

# CONCLUSIONS AND POLICY RECOMMENDATIONS

In Chapter Four, we analyzed the consequences of a major counterforce attack on Russia's nuclear forces using approximately 1,300 U.S. nuclear weapons. We concluded that such an attack would result in 11 to 17 million casualties, the majority of which are fatalities, depending upon the time of year. It should be emphasized that 1,300 weapons is well below the START II limit of 3,000 to 3,500, and the proposed START III limit of 2,000 to 2,500 but nevertheless represents a formidable counterforce capability.

Rather than continue with the established pattern of bilateral arms negotiations, the Bush administration has opted to act unilaterally to reduce the number of deployed strategic weapons.<sup>1</sup> Candidate Bush's May 23, 2000 speech on national security issues is the most detailed statement to date and deserves quoting at length.

*Russia itself is no longer our enemy. The Cold War logic that led to the creation of massive stockpiles on both sides is now outdated. Our mutual security need no longer depend on a nuclear balance of terror.*

*The premises of Cold War nuclear targeting should no longer dictate the size of our arsenal. As president, I will ask the Secretary of Defense to conduct an assessment of our nuclear force posture and determine how best to meet our security needs. While the exact number of weapons can come only from such an assessment, I will pursue the lowest possible number consistent with our national security. It should be possible to reduce the number of American nuclear weapons significantly further than what has already been agreed to under START II, without compromising our security in any way. We should not keep weapons that our military planners do not need. These unneeded weapons are the expensive relics of dead conflicts. And they do nothing to make us more secure.*

*In addition, the United States should remove as many weapons as possible from high-alert, hair-trigger status—another unnecessary vestige of Cold War confrontation. Preparation for quick launch—within minutes after warning of an attack—was the rule during the era of superpower rivalry. But today, for two nations at peace, keeping so many weapons on*

*high alert may create unacceptable risks of accidental or unauthorized launch. So, as president, I will ask for an assessment of what we can safely do to lower the alert status of our forces. These changes to our forces should not require years and years of detailed arms control negotiations. There is a precedent that proves the power of leadership. In 1991, the United States invited the Soviet Union to join it in removing tactical nuclear weapons from the arsenal. Huge reductions were achieved in a matter of months, making the world much safer, more quickly.<sup>2</sup>*

A year later, President Bush gave a speech at the National Defense University that repeated many of those themes.<sup>3</sup> He spoke of “a vastly different world,” in which “today’s Russia is not our enemy.”

Bush has also made proposals that promise to complicate the quest for deep nuclear arms reductions. These mainly have to do with plans to develop and deploy a National Missile Defense system, which means the inevitable abandonment of the ABM Treaty. We will address these proposals at the end of this chapter, but first let us examine the issue of how far initial unilateral reductions can take us without undue risk to the United States.

*The bottom line is that approximately one-third of Russia’s citizenry become casualties from an attack with only 150–200 warheads.*

If the Bush administration chooses to reduce deployed nuclear forces to about 1,500 warheads there are certain attack options that the U.S. will not be able to carry out. At that level, the U.S. could no longer simultaneously attack Russia’s nuclear forces, Russian conventional forces, high-level civilian and military leadership bunkers, and the war support industrial infrastructure. While the U.S. would not have enough warheads to execute these different types of strikes, it could still muster a formidable counterforce capability. While it would be giving up something, it would still keep quite a bit.

Why stop at 1,500 warheads? In Chapter Five we presented two countervalue scenarios. The first used the warheads aboard just a single Trident submarine to attack Russian cities, and this attack resulted in 30 to 45 million casualties. The second scenario used 150 Minuteman III ICBMs in a similar attack on Russian cities with 40 to 60 million casualties. In both instances, the majority of the casualties were fatalities. The Trident attack produced fewer casualties, with more warheads, because the targeting “footprint” is more limited. The bottom line is that approximately one-third of Russia’s citizenry become casualties from an attack with only 150–200 warheads. Obviously, through the choice of targets, the United States can hold at risk any number of Russian citizens from zero up to these egregiously high levels with only a few hundred strategic nuclear warheads.

The argument is made in some quarters—including at Strategic Command (STRATCOM)—that directly attacking or holding at risk innocent citizens in urban centers is immoral, while an attack on military forces is less so. As we have shown, because of the indiscriminate nature of the weapons involved, millions of people near military targets will be killed or wounded—what STRATCOM refers to as “collateral damage.” This kind of logic leads to the conclusion that China should improve and expand its arsenal from a few hundred warheads to a few thousand so as to capture the high moral ground.

## **RECOMMENDATIONS**

Fortunately there are better options. We recommend the following.

