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Awash in Tritium: Maintaining the Nuclear Weapons Stockpile under START

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I. Executive Summary

Since 1988, the amount of tritium required to maintain the U.S. nuclear weapons stockpile has become a moving (and shrinking) target as the Cold War fades and safety and environmental hazards proliferate at Department of Energy (DOE) weapons production facilities. Rapidly changing requirements, combined with DOE's penchant for secrecy and institutional self-preservation, have made it especially difficult for Congress and the public to judge the validity of DOE claims that ``national security" requires restart of one Savannah River Site (SRS) production reactor in 1991, and construction ``on an urgent schedule" of a New Production Reactor (NPR) for completion ``in or about the year 2000."

Our independent assessment of the available U.S. tritium inventory and likely stockpile needs over the next twenty years does not confirm the need for DOE's proposed program. On the contrary, the analysis suggests that we are witnessing another example of DOE's chronic tendency to overstate nuclear weapons materials requirements. The DOE wasted billions in the 1980's to hedge against the possibility of a plutonium ``shortage" in the 1990's that never materialized. It now appears bent on wasting billions in the next eight years on construction and operation of new and refurbished tritium production facilities that are simply not needed under even conservative assumptions about the pace of future arms reductions.

To accept DOE's current plans for tritium production, one must believe *all* of the following assumptions about the future:

(1) The Soviet Union and the United States will fail to to achieve what they have already agreed in principle to negotiate -- a second round (START II) of arms reductions.

This assumption is critical for DOE's current plans, because a START II agrement, coupled with further retirements of obsolete NATO tactical nuclear weapons, could further reduce the U.S. nuclear arsenal from the current target of about 12,000 warheads in the year 2000 to about 4000 warheads or less by the year 2010. This second round of reductions, easily accomplished under the already negotiated START framework, would postpone the need for startup of *any type* of tritium producer until about the year 2014. At that point, the production capacity required would be far smaller than either the SRS reactors or the proposed NPR, and a wider range of production technologies would be available.

(2) *Both* of the refurbished SRS production reactors will prove unsafe to operate -- even at less than half power -- for more than a few years despite the expenditure of more than $3 billion on their refurbishment. Therefore an NPR must be ready "in or about the year 2000."

This assumption is flawed because there is no evidence to suggest that the refurbished SRS reactors will be unable to operate at low power for at least several years, and perhaps decades. Even without a START II Treaty, if either SRS reactor operates at 30% of historical full power for more than a few years, the NPR would not be required "in or about the year 2000," as maintained by DOE, but some years later, depending on the expected lifetime of the SRS reactors and the size of the tritium "reserve" requirement.

(3) Immediate restart of one SRS reactor at 30% power is required "during the third quarter of 1991" because national security hinges on having an unprecedented five-year tritium reserve in the year 1997 instead of a more modest one- to two-year reserve.

This bizarre assumption is flawed in virtually all respects. The "requirement" for a five-year tritium reserve did not exist in the President's Nuclear Weapons Stockpile Memorandum (NWSM) prior to 1990, when it was inserted by DOE to inflate future requirements, thereby justifying both an earlier restart date for the SRS reactors and an "urgent" requirement for an NPR. As things now stand, we estimate that the *existing* inventory of tritium will meet weapon requirements until the year 2000 -- i.e. DOE now has an *eight year* "reserve" of tritium, generated by increased retirements of older weapons and reduced requirements in future years. Without production from one or both of the SRS reactors, we estimate that the current tritium surplus will shrink to a five-year reserve by some time in 1995.

This estimate is consistent with Secretary of Energy's statement that DOE can meet the "tritium goal" in the NWSM (which includes a five year reserve) until "after about 1994," (i.e. 1995). To maintain this five-year reserve beyond beyond 1995 would require startup of one SRP reactor beginning in the second half of 1994. Why then does DOE claim that it requires immediate startup of production in one SRP reactor operating at 30% power, three years *before* it is actually needed to maintain an unprecedented five -year reserve? The demand to restart now implies that DOE is really attempting to maintain an *eight -year* tritium reserve.

Apparently, DOE believes that it must hedge against the quadruple contingency that <u>all</u> of the following will happen:

- o it will be limited to 30% power operation of just one SRS reactor;
- o a <u>permanent</u> breakdown of <u>both</u> SRS reactors will occur during the second "planning period" of the current NWSM, from 1997-2001;
- o the NPR will be delayed until the year 2004, and;
- o there will be no START II agreement.

<u>Only the simultaneous imposition of all these constraints can justify DOE's planned tritium production program.</u> Despite the end of the Cold War, the worst of traditional "worst-case" planning apparently lives on at DOE. Having an *eight-year* reserve on the shelf *by* 1997, to support *12,000 warheads* over the years *1997-2004*, while restricted to *30% power* operation of just *one* SRS reactor*before* 1997, does indeed appear to require startup "in the third quarter of 1991." Under present circumstances, this improbable concatenation of contingencies can only be regarded as arbitrary, capricious, and self-serving. With the demise of the Cold War, a political or military rationale no longer exists for protecting the option to deploy any particular number of weapons above, *at most*, the few thousand that may be required to deter future proliferators or the rapid "break-out" of strategic defenses that could provoke massive rearmament. One eminently resonable way to respond to the DOE's worst-case scenario would be to gradually retire more weapons after the year 2000. But the Bush Administration is apparently protecting the option to maintain not 4000 warheads, but three times that many, in the decade 2000-2010.

Even *accepting* that 12,000 nuclear weapons must be maintained after the year 2000, the currently planned stockpile can be maintained until 1999 *without restarting production in an SRS reactor.* DOE has apparently steered the President into signing-off on an improbable and unprecedented "reserve" contingency with the defining feature that it *cannot* be satisfied from retirements, but "requires" additional production now. Over the next nine years, the United States is planning to reduce its nuclear weapons stockpile by some 7000 weapons. This provides considerable time for consideration of a range of tritium production options for the future:

- o <u>Until 1998, a two-year reserve requirement couldbe met from retirements alone.</u> Restarting one SRS reactor at 30% power *beginning* in 1997, and operating at this level for only three years, is all that is required to hedge against the delay of an NPR until mid-2002.

- The equivalent of *one* SRS reactor operating at 30% power for ten years (1997-2006) would extend the on-line date for the NPR until 2006.

- The equivalent of one SRS reactor operating at 45% power beginning in 1997 would meet a two-year reserve requirement for a 12,000 warhead arsenal over the remaining *combined* lifetimes of the K and L reactors (10-30 years), or until their replacement with new production capacity.

We conclude from our analysis that DOE's present plans for tritium production are being distorted by DOE's own institutional priorities and by pork barrel political imperatives that have nothing to do with meeting likely national security requirements in the next two decades. In sum:

- The scenario that no further tritium production will be required until the year 2014 is easily achieved by using the START Treaty as a framework for further reductions.

- To hedge against the failure to obtain START II reductions below the 12,000 warhead level currently planned for the year 2000 and beyond, restart of one SRS reactor is required, but no earlier than 1999, if the equivalent of 45% power is available from either one or both SRS reactors. Maintaining a two year reserve require would restart in 1997.

- The two refurbished SRS reactors, backed up by DOE's emergency capability to produce tritium in light water reactors, constitute a more than adequate hedge against a delay in bringing a new tritium producer on line after the year 2000.

- Even accepting the unprecedented five year reserve requirement, there is no justification for restarting the K-reactor for tritium production before mid-1994, leaving ample time for completion and hook-up of the new cooling tower, the completion of all necessary safety upgrades and training, and extended low-power testing.

- DOE's present plan to operate the K -reactor in violation of its Clean Water Act thermal discharge limit will result in gratuitous damage to valuable South Carolina wetlands and to the entire Savannah River ecosystem while serving no intelligible purpose other than to reassert DOE's traditional prerogative of violating environmental laws in the name of "national defense."

We used public record data on tritium production and nuclear weapon retirements as inputs to a computer model which compares the available tritium inventory to current and projected weapons requirements under the START Treaty and potential START II reductions.

