Gregory S. Jones[1]
September 18, 2018

Estimating Israel's Stocks of Plutonium, Tritium and HEU

Israel is widely believed to possess nuclear weapons. However, Israel has not released any official information about its nuclear weapon program and indeed, has not confirmed that it has nuclear weapons. It is known that a major source of nuclear material for this weapon program is the plutonium production reactor at Dimona. This reactor was provided by France and sustained its first nuclear chain reaction in December of 1963.[2] Efforts to put some bounds on the Israeli nuclear weapon program involve estimating how much plutonium might have been produced at Dimona.

Past efforts have not sufficiently taken into account that Dimona appears to be a major producer of tritium as well as plutonium, which would reduce the amount of plutonium that Dimona could produce. Further, tritium production requires Dimona to use enriched uranium fuel. This implies that Israel has some uranium enrichment capacity, giving it the capability to produce highly enriched uranium (HEU) in addition to plutonium. This Israeli produced HEU would be in addition to the HEU that Israel diverted from the U.S. in the 1960s.

Past efforts to estimate Dimona's plutonium production have used constraints based on the statements of the former Israeli nuclear technician Mordechai Vanunu. I find many of Vanunu's statements of doubtful accuracy. Therefore, I have undertaken to produce a new set of estimates of Israel's stocks of nuclear material. These estimates will take into account Dimona's tritium production and will not use any of Vanunu's statements as constraints. Yet, given the poor information regarding Israel's nuclear material production and acquisition, the estimates must necessarily be uncertain. A summary of my estimates can be found in Table 1 on page 10.

The Dimona Plutonium Production Reactor

The amount of plutonium and tritium that can be produced at Dimona is directly related to the reactor's power. Officially the reactor is listed by the International Atomic Energy Agency (IAEA) as having a power of 26 MW.[3] However, when the reactor first started operation its power was probably 40 MW and it is thought that the power has been significantly upgraded to perhaps 70 MW.[4]

Vanunu claimed that by the mid to late 1970s, the reactor had a power of 150 MW. As I wrote in 1995, I find this claim unconvincing since "such an upgrade would require significant changes

---

[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] The reactor was operated at low power during 1964 and did not reach full power until about the beginning of 1965. Avner Cohen, *Israel and the Bomb*, Columbia University Press, 1998, p. 179.

[3] Since, the reactor does not produce electricity, these are thermal megawatts, not electrical ones.

[4] Leonard S. Spector with Jacqueline R. Smith, *Nuclear Ambitions*, Carnegie Endowment for International Peace, Westview Press, 1990, p. 160.

in the fuel element design and in the design of the refueling system."[5] For example, consider the Indian CIRUS reactor. It had a power output of 40 MW and a core fuel loading of about 10 metric tons of natural uranium fuel. With a power density of 4 MW/Te, the CIRUS fuel elements were simple rods of metallic uranium with a diameter of 3.5 cm. Assuming a burnup of 1,200 megawatt-days per metric ton (MWD/Te), the fuel would be in the reactor for an average of 300 days of reactor operation. Refueling of the reactor would occur infrequently. The fuel could be allowed to cool for some time in the reactor before it is removed, yet the reactor's capacity factor would not be significantly lowered.

In contrast India's Dhruva reactor has a power of 100 MW and a fuel loading of 6.6 metric tons, giving it a power density of 15 MW/Te. With this high power density, a fuel element that was a solid rod of metallic uranium could not be sufficiently cooled. Therefore, the fuel elements at Dhruva are clusters of seven metallic uranium rods each with a diameter of 1.25 cm. Similarly, the fuel would reach full burnup on average in just 80 days which would require frequent shut downs for refueling. In order to allow the refueling to take place quickly, Dhruva required a massive 300 metric ton heavily shielded refueling machine.