### **1. Unilaterally reduce U.S. nuclear forces and challenge the Russians to do the same.**

As a first step, we should unilaterally reduce the U.S. strategic arsenal to a few hundred survivable nuclear warheads, and challenge the Russians to do the same. The United States would still have a more than adequate nuclear deterrent while we waited for Russia to act. Regardless of our actual targeting policy, under their worst-case planning assumptions, our friends in Russia would know that our weapons hold millions of people at risk.

### **2. Clarify the U.S. relationship with Russia and reconcile declaratory and employment policy.**

We also recommend a step that derives directly from our findings in this report. We stress the fact that the act of targeting an individual, a group, or a nation defines it as an enemy. It is this first step that we must reverse. We do not target friends or allies—Canada, Britain, Italy, for example—but we do target Russia, China, and several others. The United States still seems to be confused about our relationship to Russia. In his speech at the National Defense University, President Bush said, “Today’s Russia is not our enemy.” But our actions with regard to nuclear war planning project the exact opposite implication and assumption. If our words and our actions are to correspond, then it is obvious that changes must take place in the way the United States postures its forces and plans for their use. Having a permanent war plan in place that demands widespread target coverage with thousands of weapons on high-alert is a recipe for unceasing arms requirements by the Pentagon and a continuing competition with Russia. It is for this reason that we conclude that the overambitious war plan is the key source of the problem.

### **3. Abandon much of the secrecy that surrounds the SIOP and reform the process.**

A corollary problem with the war plan is the high level of secrecy that surrounds it. Because the guidance and the SIOP are so closely guarded, no one can question the assumptions or the logic. The fact that USSTRATCOM has responsibility for drawing up the target list and the plans only contributes to this secrecy. We recommend a change in this procedure. The Omaha nuclear-war-planning function should be brought to Washington and handled by a joint civilian-military staff with Congressional involvement.

### **4. Abolish the SIOP as it is currently understood and implemented.**

Having a permanent war plan in place that demands widespread target coverage with thousands of weapons on high alert is a recipe for open-ended arms requirements by the Pentagon and a continuing competition with Russia and others. It is for this reason that we conclude that the over-ambitious war plan is a key obstacle to further deep arms reductions. The current SIOP is an artifact of the Cold War that has held arms reduction efforts hostage. It is time to replace it with something else.

**5. Create a contingency war planning capability.** We recommend that the war planning functions be handled more like those for conventional forces. The United States should not target any country specifically but create a contingency war planning capability to assemble attack plans in the event of hostilities with another nuclear state. Given the much-reduced set of requirements, the plans should be adequate for any conceivable situation. The new paradigm alleviates the need for large numbers of weapons, and for keeping many of them at high levels of alert. The new approach defuses the implications that go with targeting and would help break the mind-set of the Cold War. We are in agreement with President Bush when he says that we must get beyond the Cold War. We feel though that his approach is not the “clear and clean break with the past” that he hopes for. Instead, by assuming a wider range of uses for nuclear weapons (to counter “new emerging threats”), by making space a theater for military operations, and by considering new or improved warheads for a future arsenal, President Bush is offering more of the same.

*It is highly likely that going forward with a missile defense system will have widespread ramifications, including the obvious response of causing certain nations to build more offensive weapons to overwhelm the defense.*

**6. Reject the integration of national missile defense with offensive nuclear deterrent forces.** The Bush administration spokesmen pay little regard to domestic or international criticism of their ideas and policies for ballistic missile defense, and tend to downplay them. In his confirmation hearing, Secretary of Defense Donald Rumsfeld dismissed the ABM Treaty as “ancient history,” and a “straightjacket” that limits the choices that America might or must take. If the shoe were on the other foot, it is doubtful that the United States would stand idly by and do nothing if faced with a similar situation. From the Bush perspective, other nations are expected to be calmed by mere pronouncements that we intend no harm, and therefore no one should worry about what we do.

In fact, it is highly likely that going forward with a missile defense system will have widespread ramifications, including the obvious response of causing certain nations to build more offensive weapons to overwhelm the defense. The logic is as old as warfare itself and was the dynamic that the original ABM Treaty was intended to prevent. Prudent military planners, wherever they are, plan on the basis of capabilities rather than intentions, which are much harder to divine. Actions and hardware speak louder than words when militaries view one another. Russian generals and admirals, like our own, build their assumptions on a worst-case analysis. The statement by Admiral Mies could just as easily have been said by his Russian counterpart: “Our force structure needs to be robust, flexible and credible enough to meet the worst threats we can reasonably postulate.” From the Russian vantage point, the planners must assume that defense and offense are integrated. The Russians have threatened to renege on several agreements if the United States withdraws from the ABM Treaty, an action not without consequence.<sup>4</sup> For example, the START II Treaty bans MIRVed ICBMs, a positive security advantage for the United States. If the United States proceeds to withdraw from the ABM Treaty, it is likely that Russia would retain its present force of MIRVed ICBMs and possibly even MIRV a single-warhead missile like the SS-27.

