Origin of the Mk4A AF&F

On 3rd April 1992 the US Departments of Energy and Defence began a Phase 6.2 study into future warheads for Trident missile system.[1] The alternatives to the W76/Mk4 and W88/Mk5 warheads were designated as Mk4A and Mk5A respectively. Los Alamos and Lawrence Livermore Laboratories each produced a range of options for both the Mk4A and the Mk5A. Most of the options for the Mk4A required a new AF&F.

In 1995, after the study was completed the SLBM Warhead Protection Programme (SWPP) was established to take forward this work. SWPP narrowed the options to a Pit Reuse Project and a Replacement Warhead Project. Consideration of a new AF&F for Trident continued under SWPP.

In July 1997 the formal programme to develop a new AF&F for the W76/Mk4 was started. The work was initially carried out under the SWPP Advanced AF&F project.[2]

In August 1998 the Nuclear Weapons Council Authorised a Phase 6.2 study of the W76-1/Mk4A Life Extension project. The new AF&F became a key part of this.

The work of SWPP grew into the Reliable Replacement Warhead (RRW)project. One Lawrence Livermore design for RRW was selected and then the project was cancelled. The long term plans for a new warhead have been shelved, but the proposals for a Mk4A AF&F have been implemented.

Limitations of the Mk4 fuzing system

Description of the Mk4 fuzing system

The fuzing systems in the original Mk4 AF&F (MC2912) are:

- Airburst Radar with 3 range options – prime
- Contact fuze – backup
- G-started timer – prime or backup[3]

Limitations of contact fuzes on SLBM and ICBM

It might be thought that a simple way to detonate the Mk4 warhead against a hardened target would be to use the contact fuze. However this is not the intended role of the contact fuze.

The main fuzing system on the Mk4 is the radar. The radar fuze has some resistance to jamming. In the last resort, if faced with effective jamming, it will switch off.[4] This prevents the warhead from being detonated prematurely at high altitude. But it means that there must be a back-up fuze to

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[1] Joint DoD/DoE Trident Mk4/Mk5 Reentry Body Alternate Warhead Phase 2 Feasibility Study Report, January 1994.

[2] Project P/SNL—4487. The new W76 AF&F is also listed as an SWPP project in the Stockpile Life Extension Program, Albuquerque Workload Planning Guidance 98-0, published in 1997.

[3] Survey of Weapon Developments and Technology, Sandia National Laboratory, February 1998, page 485. The component numbers are: radar MC2823, contact fuze MC2984, and G-switch MC2913.

[4] "radar fuzes in modern nuclear weapons are designed to be relatively insensitive to jamming and to deactivate in the event of severe jamming, with an alternate non-radar fuzing method taking over". Report of the Fundamental Classification Policy Review Group, 15 January 1997, Appendix F. http://www.fas.org/sgp/library/app-f.html

take over. The contact fuze is intended to fulfil this back-up role. It is not meant to be a prime fuzing system.

There are a number of reasons why contact fuzes do not make good prime fuzing options on ICBM and SLBM.

One problem is that if the contact fuze was the prime system then there would be no alternative if it failed. The probability of detonation would be lower because of the reliance on a single fuzing system.

There are also concerns about the reliability of contact fuze systems. A survey of nuclear weapons developments published in 1998 has the following table:[5]

Contact Fuzing Degree of Difficulty		
	Component	**System**
Design	Easy	Easy
Validate	Fairly Easy	Very difficult

This suggests that it is very difficult to validate that a system which depends on a contact fuze is reliable, even though it is fairly easy to validate the component itself.

Many of the subsequent pages in this report have been completely redacted. The declassified pages show computer generated forests and trees and a graph with the title "conditional probabilities of tree impacts on Reentry Vehicle Surface".[6] It is reasonable to assume that an RV could encounter a variety of uneven surfaces, of which trees are only one example, and that this reduces the probability that the contact fuze will operate correctly.

The report lists the disadvantage of contact fuzes. One of these is - "Dependability concerns (system reliability)".[7] This cannot be addressed by modifying the design of the contact fuze. Such alterations would provide "little, if any, additional protection against impact irregularities".[8]

When the USAF was developing proposals for the Small ICBM missile they considered the need to add a proximity fuze:

> "An unresolved fuzing issue is the need for a proximity fuze as an alternative for terrain and re-entry conditions where the contact fuze may not be suitable."[9]

This suggests that, in addition to the problems of unpredictable terrain, a contact fuze may be less reliable in certain re-entry conditions. The contact fuze is close to the nose of the RV. Its function might be affected by heat at the front of the RV in certain trajectories.