The model assumes that the tritium requirement for all warheads of a given type, including the tritium in the warhead and the amount tied up in the supporting pipeline, is proportional to the number of warheads of that type. The total tritium requirement is the sum of the requirement for each warhead type plus a fixed minimum inventory needed to operate the pipeline.

The nuclear warhead stockpile at the beginning of 1987 was assumed to be 23,400 weapons, the number reported to Congress by the Reagan Administration in that year. We then relied on a wide range of data in the public record concerning projected weapons requirements and retirements to provide additional data for gauging the makeup of the stockpile for three benchmark years, 1991, 2000 and 2010. Values for the intervening years were found by interpolation.

The resulting time-dependent estimate of total tritium requirement was normalized to an estimate of the requirement based on DOE's 1988 request for redundant production reactor capacity sized to maintain a stockpile of what was then 23,000 warheads.

The total inventory of tritium was found by assuming a starting inventory in 1986 that was equivalent to the requirement for that year plus a small de facto reserve, and then accounting for annual production and sales, as well as losses due to radioactive decay.

The time-dependent estimates of the tritium requirements and the tritium inventory were then checked against two recent statements by senior DOE officials which reveal when these two curves intersect under different future tritium production scenarios:

- The first statement acknowledges that the current tritium surplus, generated by increased weapon retirements and declining future force levels, is sufficient to meet annual requirements *plus* an unprecedented new requirement for a five year reserve supply of tritium, until some time in 1995.

- The second statement acknowledges that, to satisfy annual weapon requirements for tritium and sustain the ``five-year reserve" in the period 1995-1999, tritium output from the equivalent of one SRS reactor operating at 30% power is needed beginning in the spring of 1992.

Fitting these two ``data points" so constrains our model assumptions that we are confident that our model presents a reasonably accurate forecast of future tritium requirements.

Based on the above assumptions, which represent our best current understanding of the available unclassified information on tritium production, our analysis leads to the following conclusions:

1. The current and future inventory of tritium is sufficient to meet declining annual *weapons* requirements until the year 2000 *without additional production.* This conclusion is based on dropping the new requirement for a five-year reserve, and reaching an anticipated plateau in weapons retirements under START at about 12,000 total strategic and tactical weapons by the year 2000.

2. A START II agreement that reduced weapons to 4000 on each side by the year 2010 would make a resumption of tritium production -- equivalent to operating one SRS reactor at less than 30% of full power -- unnecessary until the year 2014. Adding a requirement for a two-year tritium reserve advances the production restart date to 2012. A five-year reserve would require restart in 2010.

3. A START II agreement that only reduced weapons to 6200 on each side by 2010, would make a resumption of tritium production unnecessary until the year 2009. Adding a requirement for a two-year tritium reserve advances the restart date to 2007. A five-year reserve would require restart in 2005.

4. A simple paper change in the treatment of the current tritium inventory, from a five- to a two-year ``reserve requirement," would permit deferral of K reactor restart from 1991 to 1997 without jeopardizing the amount needed for 12,000 nuclear weapons in the year 2000.

5. Restarting one SRS reactor at 30% of full power in 1997 would maintain the ``requirements plus 2-year reserve" level for a 12,000 warhead force only until mid-1999. However, 30% power operation of one reactor beginning in 1997 does assure that the available inventory will continue to exceed weapons requirements until 2006, providing considerable additional time to choose the appropriate technology and capacity for a new tritium producer.

6. Restarting of one SRS reactor at about 45% power in 1997 would provide enough tritium to maintain a 12,000 warhead stockpile plus a two-year reserve. To meet concerns about reliability and safety, the K and L reactors at the Savannah River site could alternate operation at near half-power, providing extended down-time periods for inspection and maintenance, or both reactors could be operated at lower power levels to meet the same requirement.

7. Even under the pessimistic scenario of no START II agreement by the year 2000 -- leaving a 12,000 warhead force to be maintained into the next decade -- there is no justification for beginning construction of a New Production Reactor (NPR) or Accelerator Tritium Producer (ATP) until fiscal year 1998. As noted above, 30% power from *either* of the two remaining SRS reactors starting in 1997 would be sufficient to meet a 12,000 warhead requirement until the year 2006, when a new tritium producer could be on line.

8. Independent of future decisions about tritium production capacity, the DOE complex continues to be burdened by inefficient tritium loading and reservoir exchange practices, leading to superfluous ``fixed" tritium inventories that simply decay away in processing, loading, and warhead production facilities. These inefficiencies increase the total inventory of tritium needed to maintain a given-size stockpile.

II. Background

In 1943 Edward Teller first proposed that the yield of an atomic bomb could be increased by incorporating deuterium (D) and tritium (T) within the fissile core of plutonium and/or highly enriched uranium. Before the deuterium and tritium come into play it is necessary to achieve a super-critical mass and initiate the chain reaction in the fissile material. As the chain reaction progresses a tremendous amount of energy is released in the fission process, heating the deuterium and tritium to extremely high temperatures -- in the range of tens of millions of degrees -- sufficient for the nuclei to overcome their repulsive force and fuse together in the reaction ``deuterium plus tritium yields helium-3 plus a neutron:"

$$D + T \dashrightarrow He^3 + n \,. \tag{1}$$

The copious release of neutrons from the fusion of just a few grams (g) of DT add to those from the fission process, causing a rapid increase in the rate of the chain reaction still underway. The effect is much like engaging the afterburners in a jet fighter, and the result is called ``boosting." Boosted fission warheads are more efficient than unboosted warheads, permitting greater yield (explosive energy) per unit weight, or alternatively, less weight to achieve the same yield. Since a boosted warhead requires less fissile material and less chemical high explosive (HE) than an unboosted warhead with the same yield, if the HE accidentally detonates the probability of initiating a nuclear chain reaction is smaller in the case of the boosted warhead; consequently it is a safer design against possible accidental dispersal of radioactivity.

Most warheads in the U.S. nuclear weapons stockpile are two-stage thermonuclear devices -- based on the Teller-Ulam design in which a ``primary" fission explosion is used to trigger a much larger ``secondary" fusion explosion -- with boosted ``primaries" usually comprising the first stage.[1] A few low-yield warheads are single-stage boosted fission weapons.

DT is also used in the thermonuclear secondaries of enhanced radiation warheads, sometimes referred to as ``neutron bombs." Here, DT is used instead of other fusion materials, e.g., lithium-6 deuteride, to create a weapon in which the radius of lethal neutron radiation damage to personnel exceeds the radius of major airblast overpressure damage to buildings. Enhanced radiation warheads typically require considerably more DT -- perhaps as much as 20 to 25 g of T compared to an average of about 4 g of T in a boosted warhead. There are two enhanced radiation warheads in the U.S. stockpile, the W70-3 warhead for the Lance missile and the W79 8-inch artillery shell. Only one of the warhead types remaining in the U.S. stockpile, the W33 artillery shell, contains no DT, and this weapon is being retired. It is an unboosted ``oralloy"[2] warhead based on the simple gun-assembly design principle used in the Hiroshima bomb.

Figure 1 (a) shows the yield of a hypothetical boosted fission warhead, or a boosted primary of a two-stage thermonuclear warhead, as a function of the amount of DT utilized. Above the knee of the curve the efficiency of the fission process if not significantly increased by adding more DT. Below the knee, as the amount of DT is reduced the yield drops off rapidly, eventually to a point where the warhead becomes ineffective. By operating in a region where the yield is sensitive to the DT content, the yield of the warhead can be varied by varying the amount of DT introduced into the fissile core.[3] The yield of a two-stage thermonuclear weapons can be varied similarly, since its yield depends on the compression of the secondary which is a function of the yield of

[1] For an unclassified history of the development of the Teller-Ulam design see Thomas B. Cochran and Robert S. Norris, *The New Encyclopædia Britannica*, 15th Edition, 1990 Printing, Volume 29, pp. 578-579.

[2] *O*ak *R*idge *A*lloy, or "oralloy," is uranium metal enriched to above about 90% in the fissile isotope U-235.

