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The Myth of "Denatured" Plutonium
Reactor-Grade Plutonium and Nuclear Weapons

Part Seven: Nuclear Test Controversies

This paper is the seventh and last in a series to comprehensively examine the nuclear weapon dangers posed by reactor-grade plutonium. The first paper described some of the basic properties of plutonium, how it is classified into different grades, the variation in reactor fuel burnup and how plutonium's properties can vary depending on the initial fuel enrichment and burnup of the reactor fuel that produces the plutonium.[2] The second paper provided a short history of views regarding the nuclear weapon dangers of reactor-grade plutonium and discussed how the nuclear industry's desire to recycle plutonium has led it to downplay its dangers.[3] The third paper showed that the problem of the predetonation of an unboosted implosion fission weapon is not an impediment to the use of reactor-grade plutonium to produce nuclear weapons.[4] The fourth paper demonstrated that the increased heat content of reactor-grade plutonium produced in Light Water Reactors (LWRs) does not prevent such material from being used to produce nuclear weapons.[5] The fifth paper demonstrated that the increased radiation and critical mass of reactor-grade plutonium also does not prevent it from being used to produce nuclear weapons.[6] The sixth paper examined the role that reactor-grade plutonium played in the nuclear weapon development programs of Sweden and Pakistan as well as the role that it currently plays in India's nuclear weapon program.[7]

Several nuclear tests regarding the usability of reactor-grade plutonium in nuclear weapons have generated controversy. In 1977 the U.S. revealed that in 1962 it had successfully tested a weapon with reactor-grade plutonium. While this would seem to definitely settle the issue of the usability of reactor-grade plutonium in nuclear weapons, instead it has been heavily disputed. Advocates of the viewpoint that reactor-grade plutonium is denatured have claimed that the

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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 and a faculty member of the Pardee RAND Graduate School, this paper is not related to any RAND project or the Pardee RAND Graduate School and therefore these organizations should not be mentioned in relation to this paper. I can be reached at GregJones@proliferationmatters.com

[2] Gregory S. Jones, "The Myth of "Denatured" Plutonium, Reactor-Grade Plutonium and Nuclear Weapons, Part One: Introduction, Plutonium Basics, Definitions of Grades of Plutonium, Variation in Fuel Burnup, and the Properties of Plutonium Produced in Different Reactor Fuels," July 26, 2016. Link

[3] Gregory S. Jones, "The Myth of "Denatured" Plutonium, Reactor-Grade Plutonium and Nuclear Weapons, Part Two: Short History of Reactor-Grade Plutonium and Plutonium Recycle: Why Does the Nuclear Industry Downplay the Danger of Reactor-Grade Plutonium, September 1, 2016. Link

[4] Gregory S. Jones, "The Myth of "Denatured" Plutonium, Reactor-Grade Plutonium and Nuclear Weapons, Part Three: Predetonation," October 25, 2016. Link

[5] Gregory S. Jones, "The Myth of "Denatured" Plutonium, Reactor-Grade Plutonium and Nuclear Weapons, Part Four: Heat," December 15, 2016. Link

[6] Gregory S. Jones, "The Myth of "Denatured" Plutonium, Reactor-Grade Plutonium and Nuclear Weapons, Part Five: Radiation and Critical Mass," February 27, 2017. Link

[7] Gregory S. Jones, "The Myth of "Denatured" Plutonium, Reactor-Grade Plutonium and Nuclear Weapons, Part Six: Reactor-Grade Plutonium in the Nuclear Programs of Sweden, Pakistan and India, April 3, 2017. Link

plutonium used in the 1962 test could not have been reactor-grade but only fuel-grade[8] with a Pu-240 content perhaps as low as 12%. Both the U.S. and UK have confirmed that the plutonium for this test originated in the UK but a number of sources have falsely claimed that the British were not producing any reactor-grade plutonium in 1962. Four years ago I published a paper which showed that the plutonium in the 1962 U.S. test was 20% to 23% Pu-240 and was produced in British plutonium production reactors.[9] I summarize this paper below. Additional information can be found in my original paper.

In 1953 the British conducted two nuclear tests in the Totem test series. One of the purposes of these tests was to examine the effect of increasing the percentage of Pu-240 in the plutonium used in British nuclear weapons. This has led to the claim that the British tested high Pu-240 plutonium in at least one of these tests. Further it has been claimed that since the British did not use high Pu-240 plutonium in their weapons, they must have found the test results "unsatisfactory," thereby providing an illustration of the unsuitability of reactor-grade plutonium in nuclear weapons. However, calculations of the burnup that could have been achieved by 1953 in the British Windscale plutonium production reactors show that the plutonium available for the Totem nuclear tests must have been no more than mid-range weapon-grade material, not reactor-grade. As a result, the Totem tests provide no information on the suitability of non-weapon-grade plutonium for nuclear weapons.

