Naval Nuclear Propulsion: Assessing Benefits and Risks

Charles D. Ferguson, Ph.D.
President, Federation of American Scientists

Briefing to the Middlebury Institute of International Studies at Monterey

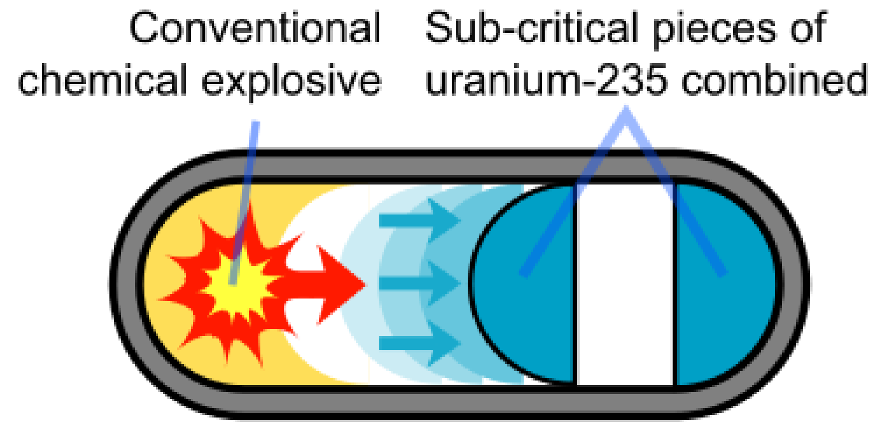
May 5, 2015

Agenda

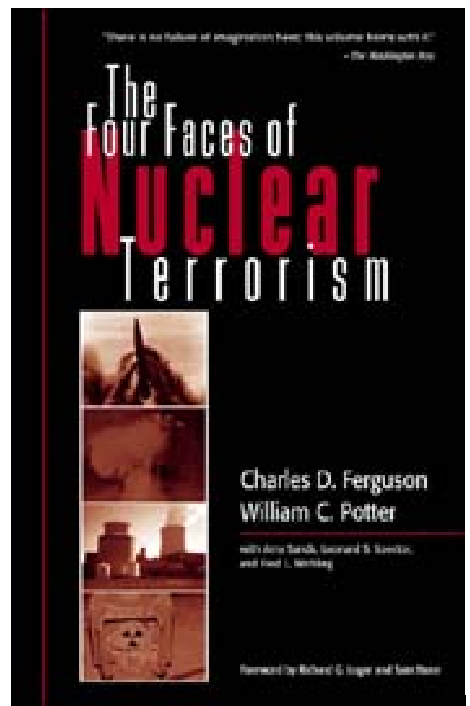
- Why should we be concerned about the use of highly enriched uranium in naval and other types of reactors?
- How has the U.S. Navy and other navies benefited from nuclear-powered ships?
- What were the research objectives and challenges of the Independent Task Force on Naval Nuclear Propulsion?
- Who was on the research team?
- What are the prospects for naval reactor R&D to design advanced low enriched uranium reactors?
- Recommendations of the Task Force
- Next steps