[3] Thomas B. Cochran, et al., *Nuclear Weapons Databook, Volume I, U.S. Forces and Capabilities*. (Cambridge, MA: Ballinger Publishing Co., 1984), p. 31.

the primary (See **Figure 1 (b)**).

While deuterium is a stable isotope, tritium decays into helium-3, with a radioactive half-life of 12.26 years (y) - 5.5 percent is lost through radioactive decay each year:

$$T \overset{\hat{a}^-}{\text{---->}} He^3 \qquad (2)$$

The tritium in the warheads therefore must be replaced periodically if the warhead is to operate within allowable limits on its yield. In U.S. warheads the deuterium and tritium along with a carrier gas are stored as a gas mixture in a reservoir - a small stainless steel bottle housed external to the fissile core (**Figure 2**). As part of the arming sequence the reservoir is opened and the DT released into the core. The reservoirs are called ``limited life components," because they must be removed from the warheads before the tritium has decayed to the minimum desirable level and replaced by fresh bottles. In some, if not all, U.S. warheads with variable yields, yield selection is probably accomplished by including more than one DT reservoir in the same warhead. In the arming sequence, the desired quantity of DT is probably released by completely discharging the appropriate reservoir(s), rather than attempting to bleed varying quantities from a single bottle. In theory, at least, it is possible to control the yield of a secondary by varying the supply of tritium to it from an external reservoir. However, we have no evidence that current tritium requirements include a requirement for secondary boosting in this manner.

The Department of Energy (DOE) produces the deuterium and tritium, fills the reservoirs, and provides them to the Department of Defense (DOD) to replace existing reservoirs nearing the end of their life span. The military services install the newly filled reservoirs in warheads in their custody in the field and returns the expiring reservoirs to DOE for recycling, that is, to separate out the remaining tritium from the helium-3 and use it in refilling reservoirs to be returned to the stockpile.[4] The DOE installs some reservoirs in newly produced warheads at the DOE Pantex Plant in Amarillo before shipment.

To supply the requirements for new warheads and to ``makeup" what is lost in deployed warheads through radioactive decay, tritium has been produced in specialized DOE heavy-water moderated reactors by neutron capture in lithium targets:

$$Li^6 + n \text{ ----> } Li^7 \text{ ----> } He^4 + T. \qquad (3)$$

[4] United States General Accounting Office, ``Nuclear Weapons: A Model for Evaluating the Tritium Reservoir Exchange," GAO/-NSIAD-91-86, May 1991, p. 11.

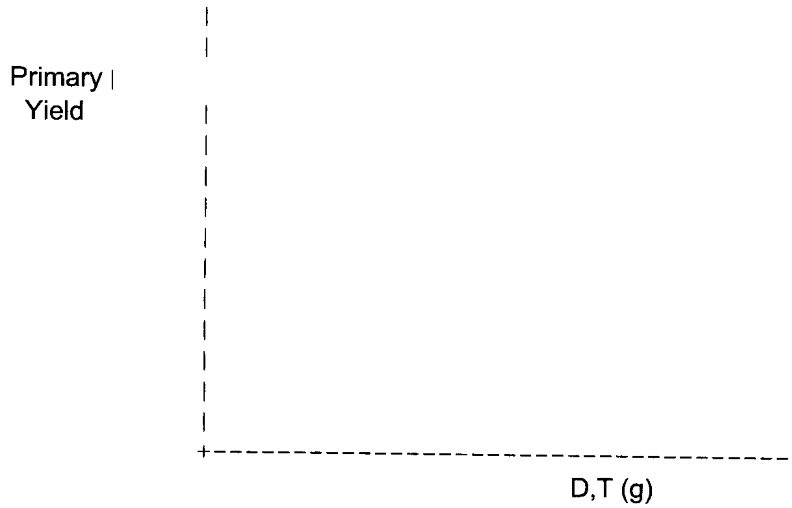

Figure 1 **a)** The yield of a boosted fission warhead (or the primary of a thermonuclear warhead) as a function of the tritium (and deuterium) loading.

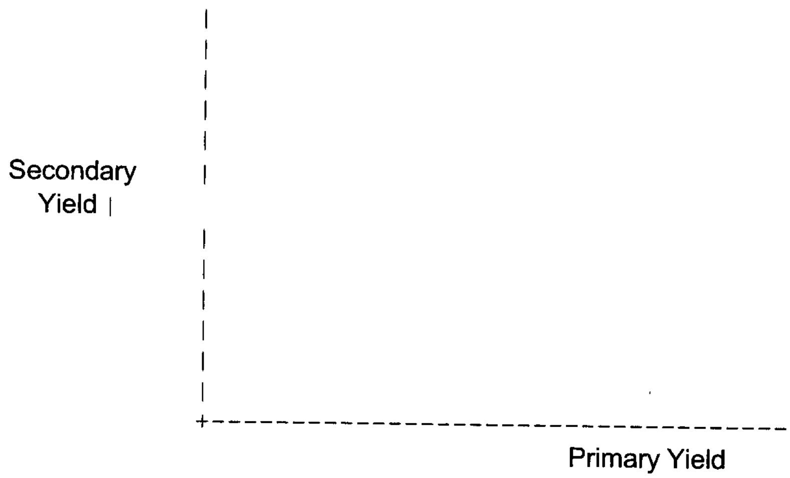

Figure 1 **b)** The yield of the secondary of a thermonuclear warhead as a function of the primary yield.

Figure 2. A picture of a tritium reservoir provided by DOE at a hearing at Aiken, South Carolina, June 8, 1991 (scale unknown).

After irradiation the lithium targets are removed from the reactor and taken to a processing facility where the metal targets are heated to drive out the tritium and helium, which are recovered as a gas mixture. The gas is then processed to separate the tritium from the helium-4 by-product. In the United States the production reactors and the tritium processing and loading facilities are located at the Savannah River Site (SRS) near Aiken, South Carolina, with backup tritium processing and loading facilities at the Mound Laboratory, Miamisburg, Ohio.

Figure 3 shows a 1988 production reactor schedule for the P-, K-, and L- Reactors at SRS. This schedule was never realized since these reactors were all shutdown for safety reasons in 1988. None have been restarted. The P-Reactor is being placed on cold standby. DOE hopes to restart the K- and L- reactors, but neither is expected to operate in the future above 30 to 50 percent of full power for safety reasons.

Historically, as revealed by the schedule, in a ``tritium run" with MK-22 lithium targets, a reactor at full power was meant to operate for about one year, after which it was shutdown for about three months for refueling and maintenance. The targets were removed in two batches; first, during a two week period following six months of reactor operation, and then again at the end the operating period year when the reactor was down for refueling. The lithium targets were typically cooled for at least three months and then processed for tritium extraction over the following months. Consequently, the time period from reactor startup to first tritium availability was about nine months. According to DOE Secretary James Watkins, after an extended outage, an initial period of 5% power testing "that can take anywhere from six weeks to two months" would extend the period from startup to tritium availability.[5]

Figure 4 illustrates the tritium reservoir exchange process.[6] Note that at the time of installation and removal of the reservoir, a second reservoir must be available to facilitate the exchange. The GAO has published results of a sensitivity study that evaluated how tritium requirements are affected by the reservoir exchange schedule (**Table 1**).[7] From these data we are able to estimate, as done below, the average warhead residence time and the average time the reservoirs spend in the pipeline in DOD and DOE custody.

We begin by defining Q_R as the amount of tritium remaining in the warhead at the time the reservoir is removed from the warhead.[8] Were the reservoir exchange scheduled optimized, this also would be the minimum tritium loading which permits the warhead to meet its design specifications, which we define as Q_M. The reservoirs are typically removed from the warheads a few months before Q_R reaches Q_M. Q_M, and therefore Q_R, is a function of the warhead design, and consequently varies with warhead type. For a given warhead type the amount of tritium in the reservoir at the time it is installed in the warhead (Q_I) is greater than Q_R by the quantity of tritium that decays in the time, T_W, that the reservoir resides in the warhead before being removed:

[5] "Watkins Sure of Restart," The Augusta Chronicle, August 4, 1991, p. 1.

[6] Ibid., p. 12.