A similar situation would confront China, which has long had the ability to put multiple warheads on its ballistic missiles and has chosen not to do so. Currently only a small number, less than two-dozen, Chinese single-warhead missiles can reach the United States. A guaranteed way to increase that number would be for the U.S. to deploy a missile defense system.<sup>5</sup>

Proceeding with national missile defense could create a domino effect. After China reacted to the United States, then India might react to China, and Pakistan might react to India, each building more weapons than they otherwise would. The Bush administration has not addressed how all of this increases U.S. security—even granting the formidable technological hurdles to be overcome to make the system work. The fact of the matter is that pursuit of a defense system is more likely to reduce the security of the United States than enhance it.

It is sometimes made to seem that a shift to defense will supplant deterrence, but this does not seem to be the case according to officials of the new administration. According to remarks made by Secretary Rumsfeld, and reported in *Aviation Week & Space Technology*, his objective is to strengthen the strategic psychology that underlies the ancient precepts of deterrence.<sup>6</sup>

*By strategic psychology, he [Rumsfeld] means re-fashioning deterrence to preempt war and aggression of all kinds, before the mentalities and conditions that lead to conflict crystallize. Deterrence, by this reasoning, is less a matter of deploying missiles and warheads than understanding an opponent's attitudes, psychology and national character.*

As he told the Senate committee in his confirmation hearing:

*Credible deterrence no longer can be based solely on the prospect of punishment through massive retaliation. It must be based on a combination of offensive nuclear and non-nuclear defensive capabilities, working together to deny potential adversaries the opportunity and the benefits that come from the threat or the use of weapons of mass destruction (WMD) against our forces [and] our homeland, as well as those of our allies.*

Punishment through massive retaliation of course dates from the Eisenhower administration and has not been our policy for decades, though punishment by selective retaliation has been. Rumsfeld does grant that punishment will remain a component of deterrence. What is different is that it will now be integrated with a defense against missiles. What kind of defense this will be remains an open question, but almost any sort will elicit a response. The technological problems of deploying a workable system are formidable, as other analysts have concluded. Countermeasures are fairly simple to develop and use to overwhelm a defense.<sup>7</sup> More than likely, an attack on the United States using WMD, by terrorist groups or countries other than Russia or China, would probably not be delivered by ballistic missiles, but by cruise missiles or smuggled weapons. In summary, proceeding ahead with a defensive system seems premature until the basic questions of the seriousness and nature of the threat, the cost, the impact on allies and adversaries, and whether the system would work have been answered.

Though packaged as something new, the Bush administration's plans for missile defense are hardly novel and are not the "clear and clean break from the past," to use the President's words. Something more fundamental must occur in order to create real change. As we have seen through our nuclear war simulation model, the place to begin is with an examination of the SIOP war plan and the assumptions upon which it is built.

## APPENDIX A

### *Functional Classification Codes*

These codes were developed as part of the U.S. Intelligence Data Handling System (IDHS) for use in the MDIB, NTB, JRADS and other government databases. Source, Reporting Manual for Joint Resources Assessment Database System (JRDS), (Washington, D. C, Joint Chiefs of Staff, March 15, 1999).

#### **Category    Category Code**

201 00	<u>Atomic energy feed materials</u>
201 10	Uranium metal production
204 00	<u>Moderator materials production</u>
204 10	Heavy water, deuterium oxide
204 20	Synthetic graphite, pile grade
204 30	Beryllium, pile grade
211 00	<u>Petroleum product plants, crude</u>
211 10	Refineries, thermal or catalytic plants
215 00	<u>Pipeline support for petroleum and gaseous fuels, general</u>
215 10	Pipeline support for petroleum and gaseous fuels, pump stations for liquid petroleum
215 20	Pipeline support for petroleum and gaseous fuels, compressor stations for natural gas
218 00	<u>Petroleum product storage</u>
218 10	Civilian/industrial utilization
218 20	Military utilization
218 30	Joint civilian/military utilization
221 00	<u>Light metal and light metal alloys</u>
221 10	Aluminum
232 00	<u>Iron and iron castings</u>
232 10	Iron, pig
233 00	<u>Steel</u>
233 10	Steel production, open hearth furnace shops
233 20	Steel production, basic oxygen furnace (BOF) shops
233 30	Steel production, electric arc furnace shops
234 00	<u>Processed and finished steel products</u>
234 10	Steel processing (roughing) mills
234 20	Basic steel rolling mills
241 00	<u>Aromatic hydrocarbons production, general</u>

