Limitations of the Mk4 fuzing system

Description of the Mk4 fuzing system

The fuzing systems in the Mk4 RV are:

- Airburst Radar with 3 range options – this is the prime system
- G-started timer – this can be a prime or a backup
- Contact fuze – this is a backup [1]

The main system is the radar fuze. If this does not function then the contact fuze provides a backup. The contact fuze is designed to detonate when the RV touches the ground.

The g-started timer has an inertial sensor. This is triggered by the g-force when the RV re-enters the earth's atmosphere. The sensor starts a timer. The warhead can then be detonated a fixed time after re-entry. The g-switch is probably mechanical and so the g-started timer will not be very accurate.[2]

Mk4 RV on the Trident C4 and Trident D5 missile

The Mk4 RV was designed for the C4 missile (Trident I). This missile 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 than C4. It was designed to destroy Soviet SS-18 missile silos.[3] 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. So most US Trident D5 missiles are armed with the W76 warhead /Mk4 RV. The British Trident system was also designed around the W76/Mk4 system.

The accuracy figures for Trident C4 and D5 are classified. However there is a significant difference between the two. A study carried out in 1999 for the Mk4A upgrade used a measure of normalised effective Circular Error of Probability (CEP) which ranged from 1.0 to 2.5.[4] It is possible that the CEP of the C4 might be as much as 2.5 times greater than that of D5.

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[1] Survey of Weapon Developments and Technology, Sandia National Laboratory, February 1998, page 485.

[2] 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.

[3] 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

[4] Weapon Systems Requirement Analysis

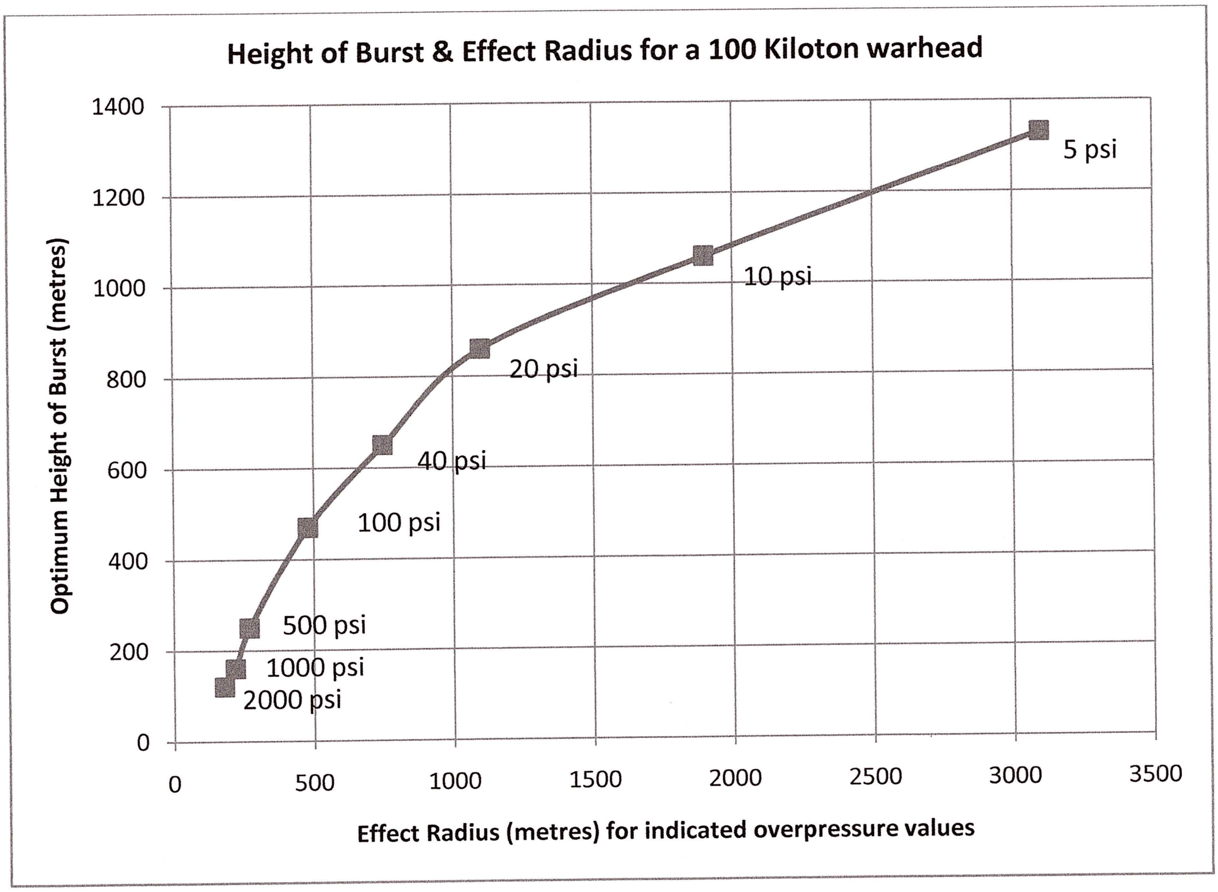
When combined with the more accurate D5 missile, the Mk4 RV has the potential to be effective against some hardened targets. But only if the fuze is altered. This is at the heart of the Mk4A upgrade plan.