Why Highly Enriched Uranium Is a Security Concern

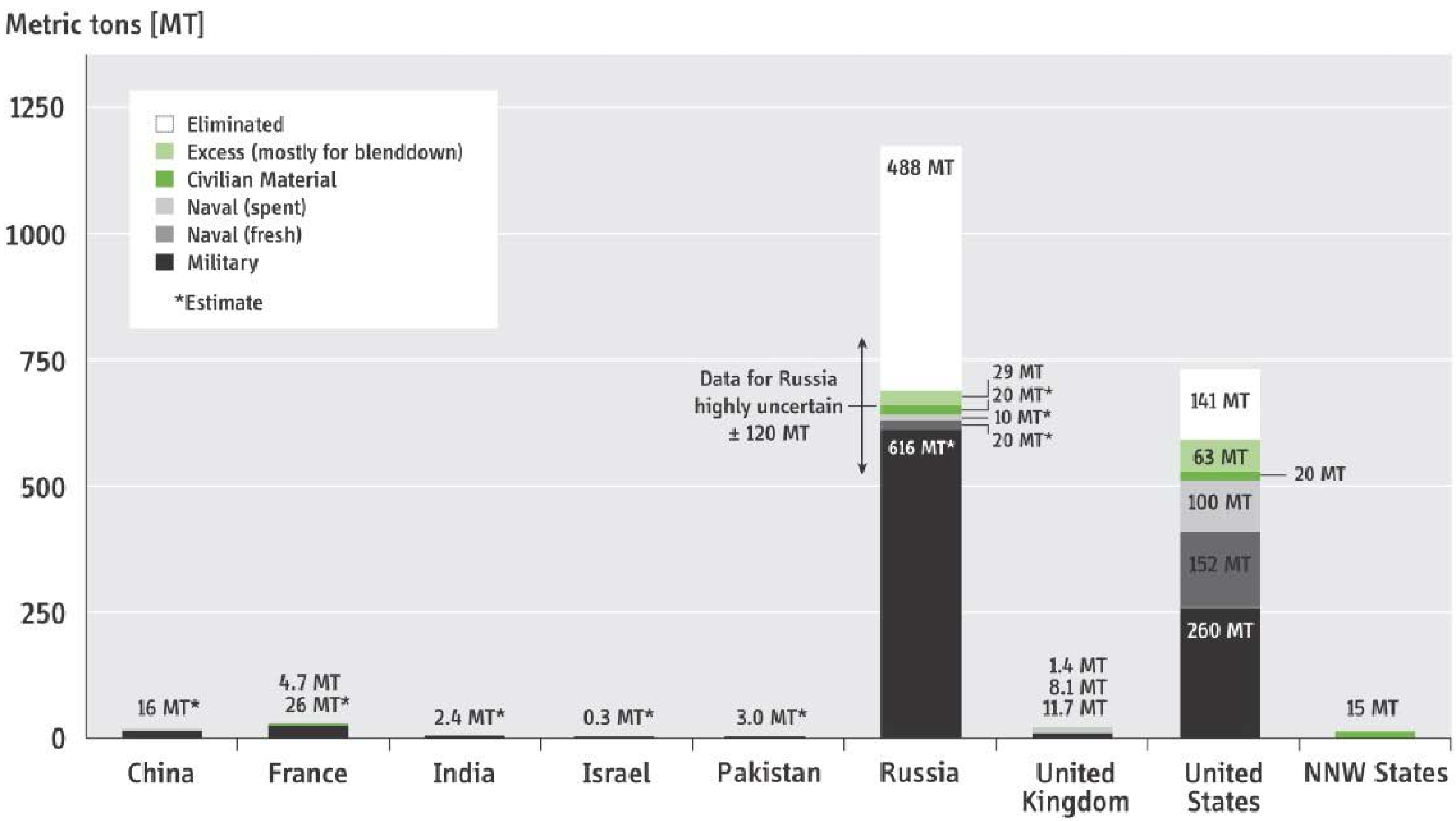
- HEU has 20% or greater content of fissile U-235 → usable in a nuclear explosive
- Weapons-grade: > 90% U-235
- Relative ease of use in improvised nuclear device that might be built by some non-state actors
- Many research reactors still use HEU but there are programs to convert them to low enriched uranium (LEU)
- Naval reactors in the U.S., UK, Russia, and India use HEU but no plans yet to convert to LEU
- But China and France use LEU in naval reactors