<b>Category</b>	<b>Category Code</b>
	241 10 Crude or refined benzene production
	241 20 Toluene production
	243 00 <u>Aromatic hydroxyl production, general</u>
	243 10 Phenol production
	251 00 <u>Sulfuric acid and metallic sulfates production, general</u>
	251 10 Sulfuric acid production
	251 20 Metallic sulfates
	252 00 <u>Ammonia, nitric acid, and nitrates</u>
	252 10 Ammonia
	252 20 Nitric acid
	252 30 Nitrates
	253 00 <u>Hydrochloric acid and chlorides production, general</u>
	253 10 Hydrochloric acid production
	253 20 Chlorine dioxide, chloride, chlorate, chlorite, perchlorate, chloric, hypochlorite, hypochlorous, chlorous compound production, general
	254 00 <u>Gaseous chemical products production, general</u>
	254 12 Argon liquid state
	254 20 Chlorine production
	254 30 Helium, specific state unknown
	254 40 Hydrogen, specific state unknown
	260 00 <u>Monomers, manmade fibers, filaments, polymers, resins, and pesticides, general</u>
	261 00 Monomers Production
	262 00 <u>Manmade fibers (filaments) production</u>
	263 00 <u>Thermoplastic polymers and resins production</u>
	264 00 <u>Thermosetting polymers (resins)</u>
	264 10 Synthetic rubbers (elastomers) production
	265 00 <u>Composite plastics, general</u>
	401 00 <u>Basic and applied nuclear research and development</u>
	401 10 Basic nuclear research laboratories
	402 00 <u>Aircraft research</u>
	402 10 Aircraft research, airframe

**Category    Category Code**

402 20	Aircraft research, aircraft engine
402 30	Airframe component research
402 40	Aircraft engine component research
403 00	<u>Electronic and communication research, general</u>
403 40	Radar equipment, all types
403 60	Computers
403 70	Electronic countermeasures
403 80	Electro-optical, including lasers and infrared devices
403 90	Miscellaneous Electronics
404 00	<u>Ordnance research and development</u>
404 10	Armored vehicle research, development, and/or testing
404 20	Artillery research, development, and/or testing
404 40	Munitions research, except underwater
404 50	Aerial bomb research
404 60	Explosives research, development, and/or testing
404 70	Underwater ammunition, research
405 00	<u>Chemical warfare and biological defense research</u>
405 10	Chemical warfare research
405 20	Biological defense research
406 00	<u>Shipbuilding research and development, general</u>
406 50	Shipbuilding equipment, ship repair yard equipment, and shipbuilding materials research and development
408 00	<u>Guided missile and space system research, development, and testing</u>
408 10	Guided missile and space system, airframe development and testing
408 20	Guided missile and space system, propulsion equipment development
408 30	Guided missile and space system, guidance and control equipment development
408 50	Guided missile and space system, propulsion-testing facilities (hot firing stands)
408 70	Guided missile and space system, propellant research
409 00	<u>General research institutes</u>
409 30	General research institutes supporting military associated research and development
41x xx	<u>Communications facilities, transmission, and reception</u>
411 21	Radio relay terminal
411 4x	Satellite ground station

<b>Category</b>	<b>Category Code</b>
	414 30 Multipurpose switching center
	419 00 <u>Special purpose, communications-electronics facilities, general</u>
	419 10 Special purpose, strategic connectivity locations
	419 20 Special purpose, national government control locations
	42x xx <u>Electric power plants and distribution facilities</u>
	420 00 <u>Electric power plants, general</u>
	421 00 Thermal electric power plants, non-nuclear
	421 10 Thermal electric power plants, steam turbine
	421 40 Thermal electric power plants, nuclear
	421 90 Thermal power plants, combination
	422 00 <u>Hydroelectric power plants</u>
	431 10 Desalination facilities
	439 00 <u>Dams</u>
	44x xx <u>Road and water transportation</u>
	441 00 <u>Bridges, highway (including viaducts, trestles, and grade separations)</u>
	441 20 Bridges, highway
	442 00 <u>Tunnels, highway</u>
	444 00 <u>Piers and Docks</u>
	445 30 Highway crossing a dam
	447 00 <u>Lines of communication, highway</u>
	45x xx <u>Railroad tracks and yards</u>
	451 00 <u>Bridges, railroad (including viaducts, trestles, and grade separations)</u>
	451 10 Bridges, railroad
	452 00 <u>Tunnels, railroad</u>
	452 10 Tunnels (except underwater)
	452 20 Tunnels (underwater)
	453 00 <u>Railroad yards</u>

