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Do India and Pakistan Possess Boosted Nuclear Weapons? Tritium Supply Considerations

Both India and Pakistan have acknowledged nuclear weapon programs. However, these countries have released no official information on the number and types of nuclear weapons in their arsenals. One important question is whether these countries possess boosted nuclear weapons. Since boosted weapons require a continuing supply of tritium, an examination of the possible sources of Indian and Pakistani tritium can provide insight into this issue. In particular, India does not seem to be producing any significant amounts of separated tritium and therefore probably has few if any boosted nuclear weapons in its arsenal. On the other hand, Pakistan could easily be producing tritium at its plutonium production reactor complex at Khushab and is therefore more likely than India to possess a significant number of boosted nuclear weapons.

Boosted Nuclear Weapons

The British have revealed a large amount of information regarding boosted fission weapons.[2] These weapons use hollow cores of fissile material. Just before detonation a tritium/deuterium gas mixture is inserted into this hollow space. The detonation of the weapon causes a fusion reaction. The energy output from this fusion reaction is small but this reaction releases a large number of high energy neutrons which significantly increase the efficiency of the fission reactions in the weapon. Many experts mistakenly believe that this increased efficiency is used to increase the yield of the weapon to produce high yield weapons but that is usually not its purpose. As the British have said, "But there was another way to look at boosting. Instead of using it to *increase* the yield of a warhead of given size and fissile content, it could be used to *reduce* the size and fissile content of a warhead while maintaining or even improving the yield."[3][Emphasis in original]

As the British have pointed out, boosted fission weapons have another important property. Implosion fission weapons that use plutonium are vulnerable to predetonation due to the neutrons from spontaneous fission. Even if such weapons contain only highly enriched uranium, they are still vulnerable to predetonation from neutrons from nearby nuclear detonations, which could be either defensive warheads or nearby "friendly" weapons. Boosted fission weapons do not have this vulnerability and can be used to manufacture what the British termed "immune warheads." Such immune warheads would produce the same yield whether they were manufactured from weapons-grade plutonium or reactor-grade plutonium.

The amount of tritium required per weapon is not officially known. I have calculated that in the past the U.S. used about 3.2 grams of tritium per weapon, though this amount is going to be

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[1] This paper is the product of the author's personal research and the analysis and views contained in it are solely his responsibility. Though the author is also a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and therefore RAND should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com
[2] Lorna Arnold, *Britain and the H-Bomb*, UK Ministry of Defense, Palgrave, 2001.
[3] *Ibid.*, p.177.

increased to about 4.5 to 5.0 grams per weapon.[4] This increase in the amount of tritium per weapon will decrease the frequency with which the tritium reservoirs in the weapons will need to be replaced and will also increase the confidence in weapon performance since there is no longer nuclear testing. The U.S. maintains a 5 year tritium reserve, which amounts to about one-quarter of the U.S.'s entire tritium stockpile.

Sources of Tritium for Boosted Nuclear Weapons

The deuterium required for boosted weapons can be extracted from ordinary water, but tritium only exists in trace amounts in nature and must be produced by either irradiating lithium in nuclear reactors or recovering the tritium produced in the moderator of heavy water nuclear reactors. Since tritium has a half-life of 12.3 years, each year 5.5% of the tritium decays away. Regular production is required to maintain a fixed amount of tritium.

Typically, nuclear weapon states such as the United States produce tritium by irradiating lithium in a nuclear reactor. Natural lithium consists of two isotopes, lithium 6 and lithium 7. Lithium 6 comprises 7.5% of natural lithium and lithium 7 the other 92.5%. When irradiated by neutrons it is the lithium 6 that produces tritium by the reaction: lithium 6 + neutron = tritium + helium 4.

Many experts assume that the lithium must be enriched (i.e. the percentage of lithium 6 increased) in order to produce tritium in a nuclear reactor, but there is no need. Since the thermal capture neutron cross section of lithium 6 is 942 barns and that of lithium 7 is 0.045 barns, when natural lithium is irradiated, 99.94% of the neutrons are absorbed by the lithium 6.

The U.S. used natural lithium to produce tritium in its plutonium production reactors during the 1950s. The target elements consisted of a lithium aluminum alloy that was 3.5% lithium by weight. The low percentage of lithium ensured that the lithium remained as a solid solution in the aluminum, giving the alloy good anti-corrosion properties. About 2% of the neutrons were absorbed in the large mass of aluminum in the target element and the remaining 98% were absorbed in the lithium.