Relationship between missile accuracy and height of burst

Modifying the AF&F does not alter the trajectory that the RV is on. But it can be used to adjust the point on the trajectory when the warhead detonates. In this way introducing a new fuzing system can make a warhead more effective.

One measure for determining the effectiveness of nuclear weapons against a variety of targets is peak static overpressure, in pounds per square inch (psi), produced by a nuclear explosion. 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.



The chart shows the effect radius for various overpressures and the optimum height of burst associated with this overpressure for a 100 kiloton warhead. [5]

In US nuclear planning, targets are not just assessed by overpressure (psi). Each type of target is given a VNTK rating. VN is the vulnerability number. T is a letter indicating the type of pressure. The basic values are calculated for a 20 kiloton warhead. K is an additional factor which indicates how much the effectiveness varies with higher yields.

In 1994 a study of alternative warheads for Trident was published. The effectiveness of the options was illustrated in a series of graphs. These have all been redacted, but some of the explanatory text has been published. The Measures of Effectiveness for the Mk4 RV on a C4 missile was target type 27P0. This is equivalent to around 150 psi overpressure. The accompanying text says:

> "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 [Systems Performance and Effectiveness Technical Working Group] considered it to be an important MOE [Measure of Effectiveness] for this system, and used it in their analysis".[6]

The Height of Burst setting on the Mk4 RV to attack 27P0 (150 psi) is probably between 300 m and 400 m.[7] 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.

This is consistent with an article written in 1997 by Rear Admiral P Nanos, the Director of Strategic Systems Programs, in which he says :

> "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." [8]

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"[9]

The 1994 study of alternative warheads for Trident proposed a number of options for a new Mk4A warhead.[10] It said:

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

[6] Joint DoD/DoE Trident Mk4/Mk5 Reentry Body Alternate Warhead Phase 2 Feasibility Study Report, January 1994. p 9-14

[7] Calculations carried out using Weapons Effects, LLNL.

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

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

"Effectiveness studies show significant value to new Mk4A height of burst options for capability against harder targets"[11]

"The SPETWG [Systems Performance and Effectiveness Technical Working Group] assumed that the HOBs [Heights of Burst] of a Mk4A would be changed from those of the W76/Mk4."[12]

The report 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".[13]

The important point is the addition of a "near surface burst" option. This was not originally available in the Mk4 AF&F.[14]

A near surface burst is "a detonation in the air that is low enough for the immediate fireball to touch the ground".[15] The radius of the fireball for a 100 kiloton warhead is around 250 metres.[16] So the proposal in 1994 was that the Mk4A would have a new fuzing option to enable the warhead to be detonated at a height of less than 250 metres.