Gun-type assembly method



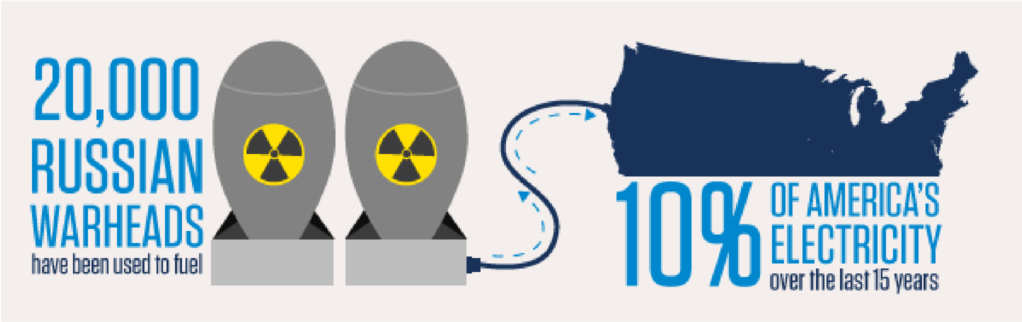
Stockpiles of HEU: More than 1,300,000 kg
Only about 25 kg weapons grade-U needed for one bomb



2012 Global Fissile Materials Report, International Panel on Fissile Materials

Efforts to Reduce Risks of HEU

- Reduced Enrichment for Research and Test Reactors (RERTR) program—ongoing for decades
- Megatons-to-Megawatts program from 1995-2013 to convert 500 tons of Russian weapons U to LEU for U.S. commercial reactors



- Global Threat Reduction Initiative, 2004 and beyond
- 2010, 2012, and 2014 Nuclear Security Summits → push to minimize use and possible eventual phase out of civilian HEU
- Will the 2016 NSS make effort on military nuclear material?
- Fissile material security programs with Russia— much progress in 1990s but now very tense relations
- Security assistance to Pakistan—very politically sensitive

Is U.S. HEU Secure?

- On July 28, 2012, one elderly nun (then 82) and two older men broke into the Y-12 National Security Complex near Oak Ridge, Tenn., which contains the Highly Enriched Uranium Material Facility (HEUMF)
- They did not intend to steal HEU but did reach the HEUMF and had several minutes beside the facility before a guard finally arrived

Concerns about Insider Threats

- Alleged diversion of HEU in the 1960s from naval fuel facility NUMEC in Apollo, Penn.
- At least five incidents of attempted theft or diversion of naval fuel from July 1993 to January 1996 in Russia
- India (acquiring nuclear-powered submarines fueled with HEU) and Pakistan has expressed interest in doing so

Concerns about Diversion When Safeguards Removed

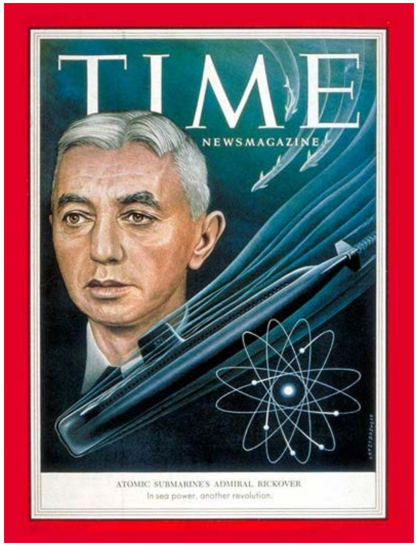
- Paragraph 14 of Comprehensive Safeguards Agreement and Article 13 of Argentina-Brazil-IAEA agreement have provision for “non-proscribed military uses” → code for naval propulsion
- Requires state party to notify the International Atomic Energy Agency of intent to remove material from safeguards
- Yet to be tested … but Brazil could be the first

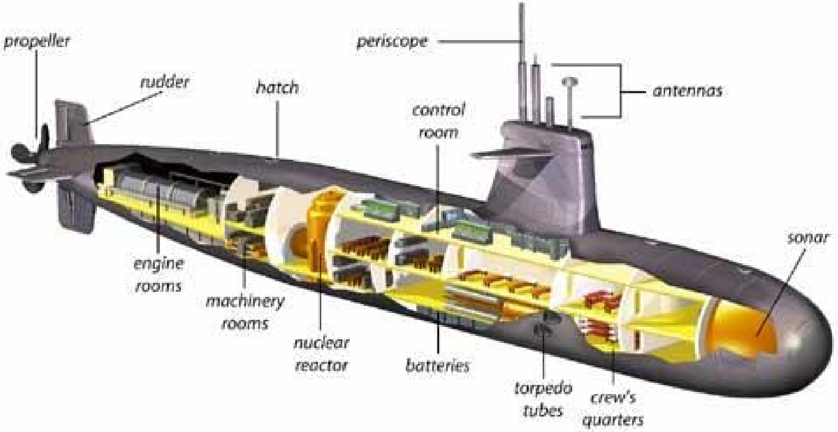
But Should We Stop Using HEU for Naval Reactors?