Limitations of the radar fuze in the Mk4 AF&F

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[5] Survey of Weapons Developments p 509
[6] Survey of Weapons Developments p536-539
[7] Survey of Weapons Developments p508
[8] Survey of Weapons Developments p540
[9] http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA245542&Location=U2&doc=GetTRDoc.pdf

The radar fuze can detonate the warhead at one of three fixed altitudes. Because the Mk4 was originally designed for the C4 missile none of these altitudes is very low.

Mk4 RV on the Trident C4 and Trident D5 missile

The C4 (Trident I) missile, for which the Mk4 RV was designed, was relatively inaccurate. The combination of C4 missile and Mk4 RV was not effective against hardened targets. The RV was unlikely to land close enough to a missile silo for the target to be destroyed.

The D5 missile (Trident II) is substantially more accurate. It was designed to destroy Soviet SS-18 missile silos.[10] This required a high level of accuracy which was achieved by adopting a system-wide approach. The designers looked comprehensively at all aspects of the Trident system in order to improve accuracy. To destroy SS-18 silos the D5 missile would require a large, 475 kiloton, W88 Warhead in the Mk5 RV.

The closure of the Rocky Flats production plant curtailed the number of W88 warheads which were produced. As a result, most US Trident D5 missiles are armed with the W76 warhead /Mk4 RV. The British Trident warheads which are deployed today on D5 missiles were designed around the Mk4 RV because the original plan, in 1980, was that Britain would procure the C4 missile.

When combined with the D5 missile, the Mk4 RV has the potential to be effective against some hardened targets, but only if the fuze is altered. This is at the heart of the plan to build a new Mk4A AF&F.

Relationship between missile accuracy and height of burst

Introducing a new fuzing system can make a warhead more effective. Changing the fuze does not alter the trajectory that the RV is on. But it can adjust the point on that trajectory when the warhead detonates.

The standard measure for determining the effectiveness of nuclear weapons against a variety of targets is blast, primarily peak static overpressure in pounds per square inch (psi). If the intention is to destroy houses in a city then this can be achieved with around 5 psi. If more substantial properties are the target then 10 psi could be required. In contrast the destruction of missile silos requires between 1,000 and 10,000 psi.

The area over which the planned overpressure will be achieved varies with the height at which the warhead is detonated. The "optimum" height of burst (HOB) for achieving 5 psi from a 100 kiloton warhead is around 1300 m. For 10 psi the optimum HOB is around 1000 m. Very hard targets, such as missile silos, will only be destroyed if the warhead is detonated close to or on the ground.

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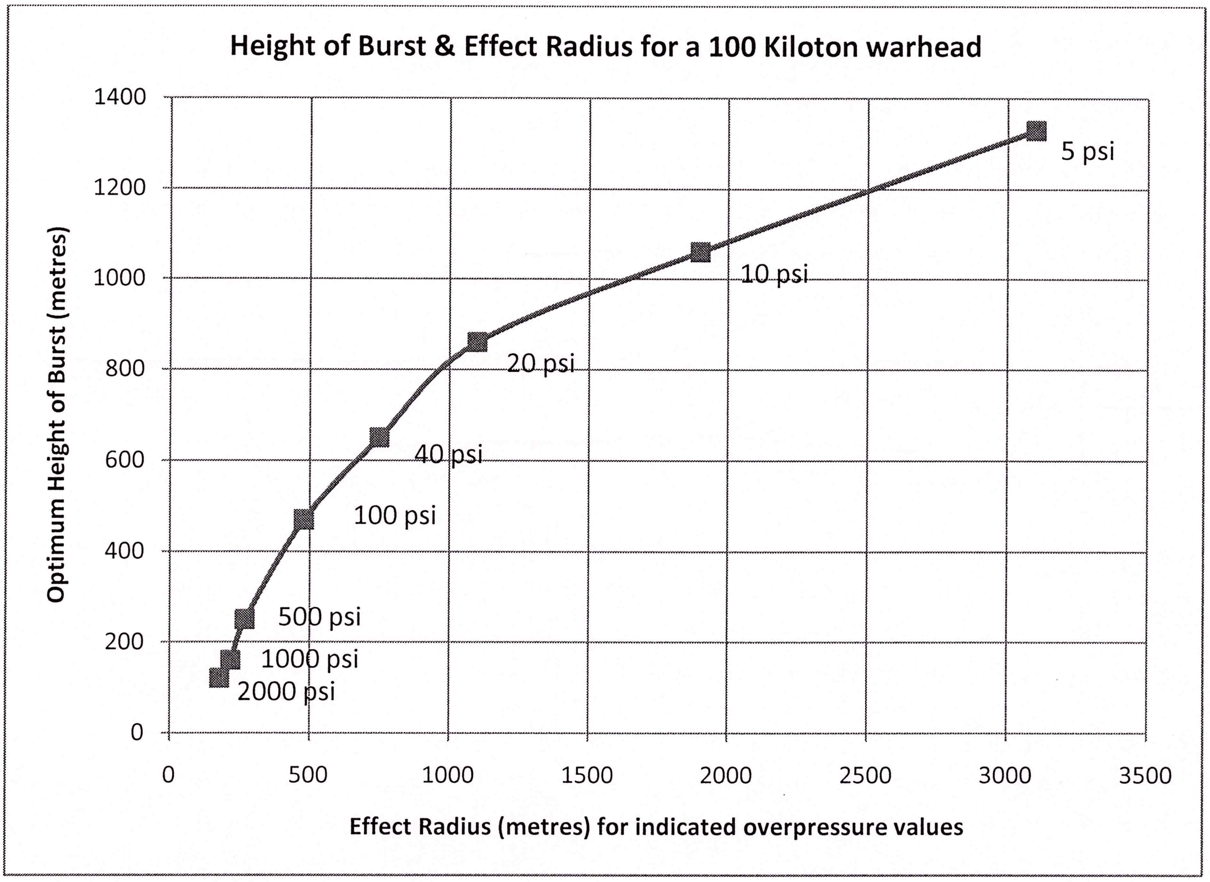
[10] At the time the D5/W88 system was developed it was assumed that SS-18 silos were hardened to 7,000 psi. It was later established that the silos were even harder. Alternate Warhead Study