Most of the options in the 1994 study required a new AF&F, but three options using the current AF&F (MC2912) were considered.[17] For the latter it was proposed that the fuze settings on MC2912 would be changed -

"The fuze settings in the existing [~~Mk4~~] AF&F are not optimal and changing these settings would improve the effectiveness of any of these candidates."[18]

In his 1997 article, Rear Admiral P Nanos said:

"With the accuracy of the D5 and Mk4, just by changing the fuze in the Mk4 reentry body, you get a significant improvement."[19]

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

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[10] Alternate Warhead Study. In this study Mk4A is used for an RV with an alternative warhead, whereas the current Mk4A is based on the existing warhead.

[11] Alternate Warhead Study pdf page 28

[12] Alternate Warhead Study p 9-10

[13] Alternate Warhead Study Appendix B page 8. This paragraph is marked Secret (SFRD) but is printed in full without any redactions.

[14] Survey of Weapon Developments page 485

[15] Nuclear matters A Practical Guide, Department of Defence, 2008, http://www.acq.osd.mil/ncbdp/nm/nmbook/references/NM_APracticalGuide.pdf

[16] 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

[17] 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.

[18] Alternate Warhead Study, page 7-43

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

"Fuze modification evaluation to enable W76 to take advantage of higher accuracy of D5 missile." [20]

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.

Incorporating Mk5 fuzing capability into the Mk4A

Description of Mk5 fuzing system

The Mk5 RV, which was designed for the D5 missile, has a more sophisticated and accurate fuzing system than the Mk4. The sub-systems available in the Mk5 are:

- Airburst Radar with 5 range options
- Proximity Radar ~~(see below)~~
- Timer – for high airburst
- Path Length – also described as inertial airburst
- Radar-Updated Path Length – this is the main option
- Contact Fuze – this is a backup

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

Proposals to incorporate the capability of the Mk5 AF&F into the Mk4 RV

A key aspect of the Mk4A upgrade has been to incorporate the technology of the Mk5 AF&F into the Mk4 RV. From 1995 this was pursued by the SLBM Warhead Protection Program (SWPP). At an early stage of this program Strategic Command were asked to compare the effectiveness of proximity and RUPL options for the Mk4.[21]

One of the goals of the SWPP was:

"Minimise changes to the functional interface of the Mk4 to allow for Mk5 functionality and Mk5 nuclear safety implementation".[22]

In 1997 one of the key areas of development for the W76 warhead was:

"Study underway to implement capability of W88/Mk5 AF&F into W76/Mk4 volume"[23]

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

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

[22] http://portal.unesco.org/en/files/5813/10312388001SCIENCEFORPEACE8light.pdf/SCIENCEFORPEACE8light.pdf

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

Sandia Laboratory's Survey of Weapons Developments in 1998 has a chart headed "fuzing options for replacement Mk4 AF&F". This includes two arrows pointing to Mk5. One says "dependable surface fuzing" (suggesting a proximity fuze) and the other says "new fuzing option for Mk4" (this could refer to near-surface burst or RUPL).[24]

In 1999 the Department of Energy's Stockpile Stewardship master plan says –

> "[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."[25]

Surface burst fuzing

One way to attack a hard target, like a missile silo, is to detonate the warhead on the surface. This can be more effective than an airburst. The original Mk4 RV has a contact fuze. However this was intended to be a backup rather than a prime fuzing system. In addition there are a number of concerns about the effectiveness of contact fuzes on ICBM and SLBM.

One problem is that there ~~can be~~ ~~no alternative~~ or backup if the contact fuze fails. If two fuzing systems are used in tandem the probability of the warhead detonating is significantly higher than if there is only one fuze.

And there are other concerns. A survey of nuclear weapons developments published in 1998 has the following table:[26]

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 prove that the component itself is reliable.

Many of the subsequent pages in this report have been completely redacted. Some of those which have been published show computer generated forests and trees.[27] One graph is titled "conditional probabilities of tree impacts on Reentry Vehicle Surface". The RV could encounter a variety of uneven surfaces, of which trees are only one example, which can reduce the probability that the contact fuze will detonate.