The U.S. did produce enriched lithium in the 1950s as part of the development of two-stage thermonuclear weapons (hydrogen bombs). Once such material was available, it was advantageous to use it to produce tritium. The enriched lithium would reduce the number of target elements required and thereby the amount of aluminum in the reactor, which increased tritium production by about 2%.[5]

Initially, the U.S. produced tritium in its plutonium production reactors but the last of these reactors was shut down in 1988. Since 2003 the U.S. has produced tritium in the nuclear power reactor Watts Bar 1. Due to the high temperatures in a nuclear power reactor, the lithium is in

[4] Gregory S. Jones, "U.S. Increased Tritium Production Driven by Plan to Increase the Quantity of Tritium per Nuclear Weapon," June 2, 2016. https://nebula.wsimg.com/08a60104185a91e6db9008fb929a0873?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[5] R. Nilson, "Conversion Ratio Incentive for Using Black Mint in an E-N Load," HW-63668, General Electric, Richland, Washington, January 28, 1960. https://www.osti.gov/servlets/purl/10174913

the form of lithium aluminate. This program has had various problems and has produced less than the desired amount of tritium.

Natural uranium-fueled reactors have only a limited amount of excess reactivity. Given the strong neutron absorbing characteristics of lithium, all reactors that have produced tritium have used enriched uranium. Due to their different masses, a gram of tritium is equivalent to 79.3 grams of plutonium. If a neutron that would have produced plutonium in a plutonium production reactor instead produces tritium, the lost mass of plutonium is 79.3 times as much as the tritium produced. However, work at Hanford showed that some tritium could be produced by using neutrons that were otherwise wasted by escaping from the reactor or were absorbed in reactor structural materials. Therefore, the actual reduction in plutonium production was somewhat less.

Instead of irradiating lithium, countries with reactors that use heavy water as a moderator have the alternative of extracting tritium from these reactors. Tritium is produced as an incidental by-product of reactor operation. Even though the thermal neutron capture cross section of the deuterium in heavy water is only 0.0005 barns, heavy water power reactors contain hundreds of metric tons of heavy water as the moderator and the production of tritium by neutron capture in deuterium is significant. Park and Kim have performed detailed calculations of the tritium buildup in the Wolsong 1 reactor,[6] which is a CANDU 6 model using a heavy water moderator and coolant with a thermal output of 2,156 MW, generating 679 MW of electrical energy.[7]

Assuming a capacity factor of 84%, Park and Kim have calculated that the equilibrium buildup of tritium is 3.26×10^{12} Bq (88.1 curies) per kilogram of heavy water in the reactor's moderator and 7.21×10^{10} Bq (1.95 curies) per kilogram of heavy water in the reactor's coolant. Data regarding the actual buildup of tritium in the four CANDU reactors at Wolsong have shown that these calculations are accurate.[8]

Park and Kim do not directly state the total heavy water content of the reactor's moderator and coolant, but from data they present in their Table 1, one can calculate that it is 263 metric tons and 204 metric tons respectively. Given tritium's half-life of 12.323 years and atomic weight of 3.0161 amu, one gram of tritium equals 9,620 curies.[9] At equilibrium the reactor would contain 2,410 grams of tritium in the moderator and 41.3 grams in the coolant. The annual production rate is found by dividing the equilibrium value by tritium's mean-life of 17.78 years,[10] giving 135 grams in the moderator and 2.3 grams in the coolant. Given the low tritium content of the reactor coolant, the moderator is the main source of tritium.

The buildup of tritium in the moderator causes safety concerns due to both worker exposure and environmental releases. Processes exist to remove the tritium from the heavy water moderator using isotope separation. Typically, these processes use hydrogen-water chemical exchange in

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[6] Tai-Keun Park and Seon-Ki Kim, "Tritium: its generation and pathways to the environment at CANDU 6 generating stations," *Nuclear Engineering and Design*, Vol. 163, 1996, pp. 406-407.
[7] *World Nuclear Industry Handbook*, Nuclear Engineering International, 2004, p. 134.
[8] Soon-Hwan Son, Sook-Kyung Lee, and Lwang-Sin Kim, "Tritium production, recovery and application in Korea," *Applied Radiation and Isotopes*, Vol. 67, 2009, p. 1337.
[9] "DOE Standard: Tritium Handling and Safe Storage," DOE-STD-1129-2015, September 2015, p. 19. https://www.standards.doe.gov/standards-documents/1100/1129-AStd-2015/@@images/file
[10] The mean-life is the half-life divided by ln 2.

the first stage, supplemented by hydrogen distillation in the later stages. Canada and South Korea are the only two countries known to have extracted significant quantities of tritium from their heavy water reactors. Canada has a separated tritium inventory of over 20 kilograms and South Korea over 4 kilograms.