It has been reported that Dimona used a core loading of 8 metric tons of natural uranium fuel.[6] At a power of 40 MW, its power density would have been only 5 MW/Te which, would have allowed the fuel elements to be single rods and it would not require quick refueling. But with a power of 150 MW, its power density would be 19 MW/Te, which is higher than even Dhruva. At this power level, Dimona's fuel elements would need to be redesigned into a cluster of smaller diameter rods and it would need to have a more heavily shielded refueling machine installed. The redesign of the fuel elements is not a trivial matter. When Dhruva first started operation, its fuel was subjected to excessive vibrations and the reactor could not operate at high power for three years until this problem was solved.

For my estimates, I assume that Dimona operated at 40 MW for the 11 years from the beginning of 1965 until the end of 1975. I then assume that the reactor was upgraded to a power of 70 MW and has operated at this power up until the present. I estimate that this power upgrade would have occurred when the reactor began to use low-enriched uranium fuel to produce tritium as well as plutonium. I further assume that the reactor has operated for 250 days per year (a 68.4% capacity factor). The reactor can probably operate at a higher capacity factor for prolonged periods but it has also probably been shut down at various times over its 54 year operating life for refurbishment. A 68.4% capacity factor represents an average capacity factor over the long-term.

The level of fuel irradiation used in plutonium production reactors is a tradeoff of various factors. At low levels of irradiation, the reactor produces more plutonium and the plutonium has a low Pu-240 content. However, low level irradiation greatly increases the amount of fuel that must be reprocessed and the amount of natural uranium required to produce this fuel. Increasing the irradiation level increases the level of Pu-240 in the plutonium and reduces somewhat the

[5] Brian G. Chow, Richard H. Speier, and Gregory S. Jones, "The Proposed Fissile-Material Production Cutoff: Next Steps," MR-586-1-OSD, RAND, 1995, p. 46. https://www.rand.org/pubs/monograph_reports/MR586-1.html
[6] U. M. Steebler and J. W. Croach Jr., "Note on Visit to Israel," May 23, 1961. https://nsarchive2.gwu.edu/israel/documents/first/13-01.htm

amount of plutonium produced. However, the amount of fuel that needs to be reprocessed and the amount of natural uranium required to produce this fuel is significantly reduced. For example, when in 1949, the U.S. increased the irradiation level in its plutonium production reactors from 200 MWD/short ton to 400 MWD/short ton, the amount of plutonium produced dropped by 3.2% and the Pu-240 content increased from 2.0% to 3.8%. The benefit was that the amount of fuel needing to be reprocessed and the natural uranium required was cut in half.[7]

The irradiation level in U.S. plutonium production reactors was set by the concentration of Pu-240. This concentration changed over time. Using declassified Department of Energy documents, I have created a history of the Pu-240 content of U.S. nuclear weapons.[8] Plutonium with a 2.0% Pu-240 content was used in the U.S. nuclear weapon program between 1945 and 1949 but by the early 1950s the U.S. used plutonium with a 5.5% content in its unboosted weapons. These weapons used a levitated weapon design, in which an air gap was placed between the nuclear material and the explosives in the weapon. Such weapons are far less sensitive to the Pu-240 content of the plutonium. The weight and yield of the first French nuclear test indicate that this weapon used a levitated design. In the 1960s France shared nuclear weapon design information with Israel. Therefore, at a minimum, the Israelis employ unboosted nuclear weapons that use a levitated design.

Further, as will be discussed below, Israel now likely uses boosted nuclear weapons, which are "immune" to predetonation. Since 1959, the U.S. has used plutonium with a Pu-240 content of 6% in its boosted weapons. Therefore, I assume that plutonium with a Pu-240 content of 6% is used in Israeli weapons as well. In a heavy water moderated reactor, plutonium with a Pu-240 content of 6% is produce by the irradiation of natural uranium fuel to about 1,200 MWD/Te. The plutonium concentration in this fuel would be 0.80 kilograms of plutonium per 1,000 MWD of reactor operation.[9] Glaser and Miller, based on some of Vanunu's statements, have assumed a burnup of only 450 MWD/Te which would produce plutonium with a Pu-240 content of about 2.5%.[10] However, not only is such a low Pu-240 content unnecessary for even unboosted levitated weapons but using a fuel burnup of 450 MWD/Te would nearly triple the amount of natural uranium required to fuel Dimona. The Israel would have difficulty providing this increased quantity of natural uranium.