- Long-lived reactor cores because of very high energy density due to very highly enriched fuel in U.S. and UK reactors
- Relatively large U.S. stockpile of HEU dedicated to naval use of 152 tons declared in 2004 → at least 60 years supply
- Performance demands of U.S. naval reactors—seems better met with HEU
- Long track record of successful reactor designs based on HEU in the U.S. and UK as well as Russia
- ***1995 Office of Naval Reactors report to Congress assessed that the costs to move away from HEU outweighed the benefits but some have raised concern that this study did not take into account use of LEU in China, France, and technological advancements of high-density LEU fuels***

Sixty Plus Years of U.S. Naval Reactors: History of Innovation

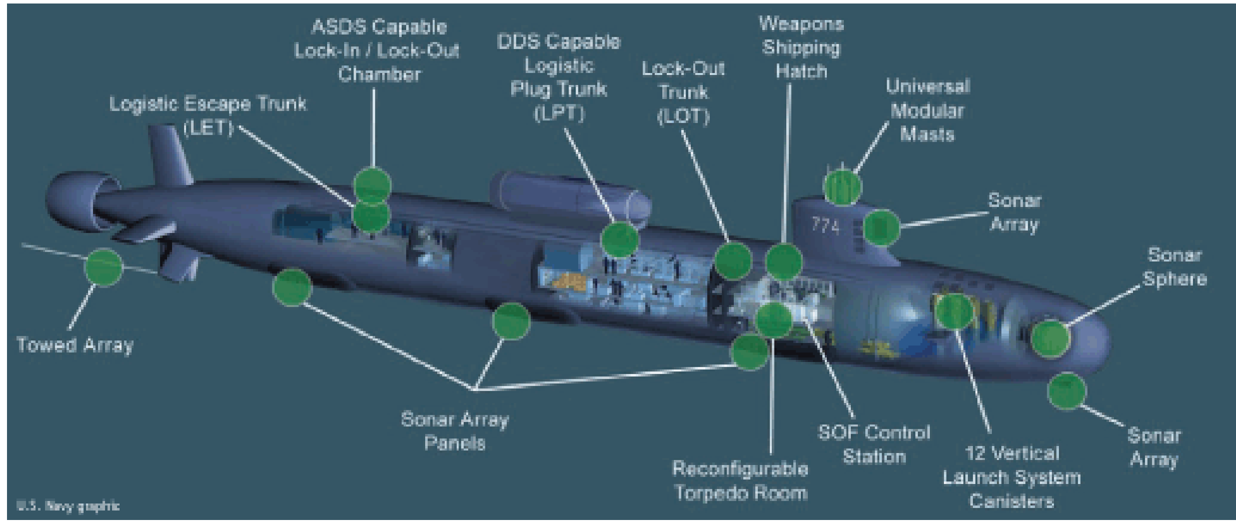
- U.S.S. Nautilus, SSN 571: 20% enriched U; needed fueling about every two years
- Took many decades to develop life-of-the-ship reactor cores for USN
- Naval reactor engineers like to innovate and take on engineering challenges





Latest Generations of U.S. Nuclear-Powered Naval Ships

- VA-class SSN: 33 years without refueling
- SSBN(X): 40+ years without refueling
- Current Ohio-class SSBN requires one mid-life refueling
- Ford-class CVN: 45 to 50 years life of ship but still requires one refueling
- All fueled with weapons-grade U



Overall Research Objectives of the Independent Task Force

(1) Understand the options for alternatives to HEU for naval propulsion and

(2) Examine effective ways to monitor and possibly safeguard HEU as well as LEU in the naval sector.