[7] Ibid, p. 16.

[8] While we assume the warhead contains a single reservoir, the derivation that follows can be generalized to more than one.

Figure 3 Production reactor schedule - March 1988 forecast.

Figure 4 Illustration of the tritium reservoir exchange process (time periods are not to scale)[9].

[9] From GAO/NSIAD-91-86 Tritium Reservoir Exchange Process, p. 12.

TABLE 1: Results from GAO Sensitivity Analysis[10]

Case		Ratio of Tritium in the Pipeline to Tritium in Warheads
1.	Benchmark	0.200
2.	Exchange on Expiration Date[a]	0.190
	Shipping Rules:	
3.	90/120 & 60/90 Shipping Rule[b]	0.175
4.	60/90 & 30/90 Shipping Rule[c]	0.150
5.	15/30/15 & 45/30/45 Shipping Rule[d]	0.125
	Maximum Deferral:	
6.	Assuming Zero DOD Pipeline	0.100

[a]*Case 2*: Shipping and handling times are identical to the Benchmark Case; but the exchange date coincides with the old reservoir's expiration date.

[b]*Case 3*: CONUS sites require 90 days to receive and install a new reservoir from DOE; 60 days are required for return of the old reservoir. (Sites outside CONUS require 120 days to receive and install a new reservoir; the return requires 90 days.)

[c]*Case 4*: CONUS sites require 60 days to receive and install a new reservoir from DOE; 30 days are required for return of the old reservoir. (Sites outside CONUS require 90 days to receive and install a new reservoir; the return requires 90 days.)

[d]*Case 5*: CONUS sites require 15 days to receive a new reservoir from DOE; installation requires an additional 30 days; and 15 days are required for return of the old reservoir. (Sites outside CONUS require 45 days for receipt; 30 days for installation; and 45 days for return of the old reservoir.)

[10] From GAO/NSIAD-91-86, "Tritium Reservoir Exchange Process," p. 16.

$$Q_I = Q_R \exp(ëT_W), \qquad (4)$$

where the radioactive decay constant $ë = \ln(2)/T_{1/2} = 0.0565$. (See box on page 15 for a complete list of parameter definitions.) The warhead residence time, T_W, depends in part on the warhead mission. For some readily accessible warheads, e.g., bombs in storage, T_W is probably in the range of 4 to 7 y. From the GAO data (**Table 1**) and Equations 5-9 below, we estimate the average tritium reservoir ``residence time" for all warheads in the stockpile is about 6.7 y.[11] The replenishment time of reservoirs used in SLBM warheads is probably timed to coincide with the submarine overhaul period. For modern Trident submarines this is reported to be ``about 12 years" after commissioning.[12] For a hypothetical warhead with a minimum tritium requirement $Q_R = M = 3$ g, the tritium loading at installation, $Q_I = 4.4$ g, if the residence time $T_W = 6.7$ y; and $Q_I = 5.9$ g, if $T_W = 12$ y.

In assessing tritium requirements we must also take into account the amount of tritium in the production-distribution ``pipeline." We will exclude from our definition of the pipeline the fresh material in irradiated targets, including targets in the reactor and those being cooled prior to processing for tritium removal. We also ignore for the moment the minimum fixed inventory of tritium needed to operate the processing and loading facilities, some of which may be in reservoirs. We define T_{FS} as the period of time from the reservoir fill date to the shipping date (during which the reservoir is in DOE custody); and T_{SI} as the period from shipment to installation (during which the reservoir is in DOD custody).

Similarly, T_{RS} is the period from the date the reservoir is removed from the warhead to the shipping date (during which the reservoir is in DOD custody); and T_{SD} is the period from shipment to tritium removal (during which the reservoir is back in DOE custody). We estimate that in 1988, prior to DOE and DOD efforts to reduce the tritium inventory in the pipeline, the average period a reservoir was in DOE custody, $T_{FS} + T_{SD} = 241$ days (d); and the average period in DOD custody, $T_{SI} + T_{RS} = 235$ d (See footnote 10). The average pipeline time, $T_P = T_{FI} + T_{RD} = (T_{FS} + T_{SI}) + (T_{RS} + T_{SD}) = 476$ d, or 1.3 y.

The reservoir fill inventory, Q_F, is found by replacing T_W in Equation 4, by $(T_W + T_{FI})$. Thus, for our hypothetical warhead where $Q_R = M = 3$ g, we find that

$$Q_F = 4.6 \text{ g, for } T_W = 6.7 \text{ y, and } T_{FI} = 250 \text{ d.}$$

The average amount of tritium in a single reservoir over its entire cycle from fill to depletion, i.e, over the period $(T_W + T_P)$, is given by

$$\langle Q_{FD}\rangle = [Q_F/ë(T_W + T_P)][1-\exp(-ë(T_W + T_P))]. \qquad (5)$$

Because of the need for the second reservoir at the time of installation and removal, the average tritium requirement per warhead is given by

$$\langle Q_W\rangle = \langle Q_{FD}\rangle ((T_W + T_P)/T_W). \qquad (6)$$

For our hypothetical warhead with $Q_R = M = 3$ g, we find that $Q_{FD} = 3.7$ g, and $\langle Q_W\rangle = 4.4$ g for $T_W = 6.7$ y, and

[11] Equations 5-9 and the data in **Table 1** permit us to estimate average values for tritium residence time in the warhead and pipeline for the year 1988, namely, $T_W = 6.707$ y; $T_{FS} = 121$ d; $T_{SI} = 130$ d; $T_{RS} = 105$ d; and $T_{SD} = 121$d (We can only estimate $(T_{FS} + T_{SD})$ and have therefore arbitrarily assumed $T_{FS} = T_{SD}$). We assume 4,000 warheads outside CONUS. See box, p. 15 for definitions.

[12] HAC, FY 990 DOD, Part 6, p. 545. The first Trident submarine, USS Ohio, was commissioned in November 1981 and deployed in September 1982. It is scheduled to enter overhaul in December 1992. See J. Handler and W. M. Arkin, "Nuclear Warships and Naval Nuclear Weapons 1990: A Complete Inventory," Greenpeace *Neptune Papers* No. 5, September 1990, p. 18.

$T_P = 1.3$ y ($T_{FI} = 0.687$ y, and $T_{RD} = 0.619$ y). If T_W is increased to 12 y, $\langle Q_{FD} \rangle$ increases by 18 percent to 4.3 g, but $\langle Q_W \rangle$ increases by only 9 percent to 4.8 g.

The ratio of average tritium inventory while the reservoir is in the warhead to the average tritium inventory while in the pipeline is given by

$$R = (\langle Q_{IR} \rangle T_W)/(\langle Q_{FD} \rangle (T_W + T_P)), \tag{7}$$

where $\langle Q_{IR} \rangle$ is the average loading of a reservoir during the warhead residence time, T_W, given by

$$Q_{IR} = [Q_I/(\ddot{e}T_W)][1-\exp(-\ddot{e}T_W)]. \tag{8}$$

In the GAO report, the ratio of the pipeline inventory to warhead inventory, f, is related to R, in Equation 7, by

$$f = (1-R)/R. \tag{9}$$

Aside from using Equations 5-9 to calculate the warhead and pipeline residence times (see footnote 10), we will be able to use these equations to confirm the reasonableness of some of our modeling assumptions described below.

Definitions[13]

$T_{1/2}$	=	radioactive half-life = 12.26 y for tritium
$\ddot{e}$	=	radioactive decay constant, $\frac{\ln(2)}{T_{1/2}} = 0.0565$ for tritium
Q_F	=	inventory of tritium in a freshly *f*illed reservoir
Q_I	=	inventory of tritium in a reservoir at the time of *i*nstallation in a warhead
Q_R	=	inventory of tritium in a reservoir at the time of *r*emoval from a warhead
Q_M	=	*m*inimum tritium required to meet the warhead's required yield
Q_D	=	inventory of tritium removed from depleted reservoir, i.e. at time of purification
$\langle Q_{FD} \rangle$	=	average inventory of tritium in a reservoir over its entire cycle from *f*ill to *d*epletion
$\langle Q_{IR} \rangle$	=	average inventory of tritium in a reservoir during the period it is in a weapon
$\langle Q_W \rangle$	=	average tritium requirement per *w*arhead
T_{FS}	=	time period from reservoir *f*ill date to *s*hipment by DOE (during which it is in

[13] Many of the subscripts in this list of parameters are keyed to labels in Figure 4.