If a reactor operates at a more or less steady capacity factor, the buildup of tritium in the moderator and coolant is determined by tritium's half-life. The fraction of the equilibrium value attained at any time t (in years) is found by the equation $(1 - e^{-\lambda t})$ where λ is tritium's decay constant.[11] After one half-life (12.3 years), the tritium content would be one-half of its equilibrium content, after two half-lives (24.6 years) it would be three quarters of its equilibrium content, and so on. It would take 41 years for the tritium content to be 90% of its equilibrium value.

If a heavy water reactor has started operation fairly recently, a country desiring tritium for nuclear weapons would probably not want to wait 30 or 40 years before extracting the tritium. On the other hand, given that the tritium extraction procedure requires processing large quantities of heavy water, one would want to wait some time to allow the tritium concentration to increase. After one year, the tritium content would be only 5.5% of its equilibrium value. A good compromise would be to wait about ten years, when the tritium would be 43% of its equilibrium value.

Note that whether a given heavy water moderated reactor is under International Atomic Energy Agency (IAEA) safeguards is not an issue. Tritium is not a safeguarded material. The word tritium does not even appear in the IAEA's Safeguards Glossary.[12]

Indian Tritium Sources

India's best source of tritium is from the heavy water moderator of its 17 operating heavy water nuclear power reactors.[13] The capacity factors of these reactors have generally been high in recent years. If one assumes that the capacity factors are the same as the 84% calculated for the Wolsong 1 reactor, then the tritium production should be proportional to the reactors' thermal power output. Fifteen of the reactors each have a thermal power output of 801 MW and the remaining two 1,673 MW each. The annual tritium production would be about 960 grams.

As long ago as 1998, a widely cited article in *Jane's Intelligence Review* claimed that India was extracting tritium from its power reactors to produce boosted weapons (which the article mistakenly calls hydrogen bombs).[14] The article referred to a source asserting that India was developing a pilot plant using liquid phase catalytic exchange (LPCE) technology to extract tritium from its power reactors.[15]

[11] The decay constant is ln 2 divided by the half-life. The decay constant is the inverse of the mean-life.

[12] "IAEA Safeguards Glossary, 2001 Edition," International Nuclear Verification Series No. 3, International Atomic Energy Agency, Vienna, 2002. https://www.iaea.org/sites/default/files/iaea_safeguards_glossary.pdf

[13] India's Department of Atomic Energy lists 18 but the Rajasthan 1 reactor has been shut down for decades.

[14] T. S. Gopi Rethinaraj, "Tritium Breakthrough Brings India Closer to an H-Bomb Arsenal," *Jane's Intelligence Review*, January 1998.

[15] This is the same technology that South Korea currently uses to extract tritium from its heavy water moderated nuclear power reactors. See: K. M. Song, S. H. Sohn, D. W. Kang and H. S. Chung, "Introduction to Wolsong

In 1998 India only had three reactors that had been operating for over ten years. The capacity factor of these reactors in the 1980s and 1990s was significantly lower than it has been in more recent times. For my calculations I assume a 42% capacity factor. Nevertheless, the amount of tritium available from these three reactors would have been around 740 grams. Even if one assumes that 5 grams of tritium were used for each weapon and that India kept a 5-year reserve, this amount would have been enough for over one hundred weapons, considerably more than India's nuclear arsenal in 1998.

However, there is no mention of this tritium removal pilot plant in any of the Indian Department of Atomic Energy (DAE) annual reports. Indeed, the reports from that era only refer to attempts at the Madras Nuclear Power Station to use its distillation facilities for upgrading heavy water to attempt to remove some tritium.[16] In 2007 India's Bhabha Atomic Research Centre (BARC) reported that it had completed the design of a pilot plant using a Combined Electrolytic and Catalytic Exchange (CECE) process[17] for removing tritium from the heavy water moderator of its nuclear power reactors and the plant was "being set up."[18] This step would have been unnecessary if India had already built a large-scale plant using the LPCE technology.