Tritium Production at Dimona

Israel provided South Africa with 30 grams of tritium over a one year period during 1977 and 1978.[11] This is one of the few facts known about the Israeli nuclear program. Dimona must be

[7] "Technical Report to the General Advisory Committee," HW-13292, General Electric, Richland, Washington, May 10, 1949, p. 3.

[8] Gregory S. Jones, *Reactor-Grade Plutonium and Nuclear Weapons: Exploding the Myths*, Nonproliferation Policy Education Center, 2018, Appendix. https://nebula.wsimg.com/3fd1e3cfbbf101d6c4f562e17bc8604c?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[9] M.J. Khan, Aslam, and N. Ahmad, "Neutronics analysis of natural uranium fueled, light water cooled, heavy water moderated and graphite reflected nuclear reactors," *Annals of Nuclear Energy*, Vol. 31, 2004, p. 1350.

[10] Alexander Glaser and Marvin Miller, "Estimating Plutonium Production at Israel's Dimona Reactor." https://www.princeton.edu/~aglaser/PU056-Glaser-Miller-2011.pdf

[11] David Albright, "South Africa's Secret Nuclear Weapons," Institute for Science and International Security, May 1994, p. 5.

the source of this tritium and the fact that Israel felt that it could spare 30 grams of tritium in one year indicates that Dimona's production rate of tritium was substantial. Israel would have had to irradiate target elements containing lithium in Dimona to achieve such a high production rate of tritium.[12]

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, the lithium 6 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) to high levels 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 at Hanford 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% 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%.[13]

Starting about 1960, the U.S. began using a lithium aluminum alloy that used lithium that was enriched to 38.5 atom percent.[14] Later this percentage was increased to 44.3 atom percent.[15] Many experts have assumed a much higher lithium enrichment but using an enrichment higher than 50 atom percent poses a problem.[16] Once formed, the tritium can diffuse through the target element and escape. The tritium is bound in the target element by the formation of lithium hydride with the remaining lithium. If the enrichment is more than 50 atom percent, then there is no longer enough lithium to retain the tritium if a high percentage of the lithium 6 is converted into tritium.

---

[12] Some tritium is produced in Dimona's heavy water moderator but even at a power level of 70 MW, the amount is only about 4 grams per year. See: Gregory S. Jones, "Heavy Water Nuclear Power Reactors: A Source of Tritium for Potential South Korean Boosted Fission Weapons," February 29, 2016. https://nebula.wsimg.com/344f048726407b8951892db91c98a0b1?AccessKeyId=40C80D0B51471CD86975&disposition=0&alloworigin=1

[13] R. Nilson, "Conversion Ratio Incentive for Using Black Mint in an E-N Load," HW-63668, General Electric, Richland, Washington, January 28, 1960.

[14] W. A. Blanton and W. H. Hodgson, "Assembly and Performance of Fuel Elements for H-Reactor E-N Demonstration Load, HW-73638, May 29, 1962.

[15] John J. Wick, Jr, Provisional Specifications for Prototypical Lithium-Aluminum Target Element 05T," HW-78901, General Electric, Richland, Washington, September 2, 1963.