DOE custody) to DOD

T_{SI} = time period from reservoir *s*hipping date to date of *i*nstallation in a warhead (DOD custody)

T_{FI} = $T_{FS} + T_{SI}$ = time period from reservoir *f*ill date to date of *i*nstallation in a warhead

T_W = time period during which the reservoir is in a *w*arhead

T_{RS} = time period from date of removal of the reservoir from the warhead to the date of shipment by DOD back to DOE (DOD custody)

T_{SD} = time period from date of shipment by DOD to DOE to the date of removal of the tritium from the reservoir for purification (DOE custody)

T_{RD} = $T_{RS} + T_{SD}$ = time period from date of removal of the reservoir from the weapon to the date the tritium is removed from the reservoir for purification

$T_{FS} + T_{SD}$ = total time a reservoir is in DOE custody

$T_{SI} + T_{RS}$ = total time a reservoir is in DOD custody

T_P = $(T_{FS} + T_{SI}) + (T_{RS} + T_{SD}) = T_{FI} + T_{RD}$

= period of time a reservoir is in the pipeline, i.e., during which it contains tritium but is not in a warhead

$T_W + T_P$ = total lifecycle of a reservoir

III. TRITIUM MODEL ASSUMPTIONS

While not designated as a ``Special Nuclear Material" under the terms of the Atomic Energy Act, tritium requirements and production operations are nonetheless handled with a considerable degree of secrecy. This makes independent, non-government assessments of these requirements and operations difficult. However, using the few data points that are on the public record, it is possible to construct a window on the tritium supply and demand picture which approximates the current situation and indicates the range of options for the future. Below we discuss separately our assumptions for estimating tritium requirements and supply.

A. Estimating requirements

Net annual tritium requirements are the sum of: the makeup required to offset tritium lost through radioactive decay, plus the tritium needed to supply new warheads, minus the tritium recovered from retired warheads. We also account for the small quantity of tritium produced by DOE that is sold commercially.

We approximate the amount of decay, the requirements for new warheads, and the recovery from retirements by first estimating the total requirement for a single benchmark year, namely, 1988. By ``total requirement" we mean the amount of tritium in warheads and the pipeline requirement to support these warheads. We choose the year 1988, because we have data permitting such an estimate, and we also have a good estimate of the number of warheads in that year. In February 1987, the Reagan Administration reported to Congress that the U.S. nuclear weapons stockpile was composed of 23,400 weapons.[14] In line with this report, we estimate that the U.S. nuclear stockpile was reduced to about 23,000 weapons by the beginning of 1988.

In December 1988 DOE stated that the supply of tritium could be assured by constructing ``two new production reactors (NPRs) at two sites to satisfy the goals of *redundancy*, *diversity* and *site duality* for tritium production." In other words, actual *requirements* for maintaining the stockpile could be met by just one of these reactors. DOE's intention at the time was that ``one NPR should be a modernized version of the current Heavy-Water Reactor (HWR), because it has the highest level of technical and production assurance (lowest uncertainties)."

> The other NPR should be a Modular High-Temperature Gas-Cooled Reactor [MHTGR]....sized to provide capacity for preproduction of tritium for contingency purposes and *for sufficient makeup tritium for maintaining the stockpile* in case of a protracted loss of the HWR (emphasis added).[15]

The proposed MHTGR plant design consists of four reactor modules, each rated at 350 megawatts-thermal (Mw_T), for a total thermal power of 1400 Mw_T.[16] This information allows one calculate a rough estimate of the ``plutonium equivalent" production capacity of this four reactor module -- about 385 kilograms (kg) annually -- which translates into a tritium production capacity of 5.35 kg.[17]

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[14] HASC, FY 1988 DOE, p.48.

[15] Report to the Congress by the President, ``United States Department of Energy Nuclear Weapons Complex Modernization Report," December 1988, pp. 14-15.

[16] "The Modular High Temperature Gas-Cooled Reactor: Inherently Safe Nuclear Power," (Undated brochure from the General Atomics Corporation, circa 1990.)

[17] Calculation assumes 1.0 g plutonium equivalent production per megawatt-day, with no tritium production in control rods, 0.75 capacity factor, and 1 g of tritium output is equivalent to 72 g of weapon grade plutonium. See T. B. Cochran, et al., *Nuclear Weapons Databook, Volume 2, U.S. Nuclear Warhead Production*, Ballinger Publishing Co., 1987, footnote, page 63, which cites HASC, FY 1982 DOE, p. 172. Capacity factor confirmed by General Atomics, August 19, 1991.

We assume 5.5 kg represents the steady state tritium requirement to maintain a stockpile of 23,000 warheads. Were the stockpile composition (the number of warheads of each type) to remain fixed, and if for each warhead type the loading of tritium reservoirs were spaced uniformly (or randomly) over the reservoir life cycle period[18], then the tritium needed annually to make up the difference between what is recovered by DOE from depleted reservoirs, and what is required to fill the fresh reservoirs would be equal to 5.5 percent of the total required inventory, including the pipeline. Thus, the tritium requirement corresponding to the 1988 stockpile of 23,000 warheads was just under 100 kg (5.35 kg/0.055 = 97.3 kg).

The inventory of weapons is not static, but is constantly changing. We assume the current (June 1991) stockpile of about 19,000 weapons will be reduced to about 11,975 weapons by the year 2000. The weapons mix that we have adopted for each of the benchmark years 1991, 2000, and 2010, is given in **Table 2**. In Table 2 and in our model, we have assumed a slightly higher stockpile in the year 2000 than appears likely, because we have included 500 SRAM-T warheads, which were included in the Administration's FY 1992 budget request. In our view it is likely that the SRAM-T and its warhead will be canceled.

If the future requirement for tritium were strictly proportional to the number of current nuclear weapons remaining in the stockpile under an indefinite production shut-down, then the 5.65 percent annual decay of tritium would force the same exponential reduction in the number of weapons in later years. This scenario is illustrated in **Figure 5**.

Future requirements, however, are not expected to scale in direct proportion to the number of warheads in the stockpile, because the different warhead types require different tritium loadings, and there is assumed to be a minimum tritium inventory required to operate the processing and loading facilities that is independent of the number of warheads. Obviously, the current determinants of this minimum ``fixed" inventory -- such as the existence of two nuclear weapon design laboratories with their own distinct blends of DT gas that require duplicate loading facilities -- inflate this ``fixed" inventory well above what may actually be required to run the reservoir exchange process in the future.

[18] Since the number of warheads is so large, we believe this is a good approximation.

TABLE 2 United States Nuclear Stockpiles -- 1991, 2000 and 2010

TABLE 2: NOTES

Figure 5 Maximum number of warheads if there is no further tritium production or commercial sales, and the average tritium requirement per warhead remains constant.

To model future tritium requirements precisely, one would have to track all reservoirs, taking into account differences in the tritium inventories of reservoirs filled to supply new warheads and the tritium inventories of reservoirs removed from retired warheads.

In our model we assume that the tritium loading in a new warhead added to the stockpile in a given year is the same as the steady state loading averaged over the entire reservoir cycle for the same warhead type (See Equation 6). We make the same assumption with regard to retired warheads. (We do *not* assume that retired warheads are always those with the lowest tritium inventory among warheads of the same type; and we do not assume new warheads are given reservoirs that are topped off.) For the warhead addition and retirement rates of interest, however, the error introduced into our estimate of the total tritium requirement by this approximation is small, amounting to not more than about 0.5 percent a year.[19] Although the errors introduced each year with our model can accumulate over several years, the two models come back into agreement after all warheads of a given type are retired, or after the life span of the reservoir, about eight years, whichever is smaller. More importantly, since our model represents one plausible scenario for reservoir management, it should not be regarded as necessarily being in error.