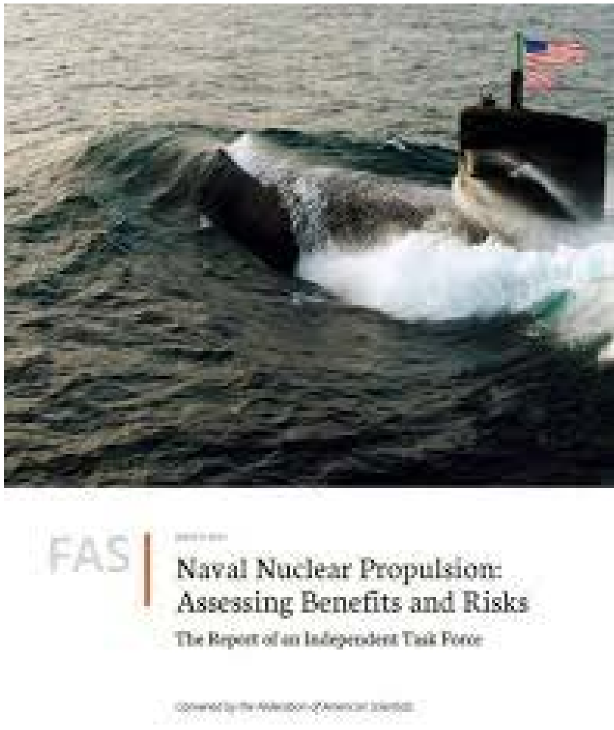
Funding provided by the John D. and Catherine T. MacArthur Foundation

What are the research questions?

- What can be done, if anything, to close the “loophole” in IAEA safeguards?
- What safeguarding (if any) and monitoring can be applied to HEU in the naval sector?
- What are the implications of naval HEU use for the proposed Fissile Material Cutoff Treaty or other variations on an FMCT?
- What has been the experience in using LEU fuel? Can the U.S. work with, for example, the French on development of advanced LEU fueled reactors?
- Are there lessons from research reactors or commercial reactors such as SMRs applicable to naval reactors?
- What are the impacts of tight defense budgets in the U.S. and the UK on naval reactors?

Methodology

- Formed a task force of about a dozen experts who have diverse expertise and who are mostly outside DC policy circles (involved several research universities and the Naval Academy)
- Assigned aspects of the research agenda to particular task force members and their graduate students to write working papers, available at FAS.org
- Reached consensus on overarching report



Research Challenges

- Only had access to unclassified information
- Limited financial and personnel resources
- Limited timeframe of about one year

Who was on the task force and who advised?

- Dr. Bethany Goldblum and Erika Suzuki, UC, Berkeley
- Dr. Ali Haghighat, Virginia Tech
- Prof. Paul Ingram, British American Security Information Council
- Dr. Alan Kuperman, University of Texas at Austin
- VADM (ret) Charles “Joe” Leidig, US Naval Academy
- Dr. Bojan Petrovic, Geogia Tech
- Prof. Nick Ritchie, University of York, UK
- Graduate students: Jack Bell, Matthew Deal, Naomi Egel, and Nathan Roskoff
- Have received advice from several others including Chris Preble (CATO), Joe Pilat (LANL), Michael Rosenthal, Richard Garwin (IBM), Scott Kemp (MIT), Cameron McCord (MIT), Marvin Miller (MIT), Frank von Hippel (Princeton), and George Moore (CNS, MIIS)
- Discussions with Office of Naval Reactors, Oak Ridge National Laboratory, and several congressional staff

January 2014 Office of Naval Reactors Report to Congress

Two options exist:

(1) substitute LEU fuel for HEU into the current naval fuel system and

(2) develop a new fuel system that can increase uranium loading to offset some impacts of using LEU fuel.

