Tritium on Ice: The Dangerous New Alliance of Nuclear Weapons and Nuclear Power.

Kenneth D. Bergeron. 234 pp. MIT Press, Cambridge, MA, 2002. Price: $25.00 ISBN 0-262-02527-2.(David Hafemeister, Reviewer.)

Tritium is a key component in the primary stage of a nuclear weapon. Without tritium–deuterium fusion boosting in the primary, the secondary will not explode with significant yield. Tritium does not add much energy to the primary's fission yield, but it shortens the time. It takes about 80 doubling generations for a primary to explode, but by getting a quick dose of neutrons, generations can be skipped, saving time before violent disassembly. By increasing the fission efficiency of the ^{239}Pu or ^{235}U, less material is needed, and the size of primaries can be reduced.

The US has not produced tritium since 1988, relying instead on existing supplies. But these are being depleted by the spontaneous decay of tritium (half-life 12.3 yr), and the Department of Energy decided in 1998 to resume production, at the Tennessee Valley Authority's (TVA) Watts Bar reactor. Kenneth Bergeron's *Tritium on Ice* raises three main concerns about this decision: (1) The urgency of the need for tritium. (2) The breach in the traditional separation between military and commercial fuel cycles. (3) Reactor and environmental safety issues.

The need for more tritium: Bergeron correctly points out that the need for tritium is driven by US plans to maintain a large enduring stockpile of nuclear weapons. One might think that the 2002 Strategic Offense Reduction Treaty (SORT) would lead to a reduction to 2200 warheads, but the US desire for flexibility, with a large "responsive force" and a considerable number of spares, actually suggests a total of about 10 000 warheads. J. Cirincioni [Phys. and Soc. **31**, 14 (July 2002)] considers the following stockpile for the year 2012:

Operational deployed force	2200
Warheads on 2 Tridents in overhaul	240
Missile and bomber warheads in response force	1350
Nonstrategic bombs assigned to US/NATO	800
Nonstrategic cruise missiles (SLCMs)	320
Non-strategic spares	160
Intact warheads in inactive reserve	4900
Total	10 000

After considering proposals to make tritium in dedicated accelerators or reactors, the DOE opted to contract for tritium services at an existing TVA nuclear power plant. One can estimate tritium demand from three factors: the decay rate of tritium (mean life $\tau = 17.7$ yr), the DOE's proposed tritium production rates, and the number of warheads in a future stockpile. Tritium is produced from the absorption of neutrons by ^{6}Li in thermal reactors. DOE stated in 1998 that it would start tritium production of 2.5 kg/yr in 2005 for nuclear weapons under START I, which sustains some 8000 strategic warheads, plus other warheads. DOE said it would postpone production of 1.5 kg/yr until 2011 if START II entered into force with a limit of 3500, plus other warheads. Deeper cuts in warheads would relax tritium requirements, and postpone even further the need for new tritium. A factor of 4 reduction, from

10 000 to 2200, would extend the time before new supplies are needed by two half-lives, or a total of 25 yr. My estimate ignores the details of the actual tritium cycle (reserves, pipeline, recycle losses).

In 2005, under START I, the tritium needed in the stockpile under steady-state conditions would be

$m_1 = \tau(dm/dt) = (17.7\ yr)(2.5\ kg/yr) – 44\ kg$,

with an average tritium budgeted per warhead of about

44 kg/10000 = 5 g.

A reduction in warheads postpones the need for tritium production as follows: SORT (START III) at 2000 warheads + 3000 reserves, tritium production begins in 2015.

m_2 = (5000 warheads) (5 g/warhead) = 25 kg,

$\Delta t = -[\ln(m_2/m_1)](\tau) = -[\ln(25\ kg/44\ kg)](17.7\ yr) = 10\ yr + 2005 = 2015$.

SORT at 2000 warheads: m_3=10 kg, Δt=26 yr+2005, begins in 2031. SORT II at 1000 warheads: m_4=5 kg, Δt=38 yr+2005, begins in 2043.

Thus the urgency of the need depends critically on the number of warheads anticipated.

Separation of the military and commercial fuel cycles: The *multilateral* Nonproliferation Treaty is our only hope to prevent the global spread of nuclear weapons. The US, as one of the five nuclear weapons states (NWSs), has long promoted the ideal of separation between military and commercial fuel cycles. This is not a legal requirement, but rather a matter of setting an example to the 180 non-NWSs. The US mostly adheres to this constraint, but there have been exceptions, such as Hanford's N reactor (shut down in 1988), which made military plutonium as it sold electricity. It is true that having the quasi-private TVA reactors make tritium would further compromise the military–commercial separation by using a commercial electricity plant to make military tritium. I don't applaud this, but it is much less significant to the other NPT parties than US failure to ratify the Comprehensive Nuclear Test Ban Treaty and the go-it-alone US trend on bilateral and multilateral arms control treaties.

Reactor and environmental safety issues: As a former nuclear-safety analyst at Sandia National Laboratory, Bergeron is concerned about the possibility of a breach in the concrete containment vessel after a loss-of-coolant accident. The TVA reactors rely on 1000 tons of ice to cool the steam from an accident and thus reduce pressure on the containment. Bergeron states that ice-condenser reactors are much less safe than reactors without ice but with larger containment vessels. The story Bergeron tells about the financial plight of TVA, thirsting for government dollars, and a NRC looking the other way, is not pretty. However, it is difficult for anyone outside of the safety profession to judge the accuracy of these stories or the magnitude of the danger. Such threats can be true, but it also is true that safety experts sometimes overemphasize their particular issues. I saw this conflict in 1976 when arranging a Senate hearing between the NRC and four whistle blowers. Bergeron argues that the TVA reactor core will be modified in ways that increase the likelihood of an accident beyond the "design basis accident." But he doesn't tell us by how much, so it is difficult to know the magnitude and probability of the additional risk. At any rate, the NRC approved the license for the Watts Bar plant on September 24, 2002.

The US considered producing tritium with modular high-temperature gas reactors, with heavy water reactors, with light water reactors (with and without ice condensers), and with accelerators. The economic data given by Bergeron (page 134) do not indicate the chosen level of tritium production. This is key, since the possibility of a smaller nuclear stockpile calls for a more flexible approach. The life-cycle costs would argue for finishing the Bellefonte light water reactor rather than using the existing ice-condenser reactor, but this conclusion would not hold for a smaller stockpile. Bergeron is convinced that Secretary of Energy Richardson picked the ice-condenser reactor because a smaller initial investment would be more politically acceptable. But Richardson might counter that he wanted more flexible contracts, to allow for reduced tritium production in the event of further arms reductions, and because of a desire to minimize the reliance on commercial reactors.

I agree with much of what Bergeron says, but he overstates the case in several instances. *Tritium on Ice* is well-researched and pleasantly readable, with information and descriptive analysis on nuclear safety and proliferation issues.

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