1962 U.S. 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.[10] Though this test would seem to definitively settle the issue as to 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.

Many proponents of the notion that reactor-grade plutonium is not suitable for use in nuclear weapons have claimed that the plutonium used in this test was fuel-grade, not reactor-grade. There have been a number of claims that the Pu-240 content of this plutonium was less than 15% with one claiming a value as low as 12%.[11]

Both the U.S. and UK governments have issued official statements saying that this plutonium originated in the UK. Despite these statements, some sources such as Albright et al, claim that the origin of this plutonium is unknown.[12] One source has claimed that "government deception"

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[8] The U.S. defines fuel-grade plutonium as having a Pu-240 content of at least 7% but less than 19%. It defines reactor-grade plutonium as having a Pu-240 content of 19% or more and weapon-grade plutonium as having a Pu-240 content of less than 7%.

[9] Gregory S. Jones, "What Was the Pu-240 Content of the Plutonium Used in the U.S. 1962 Nuclear Test of Reactor-Grade Plutonium?" May 6, 2013. Link

[10] "Additional Information Concerning Underground Nuclear Weapon Test of Reactor-Grade Plutonium," U.S. Department of Energy, Link

[11] Bruno Pellaud, "Proliferation aspects of plutonium recycling," *Journal of the Institute of Nuclear Material Management*, Fall, 2002, p.3. Pellaud's source for his claim that the plutonium was only 12% Pu-240 is a private communication from an unnamed source.

[12] 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.

is involved and that the plutonium might have originated in Canada or the U.S. and was just sent to the UK to hide the plutonium's origins.[13] At any rate since in 1962 the first of the British MAGNOX power reactors were just starting to come on-line it is claimed that the British could not have supplied any reactor-grade plutonium since the only reactors in the UK that had been operating on a sustained basis were eight plutonium production reactors whose primary purpose was the production of weapon-grade plutonium.

My research has discovered a number of declassified documents on the operation of the Hanford plutonium production reactors. 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] At this time Hanford had never produced plutonium with a Pu-240 content of higher than about 9% or 10%. To try to produce such high burnup plutonium, Hanford irradiated depleted uranium in the C reactor starting in March 1958. However, repeated fuel ruptures thwarted this effort and by September 1959 Hanford had only been able to produce about 10 kilograms of plutonium with a Pu-240 content of 15%. Since a nuclear test moratorium had begun at the end of October 1958, there was no need for Hanford to continue its efforts. (There would be no further effort to produce high Pu-240 plutonium at Hanford until 1964.) Since the U.S. had produced plutonium with a Pu-240 content of 15% by 1959, the notion that the 1962 U.S. test must have contained plutonium with less than 15% Pu-240 is clearly incorrect.

In September 1961 the Soviet Union suddenly ended the nuclear test moratorium and the U.S. raced to conduct a number of nuclear tests. There was no time for Hanford to make another attempt to produce high Pu-240 plutonium and therefore the U.S approached the British for help. But how did the British happen to have reactor-grade plutonium? In 1962 the British had eight plutonium production reactors in operation whose main task was the production of weapon-grade plutonium. In the summer of 1962 the first two British commercial MAGNOX power reactors had started operation. Though of the same basic design as the eight plutonium production reactors, these commercial reactors' goal was to produce economical electricity, which would require high burnup fuel and produce high burnup plutonium. However, it would be years before these reactors would operate long enough to produce reactor-grade plutonium. At first glance then, neither the British plutonium production reactors nor the commercial power reactors could have produced reactor-grade plutonium in 1962.

The answer to this apparent conundrum is that while the plutonium production reactors' primary mission was to produce weapon-grade plutonium it was not their only mission. In particular the reactors were being used as test-beds to develop the high burnup fuel needed by the commercial power reactors. Published data from that era shows that by 1962 the British had produced kilogram quantities of plutonium with a Pu-240 content as high as 23% in their plutonium production reactors.

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[13] Alex DeVolpi, "A Coverup of Nuclear Test Information?" *Physics and Society Newsletter*, Volume 25, Number 4, October 1996.

[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.

J. Carson Mark, who was head of the Los Alamos Theoretical Division from 1947 to 1972, has said that the U.S. 1962 test used plutonium with the highest Pu-240 content available.[15] This combined with the fact that the original requirement given to Hanford was for plutonium with a Pu-240 content of 20% indicates that the plutonium had a Pu-240 content between 20% and 23% and was thus truly reactor-grade.