The chart gives a general indication of how the optimum height of burst varies with the intended blast effect. It shows the effect radius for various overpressures and the optimum height of burst associated with this overpressure for a 100 kiloton warhead. [11]

The assessments made in US nuclear planning are more complex. Each type of target is given a VNTK rating. VN is the vulnerability number which is related to blast pressure. T is a letter indicating the type of pressure. Basic values are calculated for a 20 kiloton warhead. K is an additional factor which indicates how much the effectiveness varies with higher yields.

The Mk4A/Mk5A study in 1994 compared the effectiveness of a number of potential new Trident warheads. The Measure of Effectiveness (MOE) for the Mk4 RV on a C4 missile was target type 27P0. This is equivalent to around 150 psi overpressure. The study said:

> "When the W76/Mk4 was developed, the weapon system CEP was such that this type of target was considered difficult to successfully attack. With the improvements in CEP experienced by the C4 missile, this target is no longer the challenge it once was. Nevertheless the SPETWG considered it to be an important MOE for this system, and used it in their analysis".[12]

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[11] Calculations carried out using the Weapons Effects computer programme produced by Lawrence Livermore National Laboratory.

[12] Joint DoD/DoE Trident Mk4/Mk5 Reentry Body Alternate Warhead Phase 2 Feasibility Study Report, January 1994. p 9-14; SPETWG is the Systems Performance and Effectiveness Technical Working Group. CEP is Circular Error of Probability and is a standard measure of missile accuracy.

The Height of Burst setting on the Mk4 RV to attack 27P0 (150 psi) is probably between 300 m and 400 m.[13] This is probably the lowest of the three radar settings in the Mk4 AF&F. The highest setting is probably in the region of 1300 m, with a third setting between these two values.

Limitations of the G-started Timer in the Mk4 AF&F

Nuclear weapons often have inertial fuzing systems. These are not susceptible to jamming. The g-started timer in the Mk4 AF&F has an inertial sensor. As the RV re-enters the earth's atmosphere it is subjected to extreme g-forces, peaking at around 50g. When a particular deceleration is detected the sensor starts a clock. The warhead is then detonated after a predetermined time, measured in microseconds.

Sandia's 1998 report of Weapons' Developments lists potential fuzing components and highlights the three deployed on the Mk4 AF&F. This suggests that the sensor in the Mk4 AF&F is a mechanical g-switch rather than an electronic accelerometer.[14] The report says that mechanical g-switches have an accuracy of 1 % compared with 0.1 % for electronic accelerometers.[15]

The Mk12 RV on the Minuteman ICBM had an integrating accelerometer which started a timer at an altitude of around 3000 metres. The accelerometer had an accuracy of 0.5 %.[16] The two main sources of error in the Mk12 inertial system were variations in weather conditions, air density and temperature, and accelerometer reliability. Clock error was not a significant factor.

The g-started timer fuze in the Mk4 is probably not very accurate.[17] It may be designed for high airburst, either as a prime fuze with contact back-up or as a back-up to the highest radar setting.

