Gregory S. Jones[1]
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What Was the Pu-240 Content of the Plutonium Used in the U.S. 1962 Nuclear Test of Reactor-Grade Plutonium?

In 1977, the U.S. declassified the fact that in 1962 it had successfully tested a nuclear weapon using reactor-grade plutonium. In 1994 additional information about this test was released.[2] Though on the face of it this test would seem to definitively settle the issue about whether reactor-grade plutonium can be used in nuclear weapons, ironically the specifics related to this nuclear test have generated some of the most controversy.

Only a few facts about this successful nuclear test were released. Its yield was less than 20 kilotons, it was detonated underground at the Nevada Test Site and the plutonium used in the test was provided to the U.S. by the United Kingdom under the 1958 United States/United Kingdom Mutual Defense Agreement.

The test was specifically conducted to "obtain nuclear design information concerning the feasibility of using reactor-grade plutonium as the nuclear explosive material."[3] The Department of Energy (DOE) statement goes on to say, "The United States maintains an extensive nuclear test data base and predictive capabilities. This information, combined with the results of this low yield test, reveals that weapons can be constructed with reactor-grade plutonium." This last statement is very important and is almost always ignored in discussions about this test. It says that U.S. statements about the utility of reactor-grade plutonium for the production of nuclear weapons is not based only on this test but rather its entire nuclear test database and the predictive capabilities that have resulted. Therefore the U.S. need not have conducted nuclear tests with plutonium of all possible concentrations of Pu-240 to know that nuclear weapons can be manufactured from such material.

The U.S. has not revealed which test in 1962 was the test that used reactor-grade plutonium. The U.S. conducted the most nuclear tests in 1962 of any year—96.[4] Even if one selects only those tests where the yield is described as being less than 20 kilotons, was conducted underground in Nevada, and was weapons related, one finds that there are 36 such tests, the earliest was January 30 and the latest was December 14.

The U.S. has not revealed the exact Pu-240 content of the reactor-grade plutonium used in this test. Further the DOE statement about this test points out that in 1962 any

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[1] Though the author is a part-time adjunct staff member at the RAND Corporation, this paper is not related to any RAND project and RAND bears no responsibility for any of the analysis and views expressed in it. This paper was originally posted on the Nonproliferation Policy Education Center website.
[2] "Additional Information Concerning Underground Nuclear Weapon Test of Reactor-Grade Plutonium," U.S. Department of Energy, https://www.osti.gov/opennet/forms.jsp?formurl=document/press/pc29.html
[3] All quotations in this paragraph are from *Ibid.*
[4] *United States Nuclear Tests, July 1945 through September 1992*, DOE/NV—209-REV 15, U.S. Department of Energy, Nevada Operations Office, December 2000, http://www.nv.doe.gov/library/publications/historical/DOENV_209_REV15.pdf

plutonium with Pu-240 content higher than 7% would have been considered reactor-grade and that the current definitions of plutonium grades used by the DOE and in particular that of fuel-grade plutonium (Pu-240 between 7% and 19%) did not come into use until the 1970s.[5] Having pointed this fact out, the DOE statement then fails to say which of these two definitions of reactor-grade plutonium it is using when describing this test. This fact has allowed many to claim that the plutonium used in this test was fuel-grade rather than reactor-grade.

In 1996, Alexander DeVolpi, writing in the Physics and Society Newsletter, suggested that there is "government deception" regarding the withheld data on the 1962 test.[6] Based on a personal communication from "R.V. Hesketh", he asserts that British sources claim that the plutonium used in the test could not have been what is now defined as reactor-grade but rather was fuel-grade. Puzzlingly he then says that the plutonium might have been reactor-grade (less than 81% fissile) but near the boundary with fuel-grade plutonium. He also suggests that the plutonium might not have been produced in the UK but rather might have been produced in Canada or even in the U.S. and then transferred to the UK and then back to the U.S. to hide the material's origins.