British Totem Test Series

In October 1952 the British tested their first nuclear device, code-named Hurricane. The device had a yield of 25 kilotons. In October 1953 the British tested two additional nuclear devices in the Totem test series. One purpose of these tests was to examine the effect of increasing the percentage of Pu-240 in the plutonium that the British were producing for nuclear weapons.

There are conflicting reports about the percentage of Pu-240 in the plutonium used in this test series. On the one hand, many have jumped to the conclusion that these tests involved plutonium with a Pu-240 content significantly higher than the 8% that the British define as weapon-grade.[16] Alex DeVolpi, a leading proponent of the notion of denatured plutonium, has gone a step further. He has claimed that since the British used non-weapon-grade plutonium in these tests but used weapon-grade plutonium in their weapons, they must have found something about the non-weapon-grade plutonium unsatisfactory.[17]

On the other hand, Friends of the Earth Australia has pointed out that fallout measurements indicate the plutonium used in the Totem test series was weapon-grade.[18] However, this conclusion has been generally ignored. I will show that Friends of the Earth Australia is correct and indeed, the maximum Pu-240 content that the British Windscale plutonium production reactors could have produced in time for the Totem tests was only about 4.4%. Therefore these tests provide no information about the suitability of reactor-grade plutonium in nuclear weapons.

The two British Windscale plutonium production reactors were air-cooled and used aluminum clad natural uranium fuel. Each of the two reactors was apparently intended to each have a thermal power output of about 115 MW.[19] However, given the limited technical information available to the British, errors were made in the reactor design. After the first subcritical testing of Windscale 1 in August 1950, it was apparent that the reactors would not be able to operate at their design power. To try to improve the reactor's performance the British were required to remove all of the fuel (180 metric tons) from Windscale 1 and then shave a 1/16 of an inch off of

[15] Geoffrey Lean, "DIY Atom Bomb Link to Sellafield," *The Observer*, (London), June 6, 1993, p.3.
[16] For example, John Walker, who is generally well-informed on the British nuclear weapon program has said: "…we do know that the British tested devices with high Plutonium 240 content during the Totem trials in 1953." John R. Walker, *British Nuclear Weapons and the Test Ban 1954-1973,* Ashgate, 2010, p. 96.
[17] Alex DeVolpi, "A Coverup of Nuclear Test Information?" *Physics and Society Newsletter*, Volume 25, Number 4, October 1996. DeVolpi has repeated this claim more recently: Alexander DeVolpi, "Demilitarizing Weapon-Grade Plutonium: Part II," *APS Physics Newletter*, July 2015.
[18] Jim Green, "Can 'reactor grade' plutonium be used in nuclear weapons?" Friends of the Earth Australia, September 10, 2007.
[19] Unlike the later British Calder Hall and Chapelcross plutonium production reactors, these reactors did not produce electricity. The information on the Windscale reactors and their operation are from the official British history: Margaret Gowing assisted by Lorna Arnold, *Independence and Deterrence, Britain and Atomic Energy, 1945-1952,* Volume 2 Policy Execution, St. Martin's Press, New York, 1974.

the fuel cooling fins to reduce the amount of aluminum in the reactor.[20] Windscale 1 went "on power" on December 22, 1950 at the power level of 1 MW. The reactor's power was progressively increased from January 1951 to April 1951 when it reached the maximum that the design could sustain—76 MW.[21]

The British Butex reprocessing plant (B204) first processed Windscale spent fuel on February 25, 1952. Given that the fuel had to be cooled for at least 90 days before reprocessing, the fuel could only have been irradiated for about seven months at full power. This would produce an average fuel burnup of about 80 Megawatt Days per Metric Ton (MWD/Te).[22] Assuming that the fuel came from the central part of the reactor where the neutron flux is highest and that the reactor's flux was unflattened, similar to the French G1 plutonium production reactor,[23] then the burnup would have been almost twice this value—150 MWD/Te. At this burnup the plutonium's Pu-240 content would have been a little more than 1%.

The full amount of the plutonium for the Hurricane nuclear test had to be separated by August 1, 1952 so that three nuclear cores of various sizes could be produced. Given the time required for the fuel to cool and to process all of the spent fuel, the maximum time that the fuel could have resided in the reactor was about one year. This would produce an average burnup of about 130 MWD/Te and a central fuel burnup 250 MWD/Te. The plutonium Pu-240 content of the average fuel would be about 1% and that of the central fuel about 2%. Since three nuclear cores would require on the order of 15 kilograms of plutonium and that up to that point the reactor would have only produced about 22 kilograms of plutonium in total, more than just the central reactor fuel would have needed to be reprocessed to meet the August 1 deadline. A reasonable inference is that the British intended to produce plutonium with a Pu-240 content of 2% just as the U.S. did between fall of 1945 and spring of 1949 but the British were forced to irradiate the fuel to a lower burnup than intended to meet the deadline. The plutonium for Hurricane would have had a Pu-240 content somewhere between about 1% and 2%.