Near Surface Burst option for the Mk4A

The 1994 report on Mk4A/Mk5A alternatives includes proposed Military Characteristics for the Mk4A. This includes a paragraph on the AF&F:

> "Fuzing Options. The warhead shall be compatible with the fuzing options of air burst, near surface burst and contact burst".[18]

The important point is the addition of a "near surface burst" option. This was not originally available in the Mk4 AF&F.[19] A near surface burst is "a detonation in the air that is low enough for the immediate fireball to touch the ground".[20] The radius of the fireball for a 100 kiloton warhead is

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[13] Calculations carried out using Weapons Effects, LLNL.
[14] Survey of Weapons Developments page 485
[15] Survey of Weapons Developments page 546
[16] Least Dispersion of the Mark 12 Reentry Vehicle, Air Weather Service USAF, 1964.
[17] An illustration of the fuzing hierarchy of the Mk4 AF&F indicates that it has a g-switch rather than an electronic accelerometer. Mechanical g-switches have an accuracy of 1 % compared with 0.1 % for electronic accelerometers. Survey of Weapons Developments pages 485 and 546. The Mk12 RV had an integrating accelerometer which started a timer at an altitude of around 3000 metres. This had an accuracy of around 0.5 %. Least Dispersion of the Mark 12 Reentry Vehicle, Air Weather Service USAF, 1964.
[18] Alternate Warhead Study Appendix B page 8. This paragraph is marked Secret (SFRD) but is printed in full without any redactions.
[19] Survey of Weapon Developments page 485
[20] Nuclear matters A Practical Guide, Department of Defence, 2008, http://www.acq.osd.mil/ncbdp/nm/nmbook/references/NM_APracticalGuide.pdf

around 250 metres.[21] So the proposal was that the Mk4A should have a new fuzing option to enable the warhead to be detonated at a height of less than around 250 metres.

The 1994 report also said:

> "Effectiveness studies show significant value to new Mk4A height of burst options for capability against harder targets"[22]

> "The SPETWG assumed that the HOBs of a Mk4A would be changed from those of the W76/Mk4."[23]

Most of the alternative warheads in the 1994 report would have required a new AF&F, but three options using the original AF&F, MC2912, were considered.[24] For the latter it was proposed that the fuze settings on MC2912 would be changed -

> "The fuze settings in the existing AF&F are not optimal and changing these settings would improve the effectiveness of any of these candidates."[25]

In 1997 Rear Admiral P Nanos, the Director of Strategic Systems Programs, wrote:

> "the Mk4 was never given a fuze that made it capable of placing the burst at the right height to hold other than urban industrial targets at risk. With the accuracy of the D5 and Mk4, just by changing the fuze in the Mk4 reentry body, you get a significant improvement. The Mk4, with a modified fuze and Trident II accuracy, can meet the original D5 hard target requirement." [26]

A review of Stockpile Stewardship and Management in 1997 said that one of the areas for development of the W76/Mk4 was:

> "Fuze modification evaluation to enable W76 to take advantage of higher accuracy of D5 missile." [27]

<u>Mk5 AF&F Technology</u>

A key aspect of the Mk4A upgrade has been to incorporate the technology of the W88/Mk5 AF&F into the Mk4 RV.

In the 1970s research began into a fuzing system for an Advanced Ballistic Reentry Vehicle (ABRV). The new technology was first deployed on the Mk21 RV for ICBMs and then on the Mk5 Trident RV.[28]

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[21] Airburst fireball radius 210m, ground-contact burst fireball radius 280m. Calculations using formula published by Carey Sublette, Nuclear Weapons FAQ http://www.stardestroyer.net/Empire/Science/Nuke.html

[22] Alternate Warhead Study pdf page 28

[23] Alternate Warhead Study p 9-10; HOB is height of burst.

[24] Both of the two Los Alamos options required a new AF&F. The three Lawrence Livermore alternatives each had two sub-options, one with the current AF&F and the other with a new AF&F.

[25] Alternate Warhead Study, page 7-43

[26] Rear Admiral P Nanos, Director of Strategic Systems Programs, US Navy, "Strategic Systems Upgrade" in the Submarine Review April 1997.

[27] Stockpile Stewardship and Management Plan: First Annual Update, DOE, October 1997, obtained under FOIA by Hans Kristensen.

The Mk5 AF&F is more sophisticated than the Mk4. There are six fuzing systems in the Mk5:

- Airburst Radar with 5 range options
- Proximity Radar
- Timer – for high airburst
- Path Length – also described as inertial airburst
- Radar-Updated Path Length –the main option
- Contact Fuze –backup

Two of the main improvements from the Mk4 are the introduction of a proximity fuze and a Radar-Updated Path Length (RUPL) fuze.

Proximity Fuze

The solution to the problem of contact fuze reliability is to add a proximity fuze. This is a radar system which detonates the warhead immediately before it strikes the ground. A proximity fuze provides "dependable surface fuzing" and will "ensure detonation prior to collision".[29] It gives "adequate survivability for all impact scenarios".[30]

The ground shock from using a proximity fuze would be very similar to that from using a contact fuze.[31] The proximity fuze detonates the warhead 6 metres above the surface. So radar proximity fuzing results in "little, if any, degradation in burst height effectiveness".