**Category    Category Code**

453 10	Classification yards
453 20	Freight terminals
455 00	<u>Railroad crossing a dam</u>
456 00	<u>Facilities for repair of railroad equipment</u>
457 00	<u>Lines of communication, railroad</u>
459 00	<u>Rail transport facilities</u>
459 20	Freight terminals (interface)
459 70	Traffic control and communications facilities
459 71	Centralized train control
459 72	Computer
459 80	Interlocking
461 20	Inland locks and canals
471 00	<u>Channel overpasses, locks, overhead canals, and aqueducts</u>
474 00	<u>Port facilities</u>
5xx xx	<u>Industrial/economic</u>
520 00	<u>Communication and electronic equipment</u>
521 40	<u>Radar production, all types</u>
522 00	<u>Electronic components production</u>
522 30	Microelectronics components/semiconductor production
523 00	<u>Computer equipment production</u>
524 00	<u>Electronic countermeasures, (ESM), counter-countermeasures, (ECCM), and electronic support measures, (ESM) equipment production</u>
525 00	<u>Electro-optical equipment production [excludes television]</u>
525 10	Laser weapons production
525 20	Nonweapon lasers production [includes rangefinders, target designators, and industrial lasers]
525 30	Infrared devices production [includes night vision and heat seekers]
526 00	<u>Miscellaneous electronics equipment production</u>

<b>Category</b>	<b>Category Code</b>
	526 10 Navigation equipment production
	526 20 Hydroacoustic equipment production
	60x xx <u>Nuclear industry</u>
	601 00 <u>Production reactors</u>
	601 10 Nuclear materials production reactors
	601 40 Nuclear fuel processing facilities
	601 41 Nuclear fuel processing facilities, weapons use
	601 42 Nuclear fuel processing facilities, non-weapons use
	602 00 <u>Isotope separation and production facilities</u>
	602 10 U-235 isotope separation, gaseous diffusion
	602 50 Lithium-isotope separation
	603 00 <u>Nuclear weapon fabrication</u>
	604 00 <u>Nuclear weapons storage</u>
	604 20 Nuclear weapons storage site, operational
	611 00 <u>Airframe production and final assembly of finished aircraft</u>
	611 10 Fighters
	611 20 Reconnaissance aircraft production and assembly
	611 30 Bombers production and assembly
	611 40 Helicopters
	611 50 Transport aircraft production and assembly
	611 70 Communications/utility aircraft production and assembly [includes liaison, observation, light civilian aircraft and gliders.]
	611 80 Trainer aircraft production and assembly
	612 00 <u>Aircraft engine production and assembly, general</u>
	612 40 Gas turbine aircraft engines production and assembly
	621 00 <u>Small arms and automatic weapons through 19MM</u>
	622 00 <u>Artillery and naval ammunition, 20mm and larger</u>
	623 00 <u>Mortar ammunition</u>
	624 00 <u>Free (unguided) rockets</u>
	625 00 <u>Aerial bombs, except depth charges</u>
	626 00 <u>Underwater ammunition production</u>

**Category    Category Code**

626 10	Depth charges
626 20	Special antisubmarine ammunition
626 40	Sea mines
626 50	Torpedoes
627 00	<u>Missile warheads production</u>
632 00	<u>Weapons production, 20mm and larger, general</u>
633 00	<u>Mortars</u>
634 00	<u>Artillery, over 70mm</u>
635 00	<u>Rocket and grenade launchers</u>
641 00	<u>Motor vehicle production, general [excludes motorcycles]</u>
641 11	Truck production (up to 7 metric tons)
641 12	Truck production (7.1 to 24.99 metric tons)
641 13	Truck production (over 25 Metric Tons)
644 00	<u>Combat motor vehicle production, general</u>
644 10	Tank and assault gun production
644 30	Armored infantry combat vehicle production
644 40	Armored personnel carriers production
646 00	<u>Combat vehicle repair (major overhaul and rebuild)</u>
647 00	<u>Automotive engine production, general</u>
647 10	Truck engine production
647 50	Combat vehicle engine production
661 00	<u>Chemical warfare production, general</u>
661 10	Chemical warfare, agents production
661 20	Chemical warfare, munitions production, general
661 21	Chemical warfare production, munitions, aerial
661 22	Chemical warfare production, munitions, ground
661 30	Chemical warfare production, protective equipment, general
661 31	Chemical warfare production, protective equipment, gas masks
661 32	Chemical warfare production, protective equipment, clothing
661 33	Chemical warfare production, protective equipment, detection equipment
661 34	Chemical warfare production, protective equipment, decontamination equipment
661 35	Chemical warfare production, protective equipment, agent antidotes