At about the same time, John Carlson et al. from the Australian Safeguards and Non-Proliferation Office (ASNO) suggested that the plutonium used in this test was "what would now be termed 'fuel-grade,' probably closer to the weapons-grade end of the fuel-grade range."[7] Similar such statements have been made in other ASNO documents. In 2006 ASNO published a diagram which showed that it had revised its views somewhat as it now shows the plutonium having a likely Pu-240 content of between 14% and 18% i.e. near the reactor-grade end of the fuel-grade range.[8]

In 2002 Bruno Pellaud, the former Deputy Director General of the International Atomic Energy Agency, stated that the DOE announcement was misleading and that the plutonium used in this test was fuel-grade with a Pu-240 content of only 12%.[9] Pellaud's reference for this important assertion is a private communication from an unnamed source. He also cites Albright et al. as saying that the plutonium could not have been produced at the UK's Calder Hall and Chapelcross military plutonium production reactors since the burnup was too low.[10]

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[5] The U.S. currently defines weapon-grade plutonium as having a Pu-240 content of less than 7%. It defines fuel-grade plutonium as having a Pu-240 content of between 7% and less than 19% and defines reactor-grade plutonium as having a Pu-240 content of 19% or more. See: *Plutonium: The First 50 Years*, DOE/DP-0137, U.S. Department of Energy, February 1996, p.17.

[6] A. Devolpi, "A Coverup of Nuclear Test Information?" *Physics and Society newsletter*, Vol. 25, No.4, October 1996.

[7] John Carlson, John Bardsley, Victor Bragin, John Hill, "Plutonium Isotopics—Nonproliferation and Safeguards Issues," Australian Safeguards Office, IAEA-SM-351/64.

[8] "Reactor-Grade Plutonium: Use in Weapon Tests," ASNO Information Sheet, December 2006 (revised August 2008).

[9] Bruno Pellaud, "Proliferation aspects of plutonium recycling," *Journal of the Institute of Nuclear Material Management*, Fall, 2002, p.3.

[10] David Albright, Frans Berkhout, and William Walker, *Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies*, SIPRI, Oxford University Press, 1997, pp. 61-62.

Looking at Albright et al.'s statements in more detail, they claim that the U.S. announcement had caused a "lively private debate" between the British and U.S. governments since as was stated in the last paragraph, it is claimed that Calder Hall and Chapelcross reactors were not producing reactor-grade plutonium. They then go on to contradict this statement by saying that in fact the British Defense Minister had confirmed the U.S. statement to the House of Commons. Despite having official statements from both the British and U.S. governments that the plutonium had originated in the UK, Albright et al. say that the source of the plutonium used in the 1962 test has not been identified and that it is unclear whether the material was produced in the U.S. or the UK. Though they claim that the source of the plutonium is highly uncertain they say "it [the plutonium] was definitely fuel- rather than reactor-grade."

Also though Albright et al. focus on British plutonium production "before 1962," as was noted above, the test might well have occurred in late 1962 (5 of the 36 possible tests referred to above, occurred in December).[11] Therefore the fuel could have still been in British reactors as late as mid-1962 and there would have still been time for the plutonium to be provided to the U.S.[12]

Statements that the plutonium in the 1962 test was fuel-grade are becoming quite common. For a number of years the World Nuclear Association has stated that the plutonium used in this test contained about 85% Pu-239.[13] This would imply a Pu-240 content of about 13% to 14%. Such statements are now finding their way to sources such as Wikipedia.

Now why is it so important what the exact Pu-240 content of the plutonium was? Would it make that much difference if the Pu-240 content was 15% as opposed to 20% or 25%? As was discussed above, the purpose of this test was to validate U.S. calculations on the utility of plutonium with a relatively high Pu-240 content. There is no reason why this objective could not be achieved using plutonium with a Pu-240 content of just 15%.