[16] M. R. Louthan, Jr., "Aluminum-Lithium Technology and Savannah River's Contribution to Understanding Hydrogen Effects in Metals, WSRC-MS-2000-00061, p. 35. http://c-n-t-a.com/srs50_files/031louthan.pdf

Vanunu implausibly claimed that Israel was using 85% enriched lithium to produce tritium at Dimona. While such material could be used to produce tritium if one limited the irradiation of the lithium so that at least 50% of the lithium remained, such limited irradiation would be wasteful. Once the target element is removed from the reactor and the tritium is extracted, the remaining lithium is not recycled but rather is disposed as waste.

Whether Israel had any enriched lithium at all depends strongly on whether Israel possesses two-stage thermonuclear weapons. Many analysts, based partly on Vanunu's statements, believe that Israel acquired such weapons in the 1970s and 1980s. However, given Israel's very limited nuclear testing, I doubt that Israel has such weapons even today. France did not even test its first two-stage thermonuclear weapon until 1968, a time when France's nuclear cooperation with Israel had already ended.

A country's first two-stage thermonuclear weapons tend to be large and heavy, having high yields. An early goal for countries developing two-stage thermonuclear weapons was to achieve a yield of one megaton with a weapon weighing one metric ton. It took France at least five additional high yield nuclear tests after its first successful two-stage thermonuclear test to achieve this goal and it was not until 1976 that France was able to deploy this weapon (the TN-60). Even such a weapon would likely be too large and heavy for Israeli delivery systems.

A more suitable weapon would be similar to the French TN-70, which weighed about 200 kilograms and had a yield of 150 kilotons. However, the development of this weapon took a number of additional nuclear tests after the development of the TN-60. The TN-70 was not deployed until 1985, which was about the time Vanunu was no longer working at Dimona. Given that Israel has only conducted one relatively low yield nuclear test, I consider it very unlikely that Israel has two-stage thermonuclear weapons.[17] Therefore Israel would probably have used only natural lithium to produce tritium at Dimona.

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 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.

If Dimona had a power output of 40 MW, operated 250 days per year and used natural uranium fuel with a burnup of 1,200 MWD/Te, the reactor would produce 0.80 kilograms of plutonium per 1,000 MWD of operation, for a total of 8.0 kilograms per year. When the reactor was

---

[17] This test generated the nuclear flash seen by a U.S. Vela satellite on September 22, 1979. Though at the time the U.S. government seized on some data irregularities to claim that it might not be a nuclear test, there is little doubt today that it was. Since the 1990s, the details of the South African nuclear weapon program have become known and South Africa never conducted a nuclear test. Israel is the only other plausible candidate to have carried out this test. Given the high degree of cooperation at the time between South Africa and Israel, an Israeli nuclear test in the South African Prince Edward Island Group is quite plausible. The test had a yield in the low kiloton range, which rules out a two-stage thermonuclear device. It could well have been the test of a boosted weapon.

upgraded to 70 MW, if the reactor only produced plutonium then the plutonium production would increase to 14.0 kilograms per year.

If Dimona, when it was upgraded to a 70 MW power level, were instead to use fuel with an enrichment of 1.0%, calculations performed at Hanford indicated that the reactor would produce about 0.67 kilograms of plutonium per 1,000 MWD of operation and the plutonium equivalent of 0.23 kilograms of tritium per 1,000 MWD of operation.[18] The total annual production would then be about 11.8 kilograms of plutonium and 51 grams of tritium.[19] To produce plutonium with a Pu-240 content of 6%, the 1.0% enriched fuel would have a burnup of about 1,600 MWD/Te.

Increasing the fuel enrichment increases the tritium production and decreases the plutonium production. For a power level of 70 MW and fuel that is 1.2% enriched, the total annual production would be about 10.6 kilograms of plutonium and 72 grams of tritium. To produce plutonium with a Pu-240 content of 6%, the 1.2% enriched fuel would have a burnup of about 1,900 MWD/Te. Note that even though producing tritium reduces the production of plutonium, the upgraded 70 MW Dimona produces more plutonium than when it was operating at 40 MW and producing only plutonium (10.6-11.8 kilograms per year vs 8.0 kilograms per year).