The Air Force and Department of Energy argued that a reliable proximity fuze should be deployed on the Peacekeeper (MX) and the small ICBM missiles.[32]

Because the Mk5 was designed for attacking SS-18 missile silos it was given a reliable ground burst capability by incorporating a proximity fuze in the AF&F. The solid-state radar in the Mk5 incorporates both airburst and proximity fuzing options. The Sandia Survey of Weapons Developments report uses the term "Proximity radars (prox time-down)".[33] This suggests that the Mk5 fuzing system may use a combination of radar and timer to detonate the warhead very close to the surface.

Radar Updated Path Length Fuze

A Path Length fuze is an inertial system which measures the progress of the RV along its planned trajectory by monitoring changes in velocity with an accelerometer. It is activated on re-entry. With a Path Length fuze the warhead can be detonated at a predetermined point on the trajectory.

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[28] Survey of Weapon Developments p 503.
[29] Survey of Weapons Developments p490
[30] Survey of Weapons Developments p540
[31] Survey of Weapons Developments; The same diagram is also an illustration in Ground Shock from Earth Penetrator Weapons, Paul Yarrington, Sandia, November 1988, p21.
[32] http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA245542&Location=U2&doc=GetTRDoc.pdf
[33] Survey of Weapons Developments p485

The Radar Updated Path Length (RUPL) system on the Mk5 combines the data from the Path Length system with an altitude fix from the radar.[34] RUPL is a "compensating fuze". It can "adjust the fuzing system to make up for targeting inaccuracies".[35]

In 1982, while the Mk5 was being designed, the US Navy filed a patent for the "Burst Height Compensation" system for an SLBM system.[36] This may describe the principles behind the RUPL on the Mk5. The patent explains how the actual path of an RV varies from the projected nominal path because of errors from factors such as air density and wind. The Burst Height Compensation system calculates the difference between the actual trajectory and the nominal trajectory. It then adjusts the point at which the warhead is detonated to take account of this error. The actual trajectory is determined by measuring the velocity of the RV from re-entry with an accelerometer. A height fix from the radar enables the onboard computer to calculate the downrange deviation from the nominal trajectory.

In order to attack the SS-18 silos, which were the Mk5's primary targets, the warhead would be required to detonate either at a low height or on the surface. The development of RUPL for the Mk5 warhead suggests that this a fuzing option that is appropriate for a low airburst or near surface burst.

Development of the Mk4A fuzing system

Incorporating Mk5 capability

The 1994 report said - "The new Mk4 AF&F will function much like the Mk5 AF&F" and "The new AF&F is based on the radar technology from the W88".[37]

At an early stage of the SWPP programme, Strategic Command were asked to consider the effectiveness of two Mk5 features, proximity fuzing and Radar Updated Path Length (RUPL), for the Mk4A.[38]

In 1997 a study was underway into how to "implement capability of W88/Mk5 AF&F into W76/Mk4 volume".[39]

Sandia Laboratory's Survey of Weapons Developments in 1998 has a chart headed "fuzing options for replacement Mk4 AF&F". This highlights two Mk5 features that might be

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[34] The relevant components of the Mk5 fuzing system are a Force Balanced Integrating Accelerometer (FBIA) (MC3817), a radar system (MC3812), an onboard computer (MC3811) and an electronic clock (MC3827).

[35] Swords of Armageddon, Chuck Hansen, Vol 7, p 430, quoting Sandia Lab News, 31 Jan 1986

[36] Burst Height Compensation US Patent 4456202

[37] Alternate Warhead Study p 7-29 and 7-45

[38] Greg Mello That Old Designing Fever, Bulletin of Atomic Scientists, Jan/Feb 2000; One of the goals of SWPP was to: "Minimise changes to the functional interface of the Mk4 to allow for Mk5 functionality and Mk5 nuclear safety implementation".
http://portal.unesco.org/en/files/5813/10312388001SCIENCEFORPEACE8light.pdf/SCIENCEFORPEACE8light.pdf

[39] Stockpile Stewardship and Management Plan: First Annual Update, DOE, October 1997, obtained under FOIA by Hans Kristensen.

incorporated into the new AF&F. One is "dependable surface fuzing", ie a proximity fuze. The second is "new fuzing option for Mk4". This could refer to near-surface burst or RUPL.[40]

In 1999 the Department of Energy's Stockpile Stewardship master plan says that a new modular fuzing system will allow "the incorporation of Mk5 fuzing functionality (including radar-updated path length fuzing, and radar-proximity fuzing) as an option for a replacement of the much smaller Mk4 AF&F."[41]

Space and battery requirements

The Mk4 AF&F is considerably smaller than the Mk5.[42] One of the largest components of an AF&F is the battery. The Mk4 AF&F is dormant for most of its trajectory. It has one high powered battery which comes to life after re-entry. The sophisticated systems in the Mk5 AF&F require power from immediately after launch. So the Mk5 has two batteries, a low-voltage long-life battery and a short term negative voltage battery.