One purpose of the Totem tests was to examine the effect of increasing the percentage of Pu-240 in the plutonium used in British nuclear weapons. The British were driven to consider increasing the percentage of Pu-240 by their plans to build two additional plutonium production reactors, Calder Hall A1 and A2. The power level of these two reactors would be about double that of the two Windscale reactors. While this would triple the rate of plutonium production, it would also triple the required uranium, fuel fabrication and fuel reprocessing. Increasing the fuel burnup would decrease these requirements. For example in 1949 the U.S. increased its fuel burnup from 200 MWD/ton[24] to 400 MWD/ton. This increased the Pu 240 content of U.S. plutonium from

[20] This was 70,000 fuel elements. The process took three weeks.

[21] Later each of the two Windscale reactors was able to achieve a power level of 180 MW by supplementing the natural uranium fuel with fuel enriched to 0.92%. In October 1957 the Windscale 1 reactor caught fire and suffered major damage. Both reactors were permanently shut down. Significant radioactivity was released, making this the worst nuclear accident up to that time.

[22] (76 MW/180 Mt) x 183 days of operation equals 77 MWD/Te which I rounded to 80 MWD/Te. The life-time capacity factor for the two Windscale reactors was 86%.

[23] J. Horowitz and J. Bussac, "Thermal Flux Flattening and Increase of Reactor Output," Commissariat a l'Energie Atomique, Rapport CEA No. 1106, 1959.

[24] These are 2,000 pound tons.

about 2% to 3.8% but it halved the required amount of uranium while producing almost the same amount of plutonium.[25]

The two Totem tests occurred in October 1953 about one year after the Hurricane test. The plutonium for these tests had to have come from either the Windscale 1 reactor or the Windscale 2 reactor. If Windscale 1 produced the plutonium for these tests, the fuel could have at most been in the reactor for two years. The central fuel burnup would have been twice what it had been in 1952 i.e. about 500 MWD/Te. The maximum Pu-240 content of the plutonium would have been about 4.2%.

The Windscale 2 reactor reached full power in October 1951 about six months after Windscale 1. It managed to achieve a higher power level—about 105 MW. If this reactor provided the plutonium for the Totem tests, its fuel could have been exposed at full power for about one and one half years. This would have produced a central fuel burnup of about 520 MWD/Te which is a slightly higher burnup than the fuel from Windscale 1. The maximum Pu-240 content of the plutonium would have been no more than about 4.4%.

Therefore the plutonium used in the Totem tests could have contained no more than about 4.4% Pu-240. This is significantly higher than what would have been used in the Hurricane test but is still weapon-grade. As a result, the Totem tests provided no information on the suitability of non-weapon-grade plutonium in nuclear weapons.

Nor were the British likely to have been disappointed by the results of the two Totem tests, as DeVolpi claims. The British considered the most likely yield of the Totem 1 test to be about 5 kilotons and that of the Totem 2 test 2-3 kilotons.[26] The actual test yields were 10 kilotons and 8 kilotons respectively—hardly disappointing.

Conclusions

In 1962, the U.S. successfully conducted a nuclear test using reactor-grade plutonium. Despite numerous claims that this test did not use reactor-grade plutonium but only fuel-grade plutonium, the test, in fact, did use reactor-grade plutonium that had been produced in British plutonium production reactors. While these British reactors' primary mission was to produce weapon-grade plutonium, they also produced some reactor-grade plutonium since they were being used as test-beds for high burnup fuel that was to be used in British nuclear power reactors. The plutonium so produced had a Pu-240 content of between 20% and 23%.

Though many believe that the British Totem nuclear test series involved the use of non-weapon-grade plutonium, calculations reveal that the plutonium was weapon-grade with a Pu-240 content no higher than 4.4%. Claims that the British tested high Pu-240 plutonium in these two tests and found this plutonium unsatisfactory are false. Both nuclear tests produced yields significantly higher than expected.

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[25] "Technical Report to the General Advisory Committee," HW-13292, General Electric Co., Hanford Works, May 10, 1949.

[26] Lorna Arnold, *A Very Special Relationship: British Atomic Weapon Trials in Australia*, Her Majesty's Stationery Office, London, 1987.