Many of those who assert that the plutonium in the 1962 test was fuel-grade rather than reactor-grade plutonium also then make the statement that in all of the years of nuclear testing no country has ever used reactor-grade plutonium in a nuclear explosive. Such a statement sounds impressive but really is just empty rhetoric. After all, as far as is known, no country has ever used either neptunium or U-235 produced by laser

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[11] Forrest notes that the Tendrac nuclear test on December 7, 1962 is listed as being a joint US-UK test and suggested that this may be the date of the test. See: Eric Forrest, "Assessing the Proliferation Risk of Reactor Grade Plutonium, Massachusetts Institute of Technology, Fall 2010 p. 7 and *United States Nuclear Tests, July 1945 through September 1992*, DOE/NV—209-REV 15, U.S. Department of Energy, Nevada Operations Office, December 2000, p.27

[12] At this time the British cooled their spent fuel for 100 days before reprocessing. See: J.M. Kay, C.G. James, K. Saddington, and C.J. Turner, "Chemical processes," *The Journal of British Nuclear Energy Conference*, Vol. 4, No. 2, April 1959, p.136. If, for example, fuel was discharged on June 30, 1962, then there would be more than enough time (60 days) for the separated plutonium to be transported to the U.S. and fabricated for a test on December 7.

[13] "Plutonium," World Nuclear Association, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Plutonium/ updated March 2012 but the WNA has had the identical statement on its website since at least 2009.

enrichment for a nuclear weapon. Yet the weapons usability of these materials is determine solely by their nuclear and physical properties, not by whether anyone has used them before now. No one doubts that such materials could be used to manufacture nuclear weapons.

At any rate as we will see, it is very likely that the Pu-240 content of the 1962 nuclear test was in the range of 20% to 23% i.e. truly reactor-grade. It is quite implausible that it was as low as 12% to 14%.

At first glance it does seem odd that the U.S. would use plutonium obtained from the UK. After all, in the second half of the 1950s, the U.S. had eight plutonium production reactors in operation at Hanford in Washington State. If the U.S. wanted plutonium with a high Pu-240 content why would not the U.S. just make it itself? The answer is that the U.S. tried but failed.

In October 1957 Hanford received a request from the U.S. Atomic Energy Commission to produce 11 kilograms of plutonium with a Pu-240 content of 20%.[14] This was the first time that Hanford had been asked to produce plutonium with a high Pu-240 content and fulfilling this request was not a straightforward matter. If Hanford were to irradiate natural uranium to meet this request, it would require Hanford to subject the natural uranium fuel to a burn-up of around 3,800 MWD/Te. As Hanford had not ever irradiated natural uranium to burn-ups of higher than about 1,200 to 1,400 MWD/Te (Pu-240 content of 9% to 10%), this would require burn-ups of roughly triple what had ever been done before.

A constant concern for the reactor operators at Hanford was the rupture of the metallic uranium fuel elements. A rupture would expose the hot metallic uranium to the water coolant, leading it to oxidize and swell which would block the fuel channel. This could cut off the flow of coolant to the fuel elements in the same fuel channel which in the worst case would lead those elements to overheat, catch fire, and set the entire reactor ablaze. Therefore there were systems that detected the release of radioactivity when a rupture occurred. The reactor would then have to be shutdown immediately and the ruptured fuel element removed. In some cases the fuel element would already be sufficiently swollen so that great force would be needed to remove it from the reactor. Sometimes this effort would damage the aluminum tube in which the fuel and water coolant were contained so badly that the tube would have to be replaced. Fuel ruptures were a major cause of lost reactor operating time and thereby lost plutonium production. The chance that a fuel element would rupture increased the higher the fuel burn-up.

In order to try to avoid these problems, Hanford decided to use depleted uranium with a U-235 content of only 0.15% instead of the natural concentration of 0.71%. The use of

[14] "Feature Report: Depleted Uranium Irradiations in the Single-Pass Reactors to Produce High Pu-240 Plutonium," *Monthly Report, September 1968*, DUN-4452, Douglas United Nuclear, Inc., Richland Washington, October 16, 1968. Note that U.S.AEC operations were compartmented so that for most of its history Hanford was never told why it was requested to produce any particular reactor product including this batch of plutonium.

this depleted uranium would lessen the number of fissions that occurred in the fuel and it was hoped, decrease the chance that the fuel would rupture. Hanford estimated that it would require the irradiation of about 65 to 70 "tubes" (reactor fuel channels) worth of depleted uranium fuel elements to produce the required amount of 20% Pu 240 plutonium.[15] As a safety margin Hanford used 84 tubes of depleted uranium which if totally successful would have produced about 14 kilograms of plutonium with a Pu-240 content of 20%.