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[24] Survey of Weapon Developments p565
[25] Greg Mello That Old Designing Fever, Bulletin of Atomic Scientists, Jan/Feb 2000
[26] Survey of Weapons Developments p 509
[27] Survey of Weapons Developments p536-539

The report lists the disadvantage of contact fuzes. One of these is - "Dependability concerns (system reliability)".[28] These concerns cannot be addressed by modifying the design of the contact fuze. Such alterations would provide "little, if any, additional protection against impact irregularities".[29]

The solution 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".[30] It gives "adequate survivability for all impact scenarios".[31]

At one point this report uses the term "Proximity radars (prox time-down)".[32] This suggests that the fuzing system may use a combination of radar and timer to detonate the warhead very close to the surface.

The ground shock from using a proximity fuze would be very similar to that from using a contact fuze.[33] The proximity fuze detonates the warhead 6 metres above the surface. So, according to this report, radar proximity fuzing results in "little, if any, degradation in burst height effectiveness".

Proximity fuzing was also considered when the USAF was developing proposals for the Small ICBM missile:

> "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."[34]

This suggests that, in addition to the problems of unpredictable terrain, a contact fuze may be less reliable in certain re-entry conditions. This may be because the impact velocity varies substantially depending on the trajectory.

The Small ICBM report continues:

> "In October 1989 the Air Force directed the Peacekeeper program office to develop a reliable proximity fuze and the Small ICBM program office to retain the ability to use that fuze. Department of Energy officials advised us that a reliable proximity fuze is needed for both the Peacekeeper and the Small ICBM missiles."[35]

With regard to Trident D5, 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. It has a "smart" proximity fuze that can "adjust burst height based on local terrain topography and RV deceleration rate".[36]

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[28] Survey of Weapons Developments p508
[29] Survey of Weapons Developments p540
[30] Survey of Weapons Developments p490
[31] Survey of Weapons Developments p540
[32] Survey of Weapons Developments p485
[33] Survey of Weapons Developments; The ~~same~~ diagram is also ~~an illustration~~ in Ground Shock from Earth Penetrator Weapons, Paul Yarrington, Sandia, November 1988, p21.
[34] http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA245542&Location=U2&doc=GetTRDoc.pdf
[35] http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA245542&Location=U2&doc=GetTRDoc.pdf
[36] Swords of Armageddon, Chuck Hansen, Vol 7, p 431, quoting Sandia Lab News, 24 Feb 1989.

Radar Updated Path Length Fuze

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

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. RUPL is a "compensating fuze". It can "adjust the fuzing system to make up for targeting inaccuracies".[37]

In 1982, while the Mk5 was being designed, the US Navy filed a patent for the "Burst Height Compensation" system for an SLBM ~~system~~.[38] 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 caused by factors such as wind and air density. 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 the point of re-entry with an accelerometer. A height fix from the radar enables the onboard computer to calculate the downrange deviation from the nominal trajectory.

The components of the Mk5 fuzing system include:

- A Force Balanced Integrating Accelerometer (FBIA) (MC3817)
- A radar system (MC3812)
- An onboard computer (MC3811)
- Electronic clock (MC3827)

<u>Mk4A fuzing system</u>

Impact of new technology

The Mk4A AF&F was developed between July 1997 and September 2005.[39] 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 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.

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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[37] Swords of Armageddon, Chuck Hansen, Vol 7, p 430, quoting Sandia Lab News, 31 Jan 1986
[38] Burst Height Compensation US Patent 4456202
[39] Project details for W76 replacement AF&F, DOE science accelerator.

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.[40]

Between 1999 and 2003 Sandia developed the CMOS7r radiation-hardened Silicon-on-Insulator (SOI) processor.[41] CMOS7r processors are used in the Permafrost Integrated Circuit which was developed for the Mk4A AF&F. Permafrost has been described as "the brains of the W76-1 warhead".[42] These circuits are used in the radar Digital Signal Processor, the main logic board and the driver.