Estimates of Plutonium and Tritium Production at Dimona

To estimate Israel's plutonium and tritium stocks, I assume that Dimona operated at 40 MW for 11 years between the beginning of 1965 and the end of 1975. During this time, the reactor used natural uranium fuel and only produced plutonium. Its plutonium production during this time would be 88 kilograms.

For the 42 years since 1975 (until the end of 2017), I assume that the reactor has operated at 70 MW and produced both plutonium and tritium using enriched fuel. If the fuel were 1.0% enriched then the plutonium production would be an additional 495 kilograms for a total of about 580 kilograms of plutonium. For fuel that was 1.2% enriched, the additional plutonium production would be about 445 kilograms and the total about 530 kilograms.

To calculate Israel's current tritium stockpile, its decay needs to be taken into account. For the case where the fuel is 1.0% enriched, Dimona would produce 51 grams of tritium per year and Israel's current stockpile of tritium would be about 820 grams.[20] For the case where the fuel is 1.2% enriched, Dimona would produce 72 grams of tritium per year and the current tritium stockpile would be about 1,160 grams.

---

[18] "Hanford Reactor and Separations Facility Advantages," HW-78100, Hanford Atomic Products Operation, Richland, Washington, June 27, 1963, p. 20. The Hanford calculations assume that 0.83 kilograms of plutonium are produced in natural uranium fuel per 1,000 MWD of operation. I have scaled these results for a reactor that produces only 0.80 kilograms of plutonium in natural uranium fuel per 1,000 MWD of operation.

[19] (70 x 250 x 0.23) / 1,000 equals a plutonium equivalent production of tritium of just over 4 kilograms. Dividing by 79.3 gives the actual amount of tritium, which is 51 grams.

[20] If tritium is produced at a constant annual rate of A, then the buildup of tritium over time is found by the formula: $(A/\lambda) \times (1 - e^{-\lambda t})$. λ is the decay constant of tritium, which is the natural logarithm of 2 divided by the half-life of tritium (0.6931/12.32 years = 0.05626 yr^{-1}).

Data from the U.S. use of tritium in its nuclear weapons provides a means to convert the quantity of total tritium into the number of nuclear weapons. I have elsewhere calculated that the U.S. currently uses about 3.2 grams of tritium per weapon but plans to increase this amount to about 4.5 to 5.0 grams of tritium due in part to the lack of nuclear testing since 1992.[21] The U.S. keeps a 5 year tritium reserve (about one quarter of the total tritium stockpile) to cover possible interruptions in production.

Since Israel has only conducted one nuclear test, I assume for the purposes of my calculations that the quantity of tritium used by Israel in its weapons would probably be towards the higher end of this range. Israel would also probably want to keep an even larger tritium reserve due to its limited production options. Therefore, I assume that half of Israel's tritium stockpile is kept as a reserve. This reserve would last Israel for 12.3 years (the half-life of tritium) if tritium production were to cease. Under this latter assumption, if 4 grams of tritium are used per weapon then Israel has enough tritium for about 100 to 145 weapons. If 5 grams of tritium are used per weapon, then Israel has enough tritium for about 80 to 115 weapons.

These estimates show that Israel's plutonium and tritium stockpile are in a reasonable balance. If Israel uses 5 kilograms of plutonium per weapon then it has enough plutonium for about 105 to 115 weapons. If Israel uses 4 kilograms of plutonium per weapon (boosted weapons tend to use less nuclear material than do unboosted ones) then it has enough plutonium for about 135 to 145 weapons.

Israel's Continuing Natural Uranium Fuel Requirements

The amount of natural uranium required to fuel Dimona when it was operating at 40 MW was 8.3 metric tons per year, assuming 250 days per year of operation and a fuel burnup of 1,200 MWD/Te. This would increase to 14.6 metric tons per year if the reactor were operating at 70 MW. Operation using 1.0% enriched fuel with a burnup of 1,600 MWD/Te and a power of 70 MW would require 18.6 metric tons per year of natural uranium to produce the enriched fuel.[22] The amount of natural uranium required would increase to 20.2 metric tons per year if the enrichment were increased to 1.2% with a burnup 1,900 MWD/Te.