On seven different dates during March, April and May of 1958 these depleted uranium fuel elements were loaded into the C reactor.[16] It was anticipated that it would take irradiations of about 12 to 14 months to produce the required plutonium. However, in September 1958 there was the first fuel rupture in this batch of fuel. This rupture was fuel that had been loaded only six months earlier. In October there were four more ruptures and five more in November. In addition there was evidence that swelling in other fuel elements was making it difficult to move them in the fuel channel. All elements in channels containing either ruptured or swollen fuel elements were removed.

By this time nearly half of the initial fuel elements had been discharged. Hanford manufactured eight additional tubes of depleted uranium fuel elements using what was hoped would be an improved method. These new fuel elements were charged into the C reactor in November 1958. There was an additional rupture in the original depleted fuel in December and two more in January which were only two days apart. As a result all of the rest of the original depleted uranium fuel was discharged.

Irradiation of the new depleted fuel elements continued but in September 1959 one of these elements ruptured and all of this fuel was discharged as well.[17] It was determined that the improvement in these newer fuel elements was marginal at best. Nearly two years after the initial request, Hanford had to admit defeat and there would be no further efforts to produce high Pu-240 plutonium until 1964. However, this effort did result in the production of about 10 kilograms of plutonium with a Pu-240 content of 15%.[18]

The effect of this failure was almost immediate. Hanford had been expecting to receive from Oak Ridge a shipment of 1.2 kilograms of plutonium with a Pu-240 content of 20%.[19] This plutonium was to be used in the Physics Constants Test Reactor. However,

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[15] There were 36 fuel elements in each tube. Only the central 26 were depleted uranium, the other 10 were natural uranium. This arrangement "centered" the depleted elements in the region with higher neutron flux.
[16] W.A. Blanton, "I & E Depleted Uranium Fuel Element Ruptures Experienced Under PT-IP-132-AC," HW-58281, General Electric, Hanford Atomic Products Operation, Richland, Washington, December 1, 1958, Appendix II.
[17] R.E. Hall, "Irradiation Summary Report PT-IP-231-A, Irradiation of Depleted Uranium to High Exposure," HW-62232, October 7, 1959.
[18] The initial estimate for the plutonium produced in the 84 tubes was the 9 kilograms with a Pu-240 content of 14%. The additional 8 tubes would have produced roughly one additional kilogram. Later analysis showed that the plutonium had a Pu-240 content of 15%. *Monthly Record Report, Irradiation Processing Department, January, 1959*, HW-59041, February 20, 1959 and "Feature Report: Depleted Uranium Irradiations in the Single-Pass Reactors to Produce High Pu-240 Plutonium," *Monthly Report, September 1968*, DUN-4452, Douglas United Nuclear, Inc., Richland Washington, October 16, 1968.
[19] This material was apparently produced in the Material Testing Reactor, a high power research reactor.

Hanford was informed that it would not be receiving this material because "The Division of Military Applications" had exercised "a prior claim" on this material.[20] Work at Hanford had to be suspended illustrating just how rare plutonium with a high Pu-240 content was in 1959.