We have attempted to account for differences in future tritium requirements by assuming higher tritium loadings for some warhead types, e.g., the W70 and W79 enhanced radiation warheads, the modern B83 bomb when fully loaded to maintain all yield options, and the W88 Trident II warhead where we have assumed an extended warhead ``residence time" for the tritium reservoir that corresponds to a 12-year overhaul cycle for the Trident submarine.

We have also assumed that the minimum ``fixed" tritium inventory in DOE processing and loading facilities totals 5 kg, about 30 percent of the estimated total pipeline inventory in 1988, and 60 percent of the pipeline in DOE custody in the same year. This may seem large but we want to be conservative so as not to underestimate future tritium requirements.

In 1989, we assumed the variable (i.e., time sensitive) pipeline requirement was reduced by 2 kg due to more efficient tritium reservoir management introduced after the SRS reactors were shut down. This represents 12 percent of the pipeline in 1988, and is in line with possible reduction projected by GAO (See **Table 1**). With these assumptions, the *base* tritium requirement for the stockpile in the year 2000 (see **Table 3**, col. 3, and **Figure 6**) is projected to be about 55 kg, 9 percent greater than the tritium needed to supply the same number of warheads if the requirement were strictly proportional to the stockpile size.

B. Estimating total inventory

To project the total tritium inventory (requirement + reserves) we estimate a starting inventory at a specific time, 1986, and the record of production and commercial sales, and of course we factor in the losses through radioactive decay. We know that in 1986 the available tritium inventory exceeded the requirement, but by an amount that was surely less than the recently created

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[19] This is the relative difference in the final inventory predicted by our model (based on Equation 6) and a model assuming new reservoirs are filled (Q_F) and retired reservoirs are depleted (Q_R), for the case where one starts with a steady state inventory of 19,000 warheads containing 100 kg of T, and removes in one year 900 warheads that require 0.75 times the average tritium loading, and adds 100 warheads requiring 3 times the average loading.

TABLE 3 Projected tritium requirements and inventory assuming no tritium production after 1988, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Database for **Figures 6-8** and **10**). Eighteen month tritium reserve in 1986. No new tritium production after 1988. The stockpile is reduced to 11,975 warheads by the year 2000, due in part to START, but is maintained at that level thereafter.

Figure 6 Projection of tritium requirements assuming 11,975 warheads in the year 2000 and beyond. (Data from **Table 3**).

(1990) requirement for a ``five year reserve" supply of tritium. We have assumed an 18-month reserve, for a total starting inventory of 110.4 in 1986. Commercial sales have averaged 180 g in recent years, are about 120 g in 1991, and are projected to average about 150 g in the future.

Three reactors at SRS have operated in the tritium production mode since 1984. The C-Reactor ran a tritium campaign from March 1984 to June 1985; the K-Reactor from March 1987 to April 1988; and the P-Reactor from June 1987 to August 1988, with no production from May through July 1988. From published figures for the thermal energy output by month for each reactor, we have estimated the tritium production by month and corrected for radioactive decay.[20] For historical campaigns (1985-1988) we assume the tritium was available to the stockpile beginning nine months after the start of the tritium campaign. For future campaigns we assume the tritium is available one year after startup. The precise time of availability of tritium from historical campaigns is actually unimportant in accounting for the total inventory since radioactive decay is calculated from the month of production.

Based on the above assumptions, **Figure 7** shows the future annual decay of the existing United States tritium inventory, and its ability to meet the declining stockpile requirement for tritium until this requirement levels off at about 55 kg and 12,000 warheads in the year 2000.

IV. TESTING THE MODEL AGAINST OFFICIAL STATEMENTS OF TRITIUM PRODUCTION NEEDS

In recent years, nuclear stockpile requirements have become a moving (and shrinking) target as the Cold War fades into history and DOE's environmental liabilities proliferate. This situation, combined with DOE's usual penchant for secrecy and institutional self-preservation, have made it especially difficult for Congress and the public to judge the validity of DOE's claims that national security demands the restart of critical production facilities now shut down for noncompliance with modern environmental and safety standards. At the SRS, for example, DOE had claimed that it was urgent to restart the K-reactor by September 1990, but restart was subsequently delayed until December 1990, then July 1991, and now ``the third quarter of 1991." Citing an increased supply of tritium from retirements and a significant reduction in future force levels, the GAO concluded in a February 1991 report that:

> ...the decreased tritium requirements provide additional time for DOE to: evaluate outstanding safety and environmental issues before restarting the Savannah River reactors, and; decide whether plans for future capacity are still appropriate.[21]

GAO also noted that:

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[20] We assumed 1.04 g of plutonium equivalent production per megawatt-day (Mwd) of thermal energy production and 1 g tritium per 72 g plutonium equivalent production. We also assume 0.002 g of tritium per Mwd produced during plutonium campaigns in control rods and blankets. See Thomas B. Cochran, et al., *Nuclear Weapons Databook, Volume II, U.S. Nuclear Warhead Production*, (Cambridge, MA: Ballinger Publishing Co., 1987), footnote, page 63, which cites HASC, FY 1982 DOE, p. 172.

[21] ``Nuclear Materials: Decreasing Tritium Requirements and Their Effect on DOE Programs," GAO/RCED-91-100, February 8, 1991, p. 3.

Figure 7 Projection of tritium requirements and inventory, assuming no production after 1988, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Data from **Table 3**.)

In 1990, for the first time, DOE's requirements included *a substantial quantity of ``reserve" tritium* as a contingency against unforseen events. *We have not included these reserves in our definition of tritium requirements* (emphasis added).[22]

Disputing GAO's conclusions, Energy Secretary Watkins wrote Comptroller General Charles Bowsher on February 27, 1991 that:

The tritium requirements directed by the President include requirements for a reserve supply of tritium ....*By restarting the first reactor in the summer of 1991, as I recently announced, the tritium inventory will marginally satisfy this Presidential directive.* I find it particularly disturbing that GAO openly dismisses a Presidential directive to the Department in making such a critical and highly publicized assessment of the Department's plans (emphasis added).

In Congressional testimony on March 13, 1991, GAO Energy Issues Director Victor S. Rezendes responded to Watkins' criticism by noting that DOE's original justifications for its tritium production reactor and modernization plans had never before included a requirement for a reserve:

No reserve requirement existed prior to 1990, when initial decisions regarding the Savannah River reactors and new sources of tritium production were made. Because the reserve (1) represents a substantial addition to today's anticipated tritium requirements and (2) has implications for funding and decisions on the reconfiguration of the nuclear weapons complex, its need must be carefully evaluated in light of changing tritium requirements and other contingency options. In this regard, maintaining a tritium reserve of the size specified in the 1990 requirements has several disadvantages, including tritium's rapid decay rate and the need to constantly replenish it. DOE officials told us that they are developing a detailed justification establishing the need for the reserve (emphasis added).[23]

How large is this new reserve ``requirement"? On March 11, 1991, Steven D. Richardson, DOE Deputy Assistant Secretary for Nuclear Materials Production, testified to Congress that DOE was now planning to maintain a ``five year reserve:"

Projected future requirements for nuclear materials have decreased dramatically since the Department submitted it FY 1991 budget request....*the demand for tritium is currently being met with existing inventories and DoD weapons returns.* Chart 1 [classified chart deleted] shows the SRS tritium inventory from the beginning of October 1989 and as currently projected through October 1998 under various reactor scenarios. *The chart shows the net available tritium on hand at SRS **after satisfying the needs of the stockpile**.* The solid horizontal line labeled ``minimum" represents the estimated minimum amount of pipeline inventory required to operate the tritium processing facilities. The complex has historically operated with a larger working inventory. *The other horizontal line represents the amount of tritium necessary to meet the ``minimum" inventory plus produce **a 5-year reserve** (deleted) over the period of the analysis.* The remaining data on this chart shows *the expected available tritium reserve under reactor scenarios of (1) no restart (nonhorizontal line); and (2) a July restart of K reactor at 50% of full power level (bars)* (emphasis added).[24]

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[22] Ibid., p. 1.