One reason that the Mk5 AF&F is more advanced than the old Mk4 is because of its computing system. But by today's standard the computer in the Mk5 is very basic. For example the programmer in the Mk5 AF&F has only 2 Kb of SRAM memory.[43] The circuits in the Mk4A probably each have 500 times more memory, with at least 1 Mb SRAM.

A new Digital Signal Processor was developed for the radar on the Mk4A.[44] This will have transformed the radar's capability. There may also have been changes to the analogue elements - in 2006 the Kansas City Plant was asked to produce new "RF power amplifier transistors to support the W76 radar transmitter".[45]

A diagram of the fuzing system proposed for the Mk4A shows that the intention was to include Force Balanced Accelerometer (FBA).[46] The accuracy of the electronic clock on the Mk4A will have improved from the Mk4 and Mk5.[47]

The new Arming Fuzing System for the Mk4A includes the radar, flight computer and diagnostics in one single assembly.[48]

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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[40] http://www.osti.gov/bridge/servlets/purl/642714-4ocUvd/webviewable/642714.pdf
http://isandtcolloq.gsfc.nasa.gov/spring2002/presentations/knoll_4-30-02.pdf

[41] http://isandtcolloq.gsfc.nasa.gov/spring2002/presentations/knoll_4-30-02.pdf

[42] http://www.sandia.gov/mission/ste/capabilities/cap_cover.pdf

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

[44] http://www.sandia.gov/LabNews/LN07-23-04/labnews07-23-04.pdf

[45] Kansas City Plant Connections, March/April 2006, http://www.honeywell.com/sites/servlet/com.merx.npoint.servlets.AttachmentServlet?annid=A9DCD085C-B0D7-DC6B-E753-4EED176DD533

[46] Survey of Weapons Developments p566; The Burst Height Compensation patent shows that as an alternative to an accelerometer it would be possible to use several radar fixes.

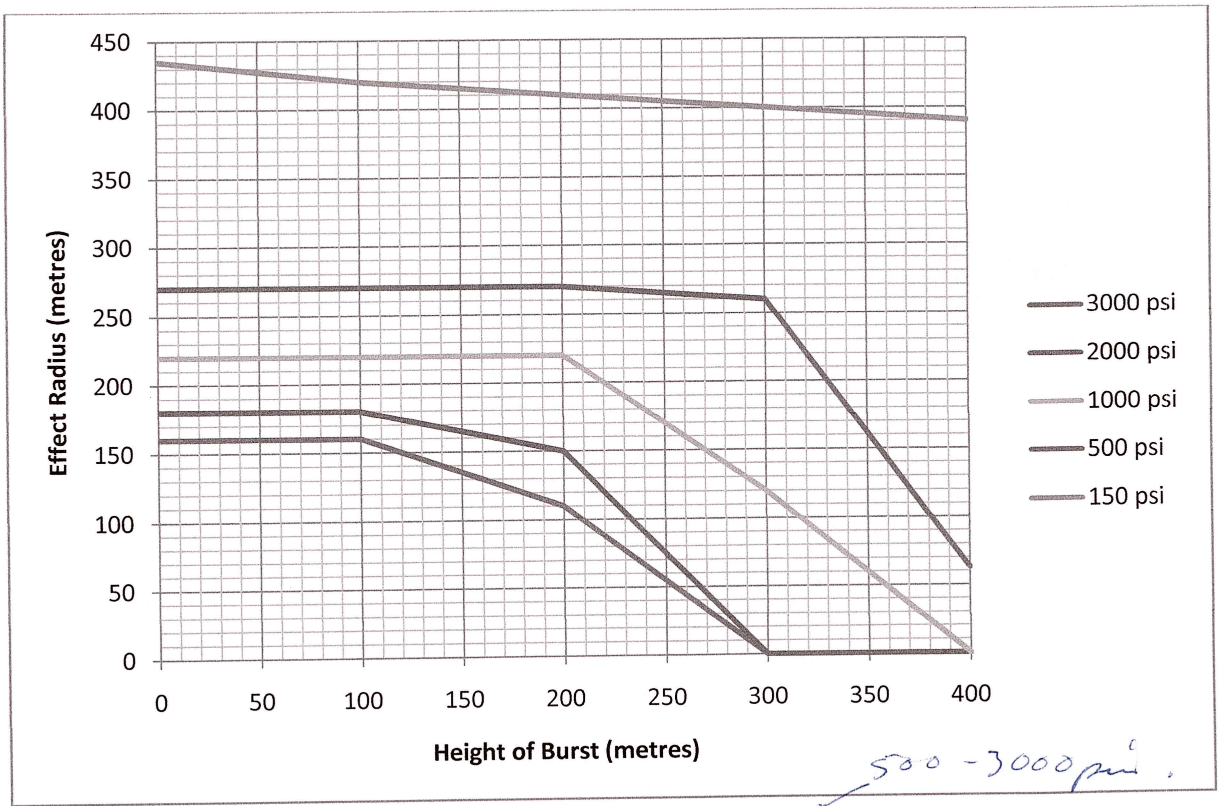
[47] The Mk4A has a Field Programmable Gate Array (FPGA) timer. http://prod.sandia.gov/techlib/access-control.cgi/2002/020253.pdf