**Category    Category Code**

661 40	Chemical warfare production, weapons, general
662 00	<u>Chemical warfare storage, general</u>
662 10	Chemical warfare storage, bulk agents
662 20	Chemical warfare storage, munitions
662 30	Chemical warfare storage, bulk agents and munitions
662 40	Chemical warfare storage, related equipment only
671 00	<u>Shipyards, basic construction</u>
671 10	Naval vessels
671 20	Submarine construction and fitting out
671 30	Commercial vessels
672 00	<u>Shipyards, fitting out, repairing, converting, or modifying</u>
672 10	Naval vessels
672 20	Submarine repair, conversion, or modification
672 30	Ship repair, commercial vessels
680 00	<u>Guided missile and space system production and assembly, general</u>
681 00	<u>Strategic land-based missile production, general</u>
681 10	Intercontinental ballistic missiles
681 20	Intermediate-range ballistic missile
681 30	Medium-range ballistic missile production
681 40	Ground-launched surface-to-surface cruise missiles
682 00	<u>Tactical land-based missile production, general</u>
682 10	Short-range ballistic missiles
682 20	Antitank missiles
682 30	Surface-to-surface cruise missiles
683 00	<u>Naval missile production, general</u>
683 10	Strategic ballistic missiles
683 20	Tactical ballistic missiles
683 30	Aerodynamic cruise missiles
683 40	Antisubmarine warfare missiles
683 50	Naval surface-to-air missiles
684 00	<u>Surface-to-air antiballistic missile production, general</u>
684 10	Strategic surface-to-air missiles
684 20	Tactical surface-to-air missiles
684 30	Endo-atmospheric antiballistic missiles
684 40	Exo-atmospheric antiballistic missiles

**Category    Category Code**

685 00	<u>Air-to-surface missile production</u>
685 10	Strategic air-to-surface missiles
685 20	Tactical surface-to-air missiles
686 00	<u>Air-to-air missile production, general</u>
687 00	<u>Space systems production</u>
687 10	Space launch vehicles (0.1-1.9 meters in diameter)
687 20	Space launch vehicles (greater than 2.0 meters in diameter)
687 30	Satellites/scientific capsules/manned vehicles
687 40	Research and meteorological rockets
687 50	Other research rockets
688 00	<u>Drone and remotely piloted vehicle production</u>
690 00	<u>Explosive, production, and storage</u>
691 00	<u>Industrial explosive production</u>
691 10	Dynamite production
691 20	Black powder production
691 30	Ammonium nitrate production
692 00	<u>Propellant for conventional weapon systems production, general</u>
693 00	<u>High explosives production, general</u>
693 50	Explosive mixture production
7xx xx	<u>Urban features and population</u>
701 00	<u>Urban area</u>
702 xx	Cities/towns
702 yy	Population concentration
730 00	<u>Military industrial areas</u>
741 00	<u>Government control centers, national level</u>
741 10	Government control centers, urban administrative
741 30	Government control centers, command posts
742 00	<u>Government control centers, state level, general (second level)</u>
742 10	FEMA headquarters and regional centers

<b>Category</b>	<b>Category Code</b>
	743 00 <u>Municipal government control centers (city halls)</u>
	752 00 <u>Military bases</u>
	772 00 <u>Financial institutions</u>
	772 10     Federal reserve banks
	772 11     Federal reserve, bank branches
	772 12     Federal reserve, bank regional offices
	772 20     Federal reserve, communications and records center
	800 00 <u>Airfields</u>
	800 30     Arctic staging base
	801 50 <u>Heliport</u>
	811 00 <u>National aviation headquarters</u>
	814 00 <u>Naval aviation headquarters</u>
	814 10     First echelon
	814 20     Second echelon
	815 00 <u>Aviation headquarters and schools</u>
	815 10     Air transport headquarters
	82x xx <u>Air defense command and control installations</u>
	820 00 <u>Air defense headquarters and control center</u>
	820 20     Second echelon
	820 60     Sub-region air defense control facilities
	821 10 <u>Air defense command facilities, first echelon</u>
	821 30     Air defense command facilities, third echelon
	822 4x     Air defense command, command post bunker
	823 20     Air defense administrative headquarters, second echelon
	823 30     Air defense administrative headquarters, third echelon
	841 00 <u>Space system operational facilities, general</u>
	841 10     Space launching facilities
	841 20     Space tracking, transmitting and readout stations, general
	841 21     Space tracking radars
	841 22     Radio telescopes
	841 23     Optical tracking systems

**Category Category Code**

841 24	DSP-related ground stations
841 30	Space coordinating and computer centers
845 00	<u>Military space systems</u>
845 52	Space detecting and tracking system (SPADATS)
845 53	SPADATS alternate control centers
845 56	Radar system
845 57	Optical tracking system
845 61	Space surveillance system (NAVSPASUR) control centers
845 63	Radio transmitters
845 64	Radio receivers
851 00	<u>Radar installations, early warning, surveillance, detection, tracking, and acquisition</u>
851 10	Radar installations, early warning/acquisition, aerodynamic
851 11	Radar facilities, early warning, aerodynamic
851 13	Radar facilities, acquisition, aerodynamic
851 20	Radar installations, ballistic missile early warning/satellite detection and tracking
851 30	Radar installations, ballistic missile early target tracking and acquisition
851 40	Radar installations, over-the-horizon detection
851 52	Radar facilities, coastal surveillance/early warning
852 00	<u>Radar installations, ground control intercept</u>
852 10	Fixed-radar installations
853 00	<u>Radar installations, missile control</u>
853 25	Radar facilities, missile control, SAM, SA-5
856 00	<u>Air traffic control and landing aids</u>
861 00	<u>Air depots, general</u>
861 10	Air depots
862 00	<u>Air conventional ammunition depots</u>
863 00	<u>Aircraft maintenance and repair bases, general</u>
863 10	Supporting military aircraft
863 20	Supporting civilian aircraft
864 xx	<u>Airfield underground/cave support facilities</u>
865 00	<u>Air logistics headquarters, general</u>
865 20	Air logistics headquarters, area