With a burnup of only 450 MWD/Te, natural uranium fuel and an operation of 270 days per year as suggested by Glaser and Miller, the annual natural uranium requirements become much larger. If Dimona's power were 40 MW, the reactor would require 24 metric tons. This would increase to 42 metric tons if the reactor's power were 70 MW and to 90 metric tons if the power were 150 MW.

Israel appears to have little if any domestic uranium production, though it may produce small amounts from indigenous phosphates. Israel has mainly acquired uranium from foreign sources. Early in its program, Israel may have purchased uranium from France and Argentina. In 1968, it

---

[21] 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

[22] Tails of 0.3%.

is well-known that Israel diverted 200 metric tons of uranium yellowcake (uranium ore concentrate) from Belgium, in what has been called the Plumbat affair. In the 1970s Israel acquired 550 metric tons of uranium yellowcake (about 400 metric tons of uranium) from South Africa.[23]

Under my assumptions if Dimona requires about 19 to 20 metric tons of natural uranium per year, the 400 metric tons from South Africa would fuel Dimona for 20 to 21 years but if the fuel burnup were as low as Glaser and Miller assume, and the reactor's power 150 MW as claimed by Vanunu, then the South African uranium would only be enough fuel for about 4.5 years. It is not clear where Israel could acquire the continuing large amounts of uranium needed to fuel Dimona under these latter assumptions. These high natural uranium requirements are another reason why I am skeptical of Glaser and Miller's assumption of low fuel burnup and Vanunu's claim of Dimona operating at 150 MW.

Israel's Stockpile of HEU

Estimates of Israel's nuclear material stockpile tend to focus just on plutonium but Israel could have sizable amounts of HEU as well. There are reports that Israel diverted about 100 kilograms of HEU from a uranium processing facility in Pennsylvania in 1965. These reports are often dismissed as being "tentative, partial and less than conclusive" and are not used in estimating Israel's nuclear material stocks.[24] However, more recent work by Gilinsky and Mattson have made it clear that this theft likely happened.[25] Further they point out that additional amounts of HEU went missing from this Pennsylvania facility through 1968 and that the total amount of diverted HEU could be as much as 330 kilograms.

In addition to this diverted HEU, Israel could well be producing its own HEU. As noted above, the production of tritium at Dimona would require Israel to have its own enrichment facilities, something that Vanunu has also claimed.[26] Since tritium production started in the mid-1970s, Israel would have needed its start its own enrichment facilities at the same time.

The dominant enrichment technology in the mid-1970s was gaseous diffusion, but the high electricity requirements for this process make it unlikely that Israel could have used it. It is far more probable that Israel uses centrifuge technology. In the mid-1970s the only likely source for this technology would have been the European Urenco enrichment consortium which had started three pilot plants each with capacities of between 15,000 SWU per year and 25,000 SWU per

[23] David Albright, "South Africa's Secret Nuclear Weapons," Institute for Science and International Security, May 1994, p. 5.

[24] Avner Cohen, *The Worst-Kept Secret: Israel's Bargain with the Bomb*, Columbia University Press, 2010, p. 9.