[23] ``Nuclear Materials: GAO's Views on Decreasing Tritium Requirements and Their Effect on DOE Programs," statement of Victor S. Rezendes, Director, Energy Issues, before the DOE Defense Nuclear Facilities Panel, HASC, March 13, 1991, GAO/T-RCED-91-21, p. 3.

[24] HAC, Energy and Water Development Appropriations for FY 1992, Part 6, pp. 748-50. (Emphasis added.)

Despite the deletion of the chart, this hearing record contains useful information about the tritium supply situation in the next decade. According to Richardson's testimony, the demand for tritium to maintain a shrinking U.S. nuclear stockpile is currently being met from existing inventories and weapons returns. Through October 1998, there will be ``net available tritium on hand after satisfying the needs of the stockpile," consisting of a ``minimum inventory" to operate the processing facilities and a ``reserve." The classified chart apparently showed a decline (``nonhorizontal line") in the ``expected available tritium reserve" in the event K-reactor is not restarted in July 1991, indicating that some (or all) of this five-year reserve already exists. A July restart of the K-reactor at half power would apparently allow the DOE to augment and/or maintain the *currently available tritium reserve* such that in October 1998 [i.e., beginning FY 1999], DOE could meet the stockpile demand for tritium for the *following* five years without additional production.

One important question left unanswered by Richardson's testimony is the *size of the currently available reserve* in relation to the projected requirements -- in other words, how long can the weapons stockpile be supported before resumption of tritium production is needed to sustain the rolling five-year reserve requirement contained in the President's Stockpile memorandum. On April 18, 1991, Secretary Watkins informed the Senate Armed Services Committee:

> We have enough tritium in the margin right now, in the stockpile, because of a reduction of old weapons, to permit us, then, to make a better assessment without pressures of having to feed tritium from the reactors into the system. We can still live with the mining of the tritium out of old weapons *for the next couple of years* (emphasis added).[25]

Watkins also told the Senate Armed Services Committee:

> We are anticipating that we can meet the goal, and I'm talking about [the] tritium goal, in the [draft] Stockpile Memorandum which has now been modified to reflect a downsizing of the entire stockpile. We believe that we have enough in the inventory to actually give us *some additional time.*
>
> In other words, we can now get the reactor on the line, wring it out, test it out, see if we have to shut it down again for any modification for continued operations, and that sort of thing, and we have some time in there. But we have no time *after about 1994* (Emphasis added).[26]

These statements indicate that the *existing inventory* of tritium will meet the *combined* annual weapons fill and reserve requirements in the President's Stockpile Memorandum until some time in 1995. However, to prevent the tritium inventory after this date from falling below the ``requirements plus 5-year reserve" target level specified in the President's Stockpile Memorandum, partial power operation of one SRS reactor apparently will be required. This conclusion is reinforced by a recent sworn affidavit filed in connection with litigation over DOE's attempt to operate the K-reactor in violation of the Clean Water Act. In this document, Secretary Watkins states:

> In order to meet the tritium requirements established by the 1991 NWSM [Nuclear Weapons Stockpile Memorandum], which was approved by President Bush on July 2, 1991, the restart of K-reactor must proceed in the third quarter of 1991....While, hypothetically, *the existing tritium inventory could be depleted and used toward satisfying immediate, non-reserve tritium requirements, the 1991 NWSM requires DOE to develop a reserve tritium inventory, not drain it* (emphasis added.)[27]

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[25] Testimony of Energy Secretary James Watkins, transcript of April 18, 1991 SASC Hearing, Alderson Reporting Co., Washington, D.C. p. 107.

[26] Ibid., p. 71.

[27] "Declaration of James D. Watkins," United States District Court, District of South Carolina, Aiken Division," July 3, 1991, pp.

In a separate affidavit executed on July 5, DOE Deputy Assistant Secretary Richardson states:

> The 1991 NWSM defines the stockpile plan for the current year and the following five years. This period is called the ``approved stockpile period." The NWSM also defines anticipated stockpile activity in a succeeding five-year ``planning period" (1997-2001) *although these later projections are necessarily tentative. For tritium, the NWSM establishes a required reserve inventory equal to the net requirements for new tritium that are projected in the NWSM for the 1997-2001 five year period.*
>
> ....Based on the NWSM and projected weapon requirements, DOE will be able to meet the annual tritium requirements for weapons, *including the nuclear material reserve requirements, in the period 1991-1999 with one reactor operating at 30 percent of its historical full power*, but only if demand for tritium and tritium recovery are all as is currently projected, and only if the reactor commences operation in the summer of 1991 (emphasis added).[28]

Taken together, the above testimony supports the following parameters for establishing the relation between tritium requirements and available inventory:

1. As shown in **Figure 8** (and **Table 3**) the current tritium surplus, generated by increased retirements and sharply declining force levels, is sufficient to meet the July 1991 NWSM requirements (including the requirement to maintain a five-year reserve) until some time in 1995 (i.e, the line representing ``tritium inventory" in **Figure 8** crosses over the ``requirements + 5 year reserve" line in 1995, per Watkins' testimony).

2. As shown in **Figure 9** (and **Table 4**) tritium output from one SRS reactor operating at 30% power is needed beginning in March-April 1992 (``third quarter 1991 restart" + 6 months) to meet the NWSM 5-year reserve requirement through 1999 (i.e. the line representing ``tritium inventory" in **Figure 9** crosses over the ``requirements + 5 year reserve" in 1999, per Richardson's testimony.)

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[28] Declaration of Steven D. Richardson, United States District Court, District of South Carolina, Aiken Division, July 5, 1991, p. 1; p. 3.

Figure 8 Projection of tritium requirements (plus a five-year reserve) and inventory, assuming no tritium production after 1988, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Data from **Table 3**.) This figure illustrates the ``official" tritium requirements and supply picture based on data points supplied by DOE officials in Congressional testimony and legal affidavits. Without further production, the available inventory of tritium will dip below the ``requirements plus 5-year reserve" level in the middle of 1995. By the year 2000, the five-year reserve will be exhausted, and the available inventory will fall below the projected tritium requirement of 55.2 kg to support 11,975 weapons.

Figure 9 Projection of tritium requirements (plus a five-year reserve) and inventory, assuming one reactor operating at 30% power beginning in 1991, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Data from **Table 3**). To prevent the depletion of the proposed five-year reserve by the year 2000, the Department of Energy is planning to pursue the course illustrated in **Figure 9** -- restart of one SRS reactor (the ``K" reactor) operating at 30% power beginning in the ``third quarter" of 1991. This means that the tritium would not be extracted from the reactor until six months later, in March-April 1992, and would not be available to the stockpile until September-October 1992 (note the shallower slope of the top inventory line, reflecting the return to production in 1992). This level of production in K-reactor would be sufficient to maintain the 5-year reserve until 1999. Maintaining a five-year reserve for 12,000 warheads after 1999 would require a shift to higher power operation, or restart of the L-reactor.

TABLE 4 Projected tritium requirements and inventory assuming a single tritium production reactor begins operating at 30 percent of full power in 1991, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Database for Figure 9.) Assumes de facto eighteen month tritium reserve in 1986. Tritium production resumes in the third quarter of 1991 (available 1 year later) with one reactor operating at 30 percent of full power. The stockpile is reduced to 11,975 warheads by the year 2000, due in part to START, but is maintained at that level thereafter.

V. DECIPHERING THE BOTTOM-LINE TIMETABLE FOR RESUMING TRITIUM PRODUCTION

In the following figures and tables, we use the model described in the preceding sections to project reasonable alternative scenarios to DOE's proposed actions for meeting future tritium requirements. These projections support the following conclusions:

1. A simple paper change in the treatment of the current tritium inventory -- shifting from a five- to a two-year "reserve requirement" -- would permit deferral of renewed tritium production at SRS from 1991 to 1997, without jeopardizing the amount needed to maintain the currently planned level of 12,000 nuclear weapons after the year 2000. Operation of just one reactor at 30% power beginning in 1997 would assure that the tritium inventory would continue to exceed weapons requirements until the year 2006, providing additional time to choose the appropriate technology and capacity for a new tritium producer (See **Figures 10 and 11**).