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

One issue may be the antenna on the Mk4 RV. This operates at different frequencies from the Mk5. The review of warhead options in 1994 pointed out that this would have to be addressed in the design of the radar system for the Mk4A:

> "The new AF&F is based on the radar technology from the W88. 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."[49]

Targets vulnerable to Mk4A but not Mk4



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. This would allow the warhead to be detonated closer to the ground than the fireball radius of around 250 metres. It suggests that to be effective against targets in the 2000 – 3000 psi range the Height of Burst would have to be lowered to 100 metres.

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

[49] Alternate Warhead Study p 7-45f

eligible for the Mk4A".[50] 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.

Name the ICBM
A v Storage
SS11 LCC
Command links

The Measures of Effectiveness used in the 1994 study of warhead options indicate the targets that might be attacked by the Mk4, Mk4A and Mk5 RVs respectively. The criteria for the Mk5 options were based on the design requirement of the Mk5/W88 to attack SS-18 silos. These silos had initially been assessed at 7,000 psi and given a VNTK rating of 52L7. They were later found to be significantly harder and a higher rating of 64L9 was introduced. The effectiveness of Mk4A against either of these targets was not assessed and it is assumed that the Mk4A is not considered to be effective, at least in terms of Single Shot Kill Probability (SSPK).

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[50] Alternate Warhead Study p9-17

Fuze modification and replacement AF&F

The 1997 review of Stockpile Stewardship and Management has a timeline which shows two W76 items separately. One is "Fuze Modification" and the second, a subheading of SWPP, is a replacement AF&F.[51] For the Fuze Modification there would be a development study in 1996 - 98, development in 1999-2000 and production in 2001 – 2005. One development flight test was scheduled in 2000 and a second in 2001. For the replacement W76 AF&F there would be advanced development in 1996 – 2002 with flight tests in 2001 and 2002. The relationship between these two items is not entirely clear.

In a statement to the Senate Armed Services Committee in 2004, Rear Admiral Young said:

> "There are technical and programmatic issues that require both a refurbished warhead and a refurbished fuze for the W76/Mk4. The Department of Energy and the Navy are executing a refurbishment program for the W76/Mk4 reentry body. The Navy's refurbishment of the W76/Mk4 fuze is supported in the Navy's FY 2004 WPN budget request."[52]

The separation of the items in the 1997 report may be due to the fact that the fuze replacement was a Navy rather than an NNSA project. Unfortunately there is no explicit reference to this in the Weapons element of the US Navy's budget for FY2004, although there are items both for Trident and Trident Modification.

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

[52] Statement by Rear Admiral Charles B Young, Director, SSP, Strategic Subcommittee of the Senate Armed Services Committee 8 April 2003. http://www.globalsecurity.org/wmd/library/congress/2003_h/youngcharles.pdf