In 2013 India reported that it was constructing a Heavy Water Clean-Up (HAWAC) plant to remove tritium from heavy water at the site of its Kota heavy water production plant.[19] This plant was termed "A Technology Demonstration Plant." It is unclear whether this plant uses LPCE or CECE technology. As of 2013 this plant was still undergoing commissioning using only "virgin heavy water," i.e. without tritium.[20] In 2012 India's Atomic Energy Regulatory Board objected to plans to store the recovered tritium at the HAWAC in the form of water, recommending instead for India to "expedite the development of technology for converting the HAWAC by-product [i.e. tritium] to metalhydride form."[21] Storing tritium as a metal hydride is the standard method for storing tritium. That India still needs to develop this technology demonstrates that India does not have significant tritium stocks.

India has large stocks of tritium in its reactors, far more than needed for its nuclear weapon program. If India were removing large amounts of tritium from its heavy water power reactors, it would have a substantial surplus which could be used in fusion research. However, a 2018 review of tritium supplies for nuclear fusion reactors did not count India as a source. While

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Tritium Removal Facility (WTRF)," *Transactions of the Korean Nuclear Society*, October 27-28, 2005. https://www.kns.org/files/pre_paper/17/173%EC%86%A1%EA%B7%9C%EB%AF%BC.pdf

[16] It said that it had "tried out" the process. "Annual Report 1998-1999," Department of Atomic Energy, Government of India, pp. 55 & 58.

[17] This process is similar to LPCE but as the name indicates, with electrolysis added.

[18] V. K. Tangri and S. K. Das, "Heavy Water Purification: Design and Development of Combined Electrolysis and Catalytic Exchange Technology," *BARC Highlights: Chemical Sciences and Engineering*, 2006-2007, pp. 74-75. http://barc.gov.in/publications/eb/golden/chemical/toc/chapter9/9.pdf

[19] "Annual Report 2012-2013," Department of Atomic Energy, Government of India, p. 48. http://www.dae.nic.in/writereaddata/areport/ar1213_sm.pdf

[20] "AERB Bulletin 2012-2013," Atomic Energy Regulatory Board, Government of India, p. 14. https://www.aerb.gov.in/images/PDF/Annual_Bulletin/2013.pdf

[21] "AERB Bulletin 2011-2012," Atomic Energy Regulatory Board, Government of India, p. 19. https://www.aerb.gov.in/images/PDF/Annual_Bulletin/2013.pdf

recognizing that India has the potential to be a tritium supplier, this review stated that India would need to "commission a tritium removal facility."[22]

Though India could recover large quantities of tritium from its heavy water power reactors, it is hard to escape the conclusion that it has not done so. India cannot have developed and deployed boosted weapons without a source of tritium. Therefore, boosted weapons do not appear to be a part of India's nuclear arsenal.

Pakistani Tritium Sources

Pakistan has an acknowledged nuclear weapon program and it is estimated that Pakistan could have 140 to 150 weapons.[23] There are indications that it may have developed boosted nuclear weapons, perhaps with foreign assistance. Since 2005 Pakistan has tested two cruise missiles (the Babur/Hatf-7 and the Ra'ad/Haft8) and since 2011 it has tested two short-range ballistic missiles (Abdali/Hatf-2 and Nasr/Hatf-9). Pakistan has described all of these missiles as "nuclear capable," but the low payload and small diameters of these missiles would seem to rule out the use of pure fission implosion weapons. This raises two possibilities. First, Pakistan is bluffing and is just conveniently applying the label "nuclear capable" to every missile regardless of whether it actually is. Second, Pakistan has developed small, lightweight boosted fission weapons.

If one assumes that Pakistan uses 5 grams of tritium per weapon and has a 5-year tritium reserve, Pakistan would require around 1 kilogram of tritium if all its weapons were boosted. Pakistan has one heavy water moderated power reactor, KANUPP (Karachi Nuclear Power Plant) but its moderator does not contain anywhere near this quantity of tritium. The reactor's thermal power output is 433 MW and it has had a capacity factor of 28%.[24] The reactor would produce only about 9 grams of tritium per year. Since it has been in high power operation since 1972, the moderator would contain about 150 grams of tritium. This would be enough for only about 22 boosted weapons. Since KANUPP is scheduled to be shut down in 2020, the tritium recovered from the reactor could not be replaced and the number of boosted weapons would rapidly decline as the tritium decayed away if KANUPP were Pakistan's only source of tritium.