2. Restarting one SRS in 1997 at about 45% power would provide enough tritium to maintain a 12,000 warhead stockpile plus a two-year reserve for the remaining combined lifetime of these two reactors (said to be on the order of 10 to 30 years), or until their replacement with new production capacity (**See Figure 12**).

3. A START II agreement by the year 2000 that resulted in 4000 total weapons on each side by the year 2010 would make the startup of *any* tritium producer -- equivalent to one SRS reactor at less than 30% of historical full power -- unnecessary until the year 2014. Adding a requirement for a two year reserve advances the production restart date to 2012. A five year reserve would require restart in 2010. Under this scenario, the average tritium requirement per warhead could actually increase from an estimated 4 grams in 1991 to about 5.5 grams per warhead in 2010, sufficient to cover any reasonable warhead maintenance scenario (See **Figures 13 - 16**).

4. A START II agreement that resulted in 6200 total weapons on each side by the year 2010 would make resumption of tritium production unnecessary until the year 2009. Adding a requirement for a two-year tritium reserve advances the restart date to 2007. A five-year reserve would require restart in 2005. The average tritium requirement per warhead could increase from an estimated 4 grams in 1991 to 5 grams in 2010 (See **Figures 14-19**).

5. Even under the highly pessimistic scenario that a START II agreement will *not* be achieved by the year 2000, leaving a 12,000 warhead force to be maintained into the next decade, and that only one SRS reactor at a time can be operated at 30% power beginning in 1997, there is still no justification for beginning construction of a New Production Reactor (NPR) or Accelerator Tritium Producer (ATP) for another six years, until fiscal year 1998. As noted above, even under this highly pessimistic scenario, a new tritium producer would not need to be on line until the year 2006.

Figure 10 Projection of tritium requirements (plus a two-year reserve) and inventory, assuming no tritium production after 1988, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Data from **Table 3**.) This figure shows the effect -- without resuming production -- of simply reducing the newly imposed ``reserve requirement" from five to two years. Under this scenario, the point at which the available tritium inventory falls below the ``stockpile requirement plus reserve" level shifts from 1995 (see **Figure 8**) to 1998. In other words, by a mere shift in the paper categorization of the existing tritium inventory, the so-called ``urgent" requirement to restart the SRS K-reactor can be postponed for 6 years, from 1991 to 1997, as illustrated in **Table 5** and **Figure 11**.

TABLE 5 Projected tritium requirements and inventory assuming a single tritium production reactor begins operating at 30 percent of full power in 1997, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Database for Figure 11): Eighteen month tritium reserve in 1986. One tritium production reactor begins operating at 30 percent of full power in 1997, with tritium available one year later. The stockpile is reduces to 11,975 warheads by the year 2000, due in part to START, but is maintained at that level thereafter.

Figure 11 Projection of tritium requirements (plus a two-year reserve) and inventory, assuming one reactor operating at 30% power beginning in 1977, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Data from **Table 5**.) This figure shows that restart of one SRS reactor at 30% of historical full power in 1997 will maintain the ``requirements plus 2-year reserve" level for a 12,000 warhead force for only about 18 months. However, 30% power operation beginning in 1997 does assure that the available inventory will exceed requirements until 2006.

Figure 12 Projection of tritium requirements (plus a five-year reserve) and inventory, assuming one reactor operating at 50% power beginning in 1977, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Data from **Table 6**.) This figure shows that restart in 1997 of one SRS reactor at 50 percent of historical full power would be more than sufficient to meet declining stockpile tritium requirements plus maintain a two-year reserve for a 12,000 warhead stockpile. To meet concerns about reliability and safety, the K- and L-Reactors at SRS could alternate operation at 50 % power, providing extended down-time periods for inspection and maintenance, or both reactors could be operated at 25% power to produce the same amount.

TABLE 6 Projected tritium requirements and inventory assuming a single tritium production reactor begins operating at 50 percent of full power in 1997, and a stockpile of 11,975 warheads in the year 2000 and beyond. (Database for Figure 12): Eighteen month tritium reserve in 1986. One tritium production reactor begins operating at one-half power in 1997, with tritium available one year later. The stockpile is reduced to 11,975 warheads by the year 2000, due in part to START, but is maintained at that level thereafter.

Figure 13 Projected tritium requirements and inventory assuming no tritium production after 1988, and the stockpile is reduced to 4,000 warheads by 2010. (Data from **Table 7**.) This figure illustrates the effect of reaching a START II agreement by the end of the decade that would reduce U.S.-Soviet nuclear arsenals to 4000 *total* warheads on each side by the year 2010. Under this scenario, no further tritium production is required, even with a two year reserve, until after the year 2010. Given that START I required 8 years to negotiate in far more adversarial circumstances than are likely to prevail in the future, this timetable for achieving such reductions can fairly be regarded as *conservative*.

TABLE 7 Projected tritium requirements and inventory assuming no tritium production after 1988, and the stockpile is reduced to 4,000 warheads by the year 2010. (Database for Figures 13-16.) Eighteen month tritium reserve in 1986. No tritium production reactor after 1988. The stockpile is reduced to 11,975 warheads by the year 2000, due in part to START, and then declines to 4000 warheads by 2010 pursuant to a START II treaty.

Figure 14 Average tritium requirement per warhead assuming the stockpile is reduced to 4000 warheads by 2010. (Data from **Table 7**.) Even without renewing tritium production for the next two decades, a total force level of 4000 warheads would permit the average tritium loading per warhead **(Figure 14)** to increase from an estimated 4.04 g in 1991 to 5.44 g per warhead in 2010, which should be sufficient to cover any reasonable nuclear warhead maintenance requirement.

Figure 15 Projection of tritium requirements (plus a two-year reserve) and inventory, assuming no tritium production after 1988, and a stockpile reduced to 4,000 warheads in the year 2010. (Data from **Table 7**.) This figure shows that under the postulated START II reduction scenario of 4000 warheads by the year 2010, maintaining a *two-year reserve* would not require restart of a tritium producer (either a reactor or linear accelerator) until after 2010.

Figure 16 Projection of tritium requirements (plus a five-year reserve) and inventory, assuming no tritium production after 1988, and a stockpile reduced to 4,000 warheads in the year 2010. (Data from **Table 7**.) Maintaining a *five-year reserve* under the START II reduction scenario of 4000 warheads by the year 2010 would not require restart of a tritium producer (either an advanced reactor or linear accelerator) until that year.

TABLE 8 Projected tritium requirements and inventory assuming no tritium production after 1988, and the stockpile is reduced to 6,200 warheads by the year 2010. (Database for Figures 17-19.) Eighteen month tritium reserve in 1986. No tritium production after 1988. The stockpile is reduced to 11,975 warheads by the year 2000, due in part to START, and then declines to 6200 warheads by 2010 pursuant to a START II treaty.

Figure 17 Average tritium requirement per warheads assuming the stockpile is reduced to 6,200 warheads by 2010. (Data from **Table 8**.) This figure shows the effect of a START II agreement by the year 2000 that would provide for 6,200 total warheads on each side by the year 2010. Absent a reserve requirement, no additional production would be needed to meet warhead requirements until the year 2009.

Figure 18 Projection of tritium requirements (plus a two-year reserve) and inventory, assuming no tritium production after 1988, and a stockpile reduced to 6,200 warheads in the year 2010. (Data from **Table 8**.) This figure shows the effect of a START II reduction to 6200 total warheads by the year 2010 on the ability to meet a two-year reserve requirement. Under this scenario, maintaining this reserve would not require restart of a tritium producer (reactor or linear accelerator) until the year 2007.

Figure 19 Average tritium requirement per warhead assuming the stockpile is reduced to 6,200 warheads by 2010. (Data from **Table 8**.) This figure shows that under a START II reduction to 6200 warheads by the year 2010, even with no additional production, average tritium use per warhead could increase from 4 g in 1991 to 5 g in 2010, thereby providing sufficient average tritium loadings to meet reasonable future maintenance scenarios.