[25] Victor Gilinsky and Roger J. Mattson, "Did Israel steal bomb-grade uranium from the United States?," *Bulletin of the Atomic Scientists*, April 17, 2014 https://thebulletin.org/2014/04/did-israel-steal-bomb-grade-uranium-from-the-united-states/ and Victor Gilinsky and Roger J. Mattson, "Revisiting the NUMEC affair," *Bulletin of the Atomic Scientists*, March/April 2010, vol. 66, no. 2, pp. 61-75. http://journals.sagepub.com/doi/abs/10.2968/066002007?legid=spbos%3B66%2F2%2F61&patientinform-links=yes

[26] The HEU from the U.S. would not be sufficient to fuel Dimona over the long-term. Even if 330 kilograms of HEU were diluted to produce low-enriched fuel for Dimona, under my assumptions for the reactor's power level, fuel burnup and capacity factor, Dimona could only be fueled for 7 to 10 years.

year in 1973.[27] Urenco would not have directly provided this technology, so Israel would have needed to steal it. Ironically Pakistan stole Urenco centrifuge technology from the Netherlands at around this same time. Under my assumptions for the power level, fuel burnup and enrichment tails, the operation of Dimona using enriched fuel would require an enrichment capacity of between 2,900 to 4,700 SWU per year.

Once Israel had an enrichment facility to produce fuel for Dimona, it could easily build a second enrichment facility to produce HEU. A facility with a capacity of around 5,000 SWU per year output could produce about 25 kilograms of HEU per year. The natural uranium required to produce this HEU would only be an additional 5.5 metric tons per year.[28] Assuming that Israel started HEU production in the 1980s and adding the 330 kilograms likely diverted from the U.S., Israel could have around one metric ton of HEU today. Assuming 15 to 20 kilograms of HEU per weapon, Israel could produce an additional 50 to 70 nuclear weapons.

Number of Nuclear Weapons

I estimate that Israel has about 530 to 580 kilograms of plutonium and around one metric ton of HEU. While sizable, these stocks are only enough for about 200 nuclear weapons and estimates of an Israeli arsenal as large as 400 weapons should be considered unlikely. Further, Kristensen and Norris have cogently argued that the expense of nuclear delivery systems would lead to a smaller Israeli nuclear arsenal and I tend to agree.[29] Israel's stock of tritium is likely between 820 grams and 1,160 grams. This amount of tritium is only sufficient for 80 to 145 nuclear weapons given Israel's need to maintain a sizable tritium reserve. I estimate that Israel's nuclear weapon stockpile is probably in this range and any additional quantities of plutonium and HEU are being held in reserve.

Israel's entire nuclear arsenal likely consists of boosted fission weapons. Such weapons can be smaller and lighter than unboosted fission weapons and would have yields in the low tens of kiloton range. Israel could use a variety of systems to deliver them. I do not believe that Israel possesses any two-stage thermonuclear weapons since it has conducted only one relatively low yield nuclear test.

If Israel's nuclear weapons are mostly or entirely boosted, then arms control proposals to freeze Middle East fissile material production by, in part, shutting down the Dimona reactor, would be a nonstarter for Israel. If the reactor were to be shut down, then over time, Israel's stocks of tritium would decay away and its nuclear weapons would become ineffective. Shutting down Dimona would be equivalent to requiring Israel to give up its nuclear weapons.

---

[27] SWU are separative work units which is the standard measure of enrichment capacity. See: D. Aston and E. Raetz, "Status of the Urenco/Centac Centrifuge Project and Advantages of the Process," IAEA-CN-36/99, *Nuclear Power and its Fuel Cycle: Proceedings of an International Conference on Nuclear Power and its Fuel Cycle Held by the International Atomic Energy Agency in Salzburg, 2-13 May 1977*, International Atomic Energy Agency, Vienna, 1977, pp. 147-148.

[28] Tails of 0.3%. Israel could have an even larger enrichment facility but then the natural uranium requirements would become more difficult to meet.

[29] Hans M. Kristensen and Robert Norris, "Israeli nuclear weapons, 2014," *Bulletin of the Atomic Scientists*, 2014, vol. 70, no. 6, pp. 97-115. https://www.tandfonline.com/doi/full/10.1177/0096340214555409

Comparison with Other Estimates

In recent years both the International Panel on Fissile Materials (IPFM) and the Institute for Science and International Security (ISIS) have produced their own estimates regarding Israel's nuclear material stocks and nuclear arsenal.[30] Table 1 shows a comparison between my estimates and those of IPFM and ISIS.