It is more likely that Pakistan uses several of its four heavy water moderated plutonium production reactors at Khushab to produce tritium by irradiating lithium. Each reactor is assumed to have a thermal power output of around 50 MW. If fueled with natural uranium and operated 250 days per year, each reactor would produce about 10 kilograms of plutonium per year.[25] To produce tritium by irradiating lithium, a reactor would need to be fueled with

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[22] Richard J. Pearson, Armando B. Antoniazzi, and William J. Nuttall, "Tritium supply and use: a key issue for the development of nuclear fusion energy," *Fusion Engineering and Design*, Vol. 136, 2018, p. 1146.

[23] Hans M. Kristensen, Robert S. Norris and Julia Diamond, "Pakistani nuclear forces, 2018," *Bulletin of Atomic Scientists*, Vol. 74, No. 5, 2018, p. 348.
https://www.tandfonline.com/doi/pdf/10.1080/00963402.2018.1507796?needAccess=true

[24] "Kanupp 1, Pakistan," World Nuclear Association. https://www.world-nuclear.org/reactor/default.aspx/KANUPP-1

[25] The reactors would also produce some tritium in their heavy water moderator but all four reactors together would produce only about 10 grams per year. Further only one of the four reactors has been in operation for more than 10 years. It is unlikely that Pakistan has obtained any tritium from these reactors' moderator.

enriched uranium, which would reduce the amount of plutonium produced. Based on work performed at Hanford in the 1960s, if 1.2% enriched fuel were used, a single reactor's plutonium production would drop to 7.6 kilograms per year and produce about 52 grams of tritium per year.[26] If only 1.0% enriched fuel were used, the amount of plutonium produced would increase and amount of tritium produced would decrease. A single reactor's plutonium production would be 8.4 kilograms per year and the tritium production about 36 grams per year.

By using 5.0% enriched fuel in a reactor, the plutonium production would drop to around 3 kilograms per year and the tritium production would increase to around 120 grams per year.[27] However, using 5% enriched fuel might require developing a different kind of fuel element and perhaps change the operating characteristics of the reactor. Therefore, I will focus on the cases where Pakistan uses 1.2% and 1.0% enriched fuel.

Assuming that each of Pakistan's four plutonium production reactors has used 1.2% enriched fuel from their start of operation,[28] Pakistan could have produced around 1.3 kilograms of tritium, which would be more than enough to boost all of its nuclear weapons. If instead, Pakistan's four reactors had all used fuel that was only enriched to 1.0%, Pakistan's could have a tritium stockpile of about 900 grams, which would be enough to boost about 90% of its weapons. Even if Pakistan had not so aggressively produced tritium, it could still have a sizable stockpile of tritium. For example, if only Khushab 2 and Khushab 3 have produced tritium since their start of operation, using 1.2% enriched fuel, Pakistan would have a tritium stockpile of about 570 grams, which would be enough to boost over half of its nuclear weapons.

Pakistan's four plutonium production reactors give it the ability to produce sizable quantities of tritium. Pakistan could have easily produced enough tritium to boost over half its nuclear weapons and may have enough tritium to boost all its weapons. Pakistan is more likely than India to possess a significant number of boosted nuclear weapons.

Conclusions

India's heavy water moderated nuclear power reactors could provide it with large quantities of tritium. However, it does not appear that India has extracted any significant amount of this tritium and India probably has few if any boosted nuclear weapons in its arsenal.

Pakistan's one heavy water moderated nuclear power reactor does not contain enough tritium to boost more than a small fraction of its nuclear weapons. Pakistan could be producing large amounts of tritium if it is irradiating lithium in several of its plutonium production reactors at Khushab. Pakistan is therefore more likely than India to possess a significant number of boosted nuclear weapons.

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[26] "Hanford Reactor and Separations Facility Advantages," HW-78100, Hanford Atomic Products Operation, Richland, Washington, June 27, 1963, p. 20. https://www.osti.gov/servlets/purl/10184818

[27] R. L. Miller, "Hanford Isotope Production Capabilities for Single Pass Reactors," DUN-4979, Douglas United Nuclear Inc., Richland, Washington, December 12, 1968, pp. 34-35. https://www.osti.gov/servlets/purl/10175357

[28] Pakistan has not stated when each of these four reactors started operation. However, based on public reporting it appears that Khushab 1 started operation in 1998, Khushab 2 in 2010, Khushab 3 in 2013 and Khushab 4 in 2015.