<b>Category</b>	<b>Category Code</b>
	87x xx <u>Surface-to-surface and surface-to-air missile installations</u>
	871 00 <u>Surface-to-surface missile sites, fixed, general</u>
	871 10     Intercontinental ballistic missile sites
	871 20     Intermediate-range ballistic missile sites
	871 30     Medium-range ballistic missile sites
	871 40     Surface-to-surface missile sites, various
	871 50     Surface-to-surface missile sites, cruise
	871 60     Short-range ballistic missile sites
	872 00 <u>Surface-to-surface and surface-to-air missile sites/complexes</u>
	873 xx <u>Missile sites/complexes, defensive</u>
	874 00 <u>Missile headquarters, surface-to-surface</u>
	874 10     Missile headquarters, national level
	874 20     Missile headquarters, army or corps level
	874 30     Missile headquarters, division level
	874 40     Missile headquarters, regimental level
	874 50     Missile headquarters, battalion level
	874 60     Missile headquarters, brigade level
	875 xx <u>Missile sites/complexes, surface-to-air, defensive</u>
	875 x1     Missile site, ABM
	876 00 <u>Missile support facilities, offensive</u>
	876 10     Missile support facilities, ICBM
	876 30     Missile support facilities, MRBM
	876 40     Missile support facilities, ground tactical
	876 50     Missile support facilities, cruise offensive
	876 60     Missile support facilities, (various)
	878 00 <u>Surface-to-surface missile launch control facilities</u>
	878 10     Intercontinental missile launch control facilities
	878 20     Intermediate-range missile control sites
	878 30     Medium-range missile control sites
	878 40     Cruise missile control sites
	879 00 <u>Missile support facilities for ship-borne missiles or coastal defense missiles (bunkers)</u>
	879 10     Support facilities for surface ship-borne missiles
	879 20     Support facilities for submarine-borne missiles
	88x xx <u>Surface-to-surface missile sites, offensive</u>

**Category    Category Code**

881 xx	<u>Surface-to-surface missile systems</u>
881 17	SS-24 Rail Deployment Site
89x xx	<u>National combined, and joint command</u>
891 00	<u>National command authorities, facilities</u>
895 10	Joint command post facilities
900 00	<u>Ground force installations</u>
900 10	Ground force Reserve Components' installations
901 00	<u>Troop installations, fixed</u>
901 10	Barrack areas, posts, and stations
901 20	Training centers/maneuver areas
902 00	<u>Troops in the field (assembly and staging areas)</u>
902 10	Concentrations of tactical troops
902 20	Assembly and staging areas
910 00	<u>Ground force headquarters</u>
910 10	National headquarters
910 20	Group headquarters
910 30	Ground-force headquarters, military district/regional headquarters
911 00	<u>Ground forces materiel support headquarters/echelons</u>
911 10	Commodity commands and echelons
911 20	Logistics management and control echelons
912 00	<u>Military transportation headquarters/echelons</u>
912 40	Tenant facilities
913 00	<u>Ground forces service support headquarters/echelons</u>
914 00	<u>State area command headquarters</u>
920 00	<u>Ground force materiel storage and depot maintenance facilities</u>
920 10	Ammunition storage and depot maintenance facilities
920 70	Pre-positioned combat equipment afloat
931 00	<u>Automatic data processing installations</u>
941 30	<u>Defense logistics depots</u>

<b>Category</b>	<b>Category Code</b>
	95x xx <u>Naval</u>
	951 00 <u>Surface ship bases</u>
	951 10     Cruiser and/or destroyer force bases
	951 20     Navy primary defense force bases
	952 00 <u>Submarine bases</u>
	952 10     Supporting, missile-armed submarines
	952 30     Operational submarine bases supporting non-missile-armed submarines
	952 50     Submarine bases for maintenance and repair of submarines
	955 00 <u>Specialized naval activities</u>
	955 30     Photographic laboratories
	955 52     Ship-borne search and rescue
	956 00 <u>Naval and maritime moorings</u>
	956 10     Naval fleet reserve
	960 00 <u>Naval headquarters</u>
	961 00 <u>National naval headquarters</u>
	962 00 <u>Naval headquarters (fleet and force)</u>
	962 10     Submarine force headquarters
	962 20     Cruiser-destroyer force headquarters
	962 30     Naval-base defense-force headquarters
	962 40     Fleet rear service auxiliary force headquarters
	962 50     Headquarters, force level, unspecified
	971 00 <u>Naval general materiel storage</u>
	971 10     Naval and materiel storage, located on a naval or coast guard base
	971 20     Naval general materiel storage, located off base
	972 00 <u>Naval conventional ammunition and/or ordnance storage</u>
	972 10     Naval conventional ordnance storage located on a Naval base
	972 20     Naval conventional ordnance storage, located off base