Now it is clear why the U.S. had to approach the British for help. But how did the British come to possess plutonium with a high Pu-240 content? The UK had eight virtually identical plutonium production reactors, four at Calder Hall and four at Chapelcross which were being operated by the United Kingdom Atomic Energy Authority (U.K.A.E.A.). Like the U.S. reactors at Hanford, these eight reactors used graphite as a moderator but unlike the U.S. reactors the British ones were designed to produce electricity as well. There is no British source that states what the burn-up of the fuel from these reactors was during the 1950s and early 1960s but apparently the fuel was only irradiated for about one year.[21] It is easy to calculate that this irradiation period would produce burnups of no more than 1,000 MWD/Te which would result in plutonium being produced with a Pu-240 content of 8% or less, i.e. British weapons grade plutonium.[22] Since it is known that the primary mission of these reactors during this time was the production of weapons grade plutonium, this is hardly surprising.

The British were also building a series of reactors to be operated by the civilian Central Electricity Generating Board (CEGB). These reactors were scaled up versions of Calder Hall and Chapelcross reactors but their mission was to produce electricity which for economic reasons meant that they would try to achieve the highest fuel burn-up possible. When these reactors started operation it was thought that the fuel could reach an average burn-up of 3,000 MWD/Te (Pu-240 content of about 17%) and hoped that it might be able to reach 5,000 MWD/Te (Pu-240 content of about 25%--this hope would be fulfilled). However, the first two of these reactors (Berkeley 1 and Bradwell 1) only started operation in the summer of 1962. Since it would take about one year for these reactors to produce plutonium with a Pu-240 content of more than 8%, these reactors were obviously not the source of the plutonium for the 1962 test. At first glance then, neither the plutonium production reactors nor the civil power reactors could have been the source of the plutonium for the 1962 test.

The solution to this seeming puzzle is that though the Calder Hall and Chapelcross reactors' primary mission was to produce weapons grade plutonium, it was not their only mission. In particular, with the advent of the CEGB power reactors there was a need to test the fuel that would be used in these reactors to see if they could attain the relatively

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[20] *Hanford Laboratories Operation Monthly Activities Report, November, 1959*, HW-62899, General Electric, Hanford Atomic Products Operation, Richland, Washington, December 15, 1959, p. B-12.
[21] John Cockcroft, "British Experience in the Technical Development of Nuclear Power Reactors," DPR/INF/261, United Kingdom Atomic Energy Authority, May 1961, p.2.
[22] The irradiation for one year at the average neutron flux would produce a burnup of about 500 MWD/Te which would have a Pu-240 content of about 4.5%. The maximum burnup would be about 1,000 MWD/Te. The British define weapons grade plutonium as having a Pu-240 content of 8% or less. Any plutonium with a Pu-240 content greater than this is defined as reactor grade. See: "Plutonium and Aldermaston-An Historical Account," http://www.fas.org/news/uk/000414-uk2.htm Note the British use the term "weapons grade" as opposed to the American "weapon-grade."

high burn-up needed to make these reactors economic. What better place to test such fuel than in the Calder Hall and Chapelcross reactors which were essentially identical in design in the new CEGB reactors. This was especially so since the U.K.A.E.A. which operated these reactors would be providing the fuel for the CEGB reactors.

Hardy et al., writing in the latter part of 1962, indicated that as part of the high burnup testing program at the Calder Hall and Chapelcross reactors, average channel burnups of over 3,000 MWD/Te had been achieved.[23] This burnup level would mean that the central fuel elements would have obtained a burnup of about 4,500 MWD/Te and it was reported that the highest burnup obtained by any fuel element was 4,650 MWD/Te. The Calder Hall and Chapelcross reactors used six fuel elements per fuel channel. By segregating the central two fuel elements from the fuel channels, one could obtain plutonium with a Pu-240 content of 23%. One could double the amount of plutonium obtained if the four central fuel elements were processed together. The resultant plutonium would blend to a Pu-240 content of about 20%. Stewart has published mean and peak fuel burnups obtained in various of the high burnup fuel channels in the Calder Hall and Chapelcross reactors as of August 1963.[24] Interpolating the data back to mid-1962 confirms Hardy's paper's burnup levels and also shows that there were a sufficient number of high burnup fuel channels so that kilogram quantities of plutonium with a Pu-240 content of 20% to 23% would have been available in mid-1962. Now it is clear why the U.S. approached the UK for help.