For the Mk4A to have the capability of the Mk5 it would require power throughout the flight of the RV. This would need two batteries. The 1994 study recommended that the fireset was moved from the AF&F to the aft of the RV. A second battery could then be housed in the space vacated by the fireset.[43] However an alternative solution was found. Engineers at Sandia Laboratory designed one complex battery which would fulfil the functions of the two batteries in the Mk5 and which would fit within the existing space in the Mk4.[44] This development was an essential part of the programme to give the Mk4A the fuzing capability of the Mk5.

New electronic technology

The jump in capability from the basic Mk4 AF&F to the sophisticated Mk5 system was made possibly by the application of new technology in the late 1970s and 1980s. But the computing power of the Mk5 is meagre by today's standards. A major aspect of the Mk4A AF&F programme has been the development and validation of new electronic hardware. The computing power of new AF&F is far greater than that of the Mk5 system. For example the programmer in the Mk5 AF&F has only 2 Kb of SRAM memory.[45] The circuits in the Mk4A probably each have 500 times more memory, with at least 1 Mb SRAM

Some Commercial-Off-The-Shelf (COTS) electronic components are used in the Integrated Circuits in nuclear RVs, but only for non-critical functions. For vital activities special components have been developed by Sandia Laboratory. These are designed and tested so they can withstand not only solar radiation but also the radiation from other nuclear weapons. Just as the performance of commercial IT hardware has rapidly improved, so Sandia Laboratory has designed more powerful

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[40] Survey of Weapon Developments p 565

[41] Greg Mello That Old Designing Fever, Bulletin of Atomic Scientists, Jan/Feb 2000

[42] The Mk5 AF&F has a base diameter of 7 inches and a height of 11.9 inches. The Mk4 AF&F has a base diameter of 6.1 inches and a height of 10.7 inches. Although both are conical the Mk5 is more cylindrical than the Mk4. Survey of Weapons Developments p 564

[43] Alternate Warhead Study p 7-29

[44] The MC4708 battery can remain active for one hour, with four voltage sections and a high pulse load at the end of its life. The battery utilises an advanced cobalt disulfide cathode material. MC4708 Thermal Battery Assembly. www.sandia.gov

[45] W88 Integrated Circuit Shelf Life Program, Sandia Report SAND98-0029, January 1998.

components for nuclear weapons. For example, the size of Sandia's SRAM memory for nuclear warheads increased from 1 kb in 1976, to 250 kb in 1996, and to 1 Mb in 2002.[46]

Sandia designed the Permafrost Integrated Circuit for the Mk4A AF&F. Permafrost has been described as "the brains of the W76-1 warhead".[47] These integrated circuits use new CMOS7r radiation-hardened Silicon-on-Insulator (SOI) processors which were developed by Sandia between 1999 and 2003.[48]

In April 2001 ALEGRA software was used to support the design and development of a new radar fuze for the Mk4A.[49] By 2003 a new Digital Signal Processor for the radar was nearing completion. This Digital Signal Processor is based on the Permafrost integrated circuit.[50] There have also been changes to the analogue elements of the radar. In 2006 the Kansas City Plant was asked to produce new "RF power amplifier transistors to support the W76 radar transmitter".[51]

A diagram of the Mk4A architecture, published in 1998, shows the relationship between the main components in the Arming and Fusing System.[52] The new system has a Force Balanced Accelerometer Integrated Circuit.[53] It can combine inertial data from this accelerometer with altitude data from the advanced radar. This will give it a sophisticated fuzing capability, similar to the RUPL system on the Mk5. The improvements to the radar could also give the Mk4A a proximity fuzing option.

The original radar in the Mk4 operates at different frequencies from the Mk5. The 1994 study identified this as an issue, but had not yet evaluated whether the Mk4A should use the Mk4 or the Mk5 frequencies.[54]

<u>Effect of the introduction of the Mk4A fuzing system</u>

A near surface burst is a type of detonation that would be used against a hardened target. In the case of a 100 kiloton warhead, the height of burst would be below 250 metres if the requirement was to produce a blast effect of greater than around 700 psi.