## APPENDIX B

### *Data Fields in the NRDC Russian Target Database*

Target ID  
Category Code (5 digit code used by the U.S. government)  
Target Name  
Target Class (NF, OMT, L-C3, or WSI)  
Target Category  
Target Type  
Organization  
Unit Abbreviation (Used in 1997 CFE Data Declaration)  
Degrees North (Latitude)  
Minutes North (Latitude)  
Seconds North (Latitude)  
Degrees East (Longitude)  
Minutes East (Longitude)  
Seconds East (Longitude)  
Elevation (meters)  
Address, street name and number  
Location (nearby town)  
Administrative Region (Oblast, Kray, Autonomous Republic, Autonomous Oblast,  
Autonomous Okrug)  
Military District (Northern, Moscow, North Caucasus, Urals, Volga, Siberian,  
Transbaikal, Far East)  
Postal Zip Code  
Country  
Description/Function  
Deployed ICBM Launchers (Number)  
Deployed ICBMs (Number)  
Deployed SLBMs (for naval bases only) (Number)  
Deployed Warheads (Number)  
Non-Deployed ICBM Launchers (Number)  
Non-Deployed ICBMs (Number)  
Training ICBM Models (Number)  
ICBM Emplacement Equipment (Number)  
ICBM Training Launchers (Number)  
Non-Deployed SLBMs (Number)  
Area (sq km) (for Road-Mobile ICBMs)  
Trains/Vehicles (Road-Mobile and Rail-Mobile ICBMs) (Number)  
Airfield (enter "AF" if target is an Airfield)  
Runway Length (meters)  
Airfield Suitability  
Unit Types  
1st Higher Echelon  
2nd Higher Echelon  
Personnel (Number)  
Combat Aircraft (Number)

CCT Aircraft (Number)  
 Training Aircraft (Number)  
 Tu-22 Blinder (Number)  
 Tu-22M Backfire (Number)  
 Tu-160 Blackjack (Number)  
 Tu-95M Bear (Number)  
 Tu-16 Badger (Number)  
 Su-17 Fitter (Number) (Fighter)  
 Su-22 Fitter (Number) (Fighter)  
 Su-24 Fencer (Number)  
 Su-25 Frogfoot (Number) (Fighter)  
 Su-27 Flanker (Number)  
 MiG-21 Fishbed (Number) (Fighter)  
 MiG-23 Flogger (Number)  
 MiG-25 Foxbat (Number) (Fighter)  
 MiG-27 Flogger (Number)  
 MiG-29 Fulcrum (Number) (Fighter)  
 MiG-31 Foxhound (Number) (Fighter)  
 L-29,-39 Training Planes (Number)  
 Attack Helicopters (Number)  
 Combat Support Helicopters (Number)  
 Unarmed Helicopters (Number)  
 Other (Number)  
 Tanks (Number)  
 Armored Combat Vehicles (ACV) (Number)  
 Armored Personal Carriers (APC) and Armored Infantry Fighting Vehicle (AIFV)  
 (Number)  
 AVLB (Number)  
 Artillery (Number)  
 Primary Fuel (used in power plants)  
 Capacity  
 Unit of Measure (e.g., MWe for power plants, bbl/d for oil refineries)  
 River (for hydroelectric power plants only)  
 Pipelines from pipeline node  
 VLF Transmitter Site  
 LF Transmitter Site  
 MF Transmitter Site  
 HF Transmitter Site  
 UHF Transmitter Site  
 SHF Transmitter site  
 EHF Transmitter Site  
 Priority (identifies potential targeting scenarios)  
 VT: Physical Vulnerability Type (P = Point; E = Equal Target Area)  
 VN1: Physical Vulnerability Number for Point Type Targets

VN2: Physical Vulnerability Number for Equal Target Area Type Targets  
ONC (the Operational Navigational Chart where the target is located)  
JOG (the Joint Operations Graphic where the target is located)  
CFE (whether the target is listed in the 1997 CFE data declaration)  
References (the sources of the data for the target description/function)  
Date when the target information was last modified  
Last Modified by (initials of the person that last modified the data fields for this target)  
Coordinate Reference (the reference for the target coordinates)  
Additional Comments

## APPENDIX C

### NRDC Russian Target Database Target Classes, Categories, and Types

(Abbreviations or acronyms in bold.)

#### Nuclear Forces (**NF**)

##### ICBM (Fixed) (**ICBM-F**)

ICBM-Fixed Silo