with which inputs, under what confidence, and with what path to intervention. Displays should help teams form an accurate picture under stress instead of rewarding the fastest button press. Alarms should support diagnosis, not merely announce that many thresholds have been crossed. Procedures should help people adapt when reality does not match the script while preserving clear boundaries around actions that require authorization.

More automation does not remove the human problem. It changes it. A highly automated plant can reduce routine workload while making rare intervention more cognitively demanding. Operators may be asked to take control precisely when the system is least familiar and the evidence most ambiguous. Good design therefore preserves skill, visibility, and meaningful practice rather than treating the human as an emergency accessory.

Organizations often describe safety culture as an attitude: care more, follow procedures, speak up. Those expectations matter, but culture is also an information architecture. Which observations are recorded? Which near misses are investigated? Who can stop work? What happens to the person who reports an inconvenient defect? Does an anomaly become data, or does it become a reason to blame the operator and move on?

The naval program's centralized authority can support rapid technical feedback and consistent standards. It can also produce familiar hierarchical risks: fear, deference, and the temptation to treat dissent as disloyalty. The lesson is not "be more authoritarian." High-reliability work needs disciplined compliance and protected challenge at the same time. A procedure should be followed; a defective procedure must also be reportable. Expertise should carry authority, and authority should still be contestable by evidence.

Civilian regulators identify a questioning attitude, effective safety communication, problem identification, and continuous learning as components of a healthy safety culture.[8] Those ideas become real only when incentives support them. Outage schedules, production targets, contractor penalties, executive compensation, and regulatory metrics all transmit priorities. If the formal message says safety first while every operational signal punishes delay, workers learn the actual specification.

The comparison has limits that nuclear advocacy sometimes treats as annoyances. Naval reactors serve a strategic mission for which cost is important but not dispositive. The government can sustain specialized laboratories, training pipelines, shipyards, and a permanent technical authority across decades. The workforce operates under military law and a command structure. Designs and performance data are classified. The fleet uses a relatively small number of related propulsion architectures. The public does not choose a submarine through a competitive retail electricity market.

Civilian nuclear power, by contrast, must justify capital cost, schedule, financing risk, electricity price, land use, emergency planning, waste, environmental justice, and community consent. It must expose enough information for independent regulation and public argument. Its safety case cannot rely on trust in a closed institution, however impressive that institution's record.

The naval example is therefore not a case for deregulation. In one sense, the program is intensely regulated from within: technical authority, qualification, documentation, testing, inspection, and lifecycle control constrain what participants may do. Civilian nuclear power needs that internal discipline plus an external regulator capable of challenging the owner. Removing public regulation while leaving fragmented commercial incentives would copy the Navy's secrecy and omit its accountability.

So what can actually come ashore? First, continuity. Nuclear programs outlive administrations, executives, contractors, and market cycles. The United States needs durable technical institutions that preserve knowledge across projects without becoming captive to the firms they oversee.

Second, sequence rather than spectacle. Demonstration reactors matter, but a demonstration that leaves no trained workforce, licensed follow-on design, qualified supply chain, or committed customer is an experiment, not an industry. Program design should make learning cumulative.

Human factors also need to enter before the interfaces and procedures harden. Operators, maintainers, cybersecurity staff, emergency planners, and community stakeholders should help shape requirements from the beginning. Simulator testing should examine team cognition, alarm behavior, handoffs, and degraded modes, not merely whether a trained user can complete a nominal task.

Responsibility must be legible as well. The public should know which organization owns each safety claim, which evidence supports it, how dissent is handled, what happens after an incident, and who pays for the final fuel and facility disposition. Civilian legitimacy requires more than assurances borrowed from a military record.

And speed has to remain different from haste. The naval program moved quickly when it succeeded, but it did so through concentrated expertise, prototype testing, standardization, and aggressive problem solving. Skipping review is not the same as removing bureaucratic duplication. A fast system removes unnecessary handoffs while strengthening the points where evidence must stop a bad design.

The future I find most convincing is almost boring. The United States has already shown that nuclear technology can operate for decades in compact, demanding, mobile environments. That achievement deserves admiration, but it also deserves accurate interpretation.

Rickover's central contribution was not a mystical reactor or a list of six rules. It was an institution that made technical responsibility difficult to evade. The program aligned design, training, operation, and long-term stewardship closely enough that a small deviation could become system knowledge instead of an isolated inconvenience.

Civilian nuclear power cannot inherit the Navy's command structure, secrecy, or strategic budget. It can inherit the deeper idea: safety is not a property installed in steel and left behind. It is continuously produced by organizations, interfaces, incentives, memory, and people.

The reactor is not the system. The system is everything that makes the reactor predictable when no one is giving a speech about it. The most impressive nuclear future will not look dramatic from the control room. It will look boring, because the institution has done the hard work required to make an extraordinary machine ordinary.

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1. U.S. Department of Energy, National Nuclear Security Administration, "Powering the Navy"; U.S. Naval Nuclear Propulsion Program, Occupational Radiation Exposure from U.S. Naval Nuclear Plants and Their Support Facilities, report NT-25-2, 2025. As of the end of 2024, the Navy operated seventy nuclear-powered submarines, twelve nuclear-powered aircraft carriers, and three moored training ships. Source

2. U.S. Department of Energy, National Nuclear Security Administration, U.S. Naval Nuclear Propulsion Program, 2016; Richard G. Hewlett and Francis Duncan, Nuclear Navy, 1974. Source

3. U.S. Nuclear Regulatory Commission, historical materials on the Shippingport Atomic Power Station; Hewlett and Duncan, Nuclear Navy. Source

4. Naval Nuclear Laboratory, "Naval Nuclear Propulsion Program"; Executive Order 12344 and its statutory codification. Source

5. U.S. Department of Energy, "Powering the Navy"; Naval Nuclear Laboratory, Kesselring Site overview. Source

6. U.S. Department of Energy, Office of Nuclear Energy, "5 Ways the U.S. Nuclear Energy Industry Is Evolving in 2024," September 30, 2024; and "Commercializing Advanced Nuclear Reactors Explained in Five Charts," March 30, 2023. The reports emphasize completed designs, trained workforces, repeat deployments, standardization, and supply-chain development as mechanisms for reducing cost and schedule risk. Source

7. International Atomic Energy Agency, Human and Organizational Aspects of Assuring Nuclear Safety: Exploring 30 Years of Safety Culture, 2018. Source

8. U.S. Nuclear Regulatory Commission, "Safety Culture Policy Statement" and supporting safety-culture guidance. Source