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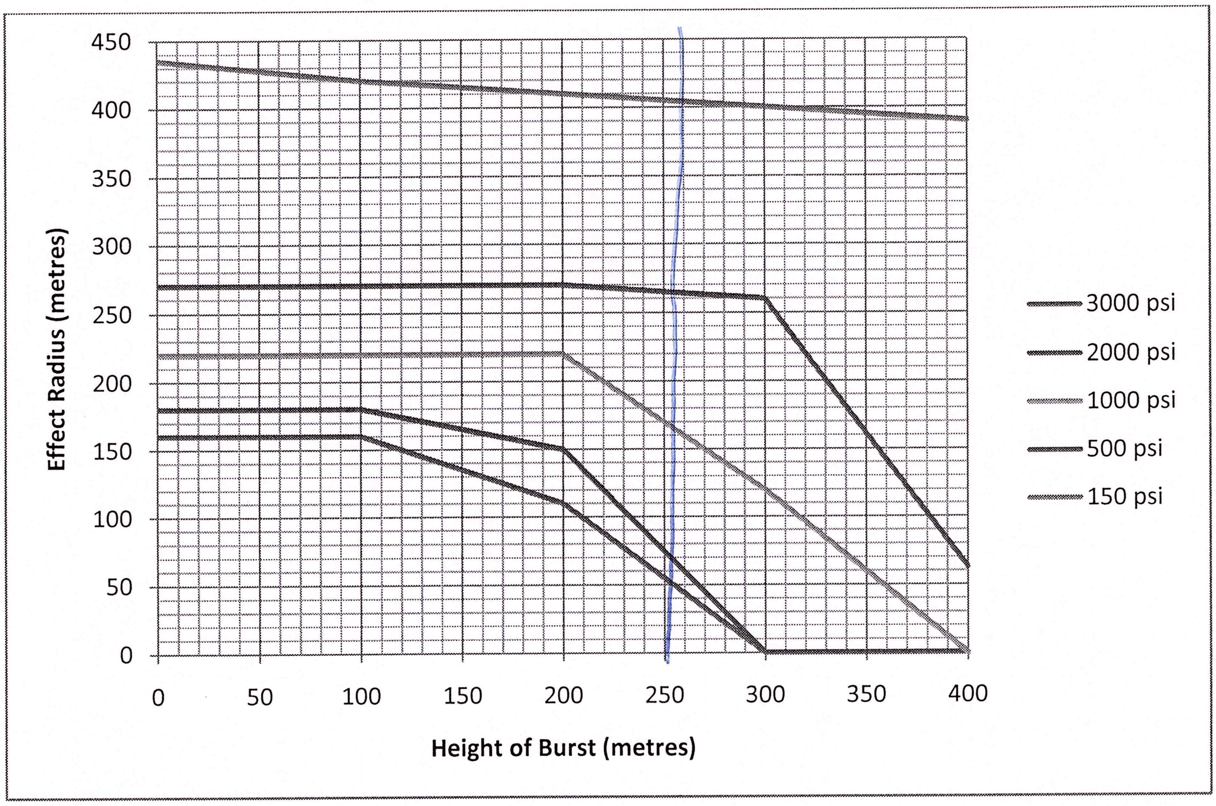
[46] http://www.osti.gov/bridge/servlets/purl/642714-4ocUvd/webviewable/642714.pdf
http://isandtcolloq.gsfc.nasa.gov/spring2002/presentations/knoll_4-30-02.pdf
[47] http://www.sandia.gov/mission/ste/capabilities/cap_cover.pdf
[48] http://isandtcolloq.gsfc.nasa.gov/spring2002/presentations/knoll_4-30-02.pdf
[49] http://www.sandia.gov/LabNews/LN04-20-01/labnews04-20-01.pdf
[50] http://www.sandia.gov/LabNews/LN07-23-04/labnews07-23-04.pdf
[51] Kansas City Plant Connections, March/April 2006,
http://www.honeywell.com/sites/servlet/com.merx.npoint.servlets.AttachmentServlet?annid=A9DCD085C-B0D7-DC6B-E753-4EED176DD533
[52] Survey of Weapons Developments p 566
[53] Survey of Weapons Developments p 566; The Burst Height Compensation patent shows that as an alternative to an accelerometer it would be possible to use several radar fixes.
[54] "The Mk5 radar operates at different frequencies than the Mk4 antennas are designed for. Whether it would be better for the new radar to operate at the Mk4 frequency (compatible with the Mk4 RB RF system) or operate at the Mk5 frequencies (compatible with the Mk5 radar, but not compatible with the Mk4 antenna cavity) has not yet been evaluated." Alternate Warhead Study p 7-45



The chart shows the effect radius for different psi values if a 100 kiloton warhead is detonated at different heights. It illustrates the range of hard targets that might be attacked with a near surface burst capability on the Mk4A.