Table1

Comparison of this Paper's Estimates of Israel's Stocks of Plutonium, HEU and Tritium with those of IPFM and ISIS

Source of Estimate	Plutonium (kilograms)	HEU (Metric Tons)	Tritium (grams)	Number of Weapons
This Paper*	530-580	~ 1	820-1,160	80 to 145
IPFM**	720-980	0.3	400	100 to 150
ISIS**	545-775	0	0	80-150

*End of 2017
**End of 2014

The IPFM's plutonium estimates are significantly higher than my own. This is due to the IPFM assuming a higher power level for Dimona, lower fuel burnup and that tritium production does not reduce Dimona's plutonium production. The IPFM's tritium estimates are significantly lower than my own. It assumes that only 50 Israeli weapons are boosted and that each weapon is initially loaded with 8 grams of tritium to ensure a minimum of 4 grams of tritium over a 12.3 year period before the tritium is replenished. The IPFM does not explicitly discuss any Israeli tritium reserve. The IPFM has not explained how it derived its estimate of Israel's HEU stockpile.

The ISIS's plutonium estimates are higher than mine but lower than that of IPFM. The ISIS assumes Dimona power levels similar to the ones I use but uses a low fuel burnup similar to that of the IPFM. The ISIS assumes that no tritium production is taking place at Dimona and that the reactor is a pure plutonium producer. A major reason for the difference between my plutonium estimates and those of the ISIS is that I assume that tritium production is ongoing at Dimona and this tritium production significantly reduces the amount of plutonium produced. The ISIS estimates that Israel does not possess any HEU.

Interestingly all three estimates of the number of nuclear weapons in Israel's arsenal are roughly the same. These estimates would seem to imply that currently the number of nuclear weapons

[30] For IPFM see: Zia Mian and Alexander Glaser, "Tilting At Windmills?: Research, Collaboration, Advocacy and Agenda Setting on Fissile Materials," International, Panel on Fissile Materials, August 1, 2014. http://www.princeton.edu/~aglaser/CP045-Mian-Glaser-Windmills.pdf and Alexander Glaser and Marvin Miller, "Estimating Plutonium Production at Israel's Dimona Reactor." https://www.princeton.edu/~aglaser/PU056-Glaser-Miller-2011.pdf For ISIS see: David Albright, "Israel's Military Plutonium Inventory," Institute for Science and International Security, November 19, 2015. https://isis-online.org/uploads/isis-reports/documents/Israel_Military_Plutonium_Stock_November_19_2015_Final.pdf

that Israel possesses is no longer determined by nuclear material constraints but rather are determined by operational or strategic factors.

Conclusions

I estimate that Israel has a stockpile of 530-580 kilograms of plutonium, roughly one metric ton of HEU and 820-1,160 grams of tritium. It is likely that most if not all of Israel's weapons are boosted and as a result, Israel's supply of tritium is the limiting factor in its production of nuclear weapons. Its stockpile of tritium is only sufficient for about 80 to 145 nuclear weapons, given Israel's need to maintain a sizable tritium reserve.

Israel's stocks of plutonium and HEU by themselves would be enough to produce a total of 200 unboosted fission weapons. However, I do not believe that Israel has produced any sizable number of unboosted weapons and excess plutonium and/or HEU is held in reserve rather than weaponized to limit the expense of the associated delivery systems.

Israel's boosted weapons would be small, light-weight and limited to yields in the low tens of kilotons. Since Israel has conducted only one nuclear test, it is unlikely that Israel possesses any two-stage thermonuclear weapons (hydrogen bombs). If Israel's nuclear arsenal consists mainly of boosted weapons, then the continued operation of Dimona is required to provide tritium for them.