None of this directly indicates the Pu-240 content of the plutonium in the U.S. 1962 test. However in 1993, J. Carson Mark who was head of the Los Alamos Theoretical Division from 1947 to 1972 said that the 1962 test used plutonium with the highest Pu-240 content available.[25] Since the U.S. had already produced plutonium with a Pu-240 content of 15%, claims by Pellaud, Carlson et al. and the World Nuclear Association that the plutonium had only a Pu-240 content of 12% or 14% are obviously not true.

Further the Pu-240 content must have been significantly higher than 15%, otherwise there would have been no reason to have approached the British. As we have seen the highest available Pu-240 content from the British was in the range of 20% to 23%. Given what Mark has said about using the highest Pu-240 content available, it is very likely that the 20% to 23% range represents what was used in the 1962 test. This conclusion is supported by the observation that the original requirement for Hanford had been a Pu-240 content of 20%. Also recall that in November 1959 Hanford did not receive 1.2 kilograms of plutonium with a Pu-240 content of 20% because The Division of Military Applications had exercised a prior claim on the plutonium. So despite numerous statements to the contrary, it appears that the plutonium in the 1962 test was reactor-

[23] Hardy H.K., Bishop J.F.W., Pickman D.O., Eldred V.W., "The development of uranium-magnox fuel elements for an average irradiation life of 3000 MWD/te," *Journal of the British Nuclear Energy Society*, Vol.2, January 1963, p.40. Though the article was published at the beginning of 1963, the data had to have been from the latter part of 1962.
[24] J.C.C. Stewart, "Development and Manufacture of Magnox Fuel," *Proceeding of the Institution of Mechanical Engineers*, Vol. 178, Part 1, No. 9, 1963-1964, p.238.
[25] Geoffrey Lean, "DIY Atom Bomb Link to Sellafield," *The Observer*, (London), June 6, 1993, p.3.

grade after all even by the current definition requiring such material to have a Pu-240 content of at least 19% and was very likely in the range of 20% to 23% Pu-240.

No doubt there will be some who will argue that even if the 1962 test did use plutonium with a Pu-240 content of 20% or 23% that plutonium discharges from current reactors have a significantly higher Pu-240 content (the equivalent of over 30%) and that such material has never be tested in a nuclear weapon. While such a statement would be true, it ignores the point discussed above that is worth repeating: "The United States maintains an extensive nuclear test data base and predictive capabilities. This information combined with the results of this low yield test, reveals that weapons can be constructed with reactor-grade plutonium." U.S. statements about the utility of reactor-grade plutonium for the production of nuclear weapons are not based only on the 1962 nuclear test but rather its entire nuclear test database and the predictive capabilities that have resulted. Therefore the U.S. need not have conducted nuclear tests with plutonium of all possible concentrations of Pu-240 to know that nuclear weapons can be manufactured from such material.

In 1976, U.S. nuclear weapon designer Robert W. Selden stated: "The concept of 'denatured' plutonium (Pu which is not suitable for nuclear explosives) is fallacious."[26] Yet despite repeated authoritative statements from both the U.S. and British governments there are still those who try to argue that plutonium can be isotopically altered so that it is denatured and cannot be used to manufacture nuclear weapons.[27] The claim that the 1962 nuclear test was of fuel-grade rather than reactor-grade plutonium is only one example of the fallacious arguments being used. Others have used calculations of weapon predetonation probabilities or thermal analysis of weapons to try to argue this same point. However, these analyses are flawed as well and the U.S. has made clear that despite the higher neutron background or thermal output of reactor-grade plutonium, this material can be used to manufacture devastating nuclear weapons. It is time for this harsh fact to be generally acknowledged.

[2626] Robert W. Selden, "Reactor Plutonium and Nuclear Explosives," November 1976, http://www.aaas.org/cstsp/files/selden.pdf

[27] The only exception is plutonium with a Pu-238 content of 80% or more which is acknowledged to be unusable for the manufacture of nuclear weapons.