One of the Measures of Effectiveness for the Mk4A RV on the Trident D5 missile in the 1994 report is a target with a VNTK value of 46L8. This is the rating for an SS-11 missile silo. The equivalent peak static overpressure for a 100 kiloton warhead is between 2,500 and 3,000 psi. As well looking at the effectiveness of various Mk4A warhead options against a 46L8 target the report also looked at their effect on a range of targets softer than 46L8 saying – "This represents a set of targets likely to be eligible for the Mk4A".[55] This suggests that an SS-11 silo is at the top end of the range of targets that a single Mk4A might be effective against. Russia withdraw all SS-11 missiles from service by 1996.

Development of follow-on AF&F

A 1997 timeline for the development of the AF&F for the W76 warhead indicates that this would be done in two stages - "The first iteration will be complete in 2006, and the second in 2011".[56] Work on a follow-on AF&F ~~may have~~ begun before the Mk4A was fully developed.

As the Mk4A AF&F was entering production the proposal for a new Reliable Replacement Warhead (RRW) ~~began to~~ be developed. In May 2005 the Kick-Off meeting for the RRW Project Officers Group (POG) said that for the Navy version of RRW – "the Mk4A AF&F will be used as it is".[57] Studies were

[55] Alternate Warhead Study p9-17
[56] Stockpile Life Extension Program, Albuquerque Workload Planning Guidance 98-0
[57] RRW POG Kick Off meeting minutes 11 May 2005

commissioned to consider what modifications might be required, particularly to adapt the Mk4A AF&F for the Mk5 RV. An early issue was to "Determine Mk4A AF&F radar performance in Mk5 shell".[58]

Although funding for RRW was withdrawn in FY2008 the Navy managed to retain $15 million from the RRW budget. This was partly for work on a follow-on AF&F. In FY2009 $13 million was withheld from RRW but use to fund research into integrated AF&F systems.[59]

[58] RRW 2nd POG meeting minutes June 2005

[59] The Reliable Replacement Warhead Program: Background and Current Developments, Jonathan Medalia, Congressional Research Service, 27 July 2009.

On 4 December 2009 the Defence Minister Bob Ainsworth admitted that three key components for Trident warheads are purchased from the United States – the Gas Transfer System, Neutron Generator and Arming, Fuzing and Firing System (AF&F). This follows an earlier acknowledgement by Des Browne on 28 March 2007 that the Mk4A AF&F was being introduced into the UK Trident warhead.

In the United States there have been a series of proposals over two decades to build new warheads for Trident. While these plans have been shelved, one related project has thrived. This is the design, development and production of a new AF&F to improve the capability of the existing W76 warhead.

Initial proposals to modify the Mk4 fuzing system

A presentation which lists the problems encountered with various components of nuclear warheads has the following entry beside MC2823 (the radar system for the Mk4 RV) –

> "customer preferred fuzing option"[60]

In his 1997 article, Rear Admiral P Nanos said:

> " ".[61]

This document shows a number of Research and Development programmes. "Fuze Modification" shows as a separate item from "Replacement W76 AF&F". A development study into fuze modification was scheduled for 1996 – 1998, followed by development in 1999 -2000, flight tests in 2000 and 2001, and production in 2001 – 2005.

<u>Incorporating Mk5 fuzing capability into the Mk4A</u>

The Mk4A AF&F was developed between July 1997 and September 2005.[62] From 1994 onwards had been planned that any proposed Mk4A AF&F would have a near surface burst capability. In 1999 the options of adding a proximity fuze and RUPL, as in the Mk5 RV, were being considered. Some technical details of the Mk4A AF&F are in the public domain. Unfortunately there is no direct

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[60] http://smaplab.ri.uah.edu/Smaptest/Conferences/lce/cieslak.pdf

[61] Rear Admiral P Nanos, Director of Strategic Systems Programs, US Navy, "Strategic Systems Upgrade" in the Submarine Review April 1997.

[62] Project details for W76 replacement AF&F, DOE science accelerator.

confirmation that the new system has a near-ground burst option, a proximity fuze or RUPL. What is available is information on the electronic hardware developed for the new fuzing system.

The accuracy of the electronic clock on the Mk4A will have improved from the Mk4 and Mk5.[63]

The new Arming Fuzing System for the Mk4A includes the radar, flight computer and diagnostics in one single assembly.[64]

It is reasonable to assume that with the improved radar, clock, accelerometer and computer the effectiveness of the warhead will be improved in a number of ways:

- *The accuracy of the radar fuze is probably improved*
- *The number of airburst radar height options could be increased*
- *A near surface burst option is likely*
- *A proximity fuze could be added*
- *A sophisticated fuzing system, such as RUPL, could be added*

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[63] The Mk4A has a Field Programmable Gate Array (FPGA) timer. http://prod.sandia.gov/techlib/access-control.cgi/2002/020253.pdf

[64] http://www.sandia.gov/LabNews/LN03-19-04/LA2004/Accomp_2004.pdf