2014 Naval Reactors’ Report continued

- “… recent work has shown that the potential exists to develop an advanced fuel system that could increase uranium loading beyond what is practical today while meeting the rigorous performance requirements for naval reactors. Success is not assured …”

- “The capability to develop advanced naval fuel resides within a small cadre of highly specialized, experienced, and qualified engineers and scientists…”

2014 Naval Reactors Report … opening the door to LEU use: but need lots of time and $$

- “It will not be practical to sustain these capabilities or work on an advanced fuel system without additional sources of funding. Consequently, until this funding can be secured advanced fuel is not being pursued beyond the early concept stage.”

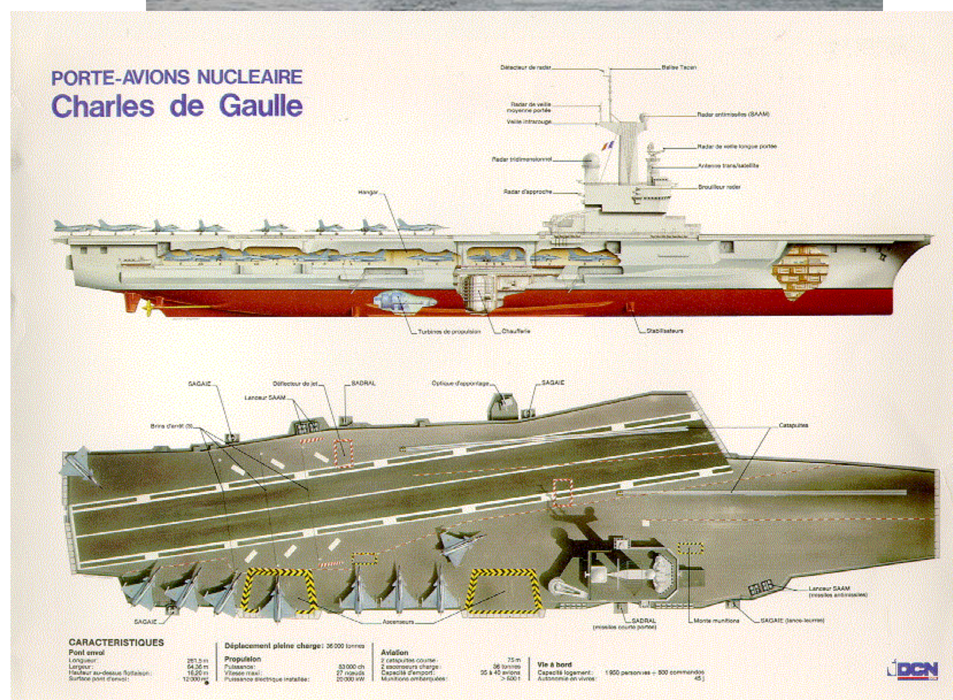
- “The investment to develop a fuel technology and determine its viability is estimated to be up to $2 billion over at least 10 to 15 years. At least another ten years beyond that would be needed to deploy a nuclear reactor with this fuel.”

New designs are well in progress … but opportunities may unfold

- SSN, SSBN, and CVN designs require long lead time
- Very unlikely, if not impossible, to change the current and just developing designs
- But what about the next-next generation?
- Depends on stockpile of available HEU and U.S. nuclear security policy as well as potential for influence on other nations' nuclear navies
- Depends on national enrichment capacity
- Depends on possible future agreement to stop production of HEU for any military purposes

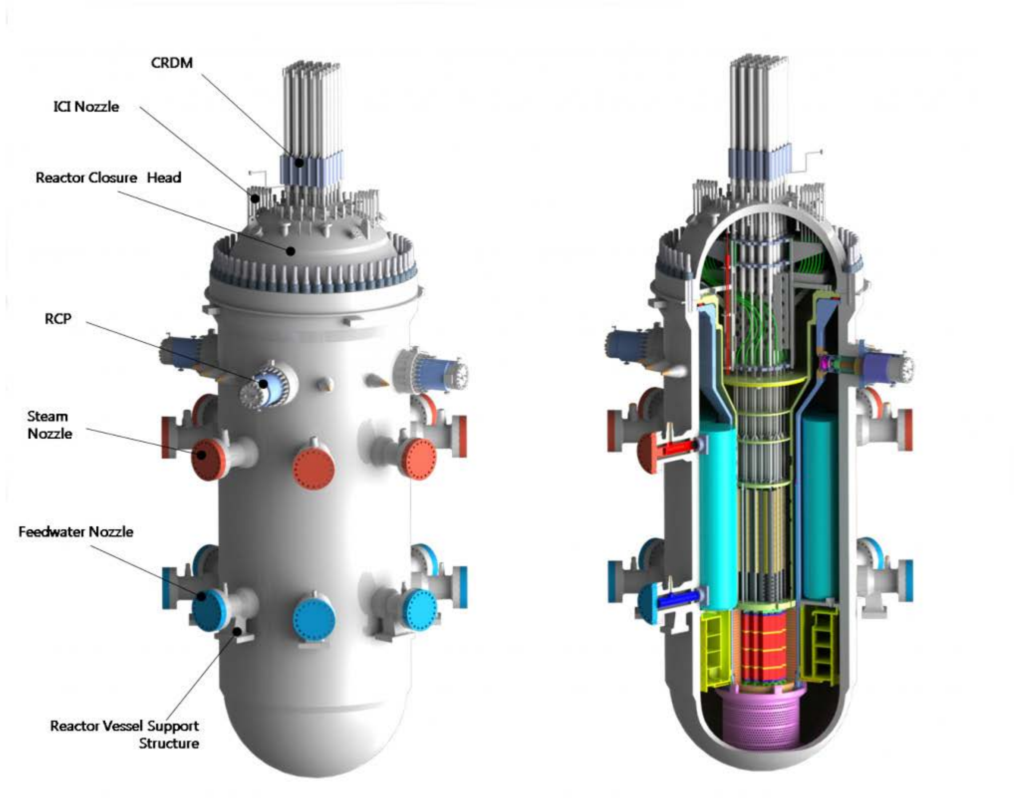
Could the U.S. Learn from the French?

- All French nuclear ships now use LEU, enriched to 7.5% U-235; high-density “caramel” fuel
- Decision made on economics: wanting to use commercial LEU facility and not wanting expense of new HEU enrichment plant
- Refueling hatch to save on time in shipyard and workers’ radiation exposure
- Likely move toward 5% U-235 in future to further save costs on enrichment but could add costs on number of refueling operations
- Need to refuel about every 10 years with current fuel type
- How does French ships’ performance compare to USN’s nuclear-powered ships’ performance?



To fit LEU-fueled core inside a small reactor compartment could use an integrated nuclear plant design

- To save on reactor compartment space, use an integrated design for advanced LEU reactors
- For example, designs for small, modular reactors such as Korea's SMART SMR to integrate the steam generators and core coolant piping inside the pressure vessel



Recommendations of the Task Force

1. U.S. should try to develop lifetime LEU core for SSN generation following the VA-class and begin R&D by FY2017
2. U.S. should ensure adequate resources for the entire naval nuclear enterprise
3. U.S. should announce this LEU initiative at the 2016 Nuclear Security Summit and encourage other nations to follow suit
4. U.S. and UK should move forward with investigation of feasibility of transparency and safeguards system that would protect naval operations and other classified and proliferation sensitive information
5. U.S. and other nations should work urgently with the IAEA to develop effective means of monitoring and safeguarding nuclear material in the naval sector

Some Important Next Steps

- Need for comprehensive costs vs. benefit analysis for HEU and LEU options
- Track 2 dialogue among states with nuclear navies and those with interest in such to explore how to work together
- Understand how to address the resource needs of the naval nuclear enterprise: replacing or upgrading aging facilities, spent fuel storage and handling, training and well being of the crews, etc.
- Analyze options for the USN that would allow for ability to reach goal of 308 ships (and 48 attack and 12 ballistic missile submarines) while balancing federal budget constraints
- For example, could advanced diesel electric boats substitute for some SSNs? Need to consider broader mission and roles of USN especially to operate in littoral waters of Asia and the Middle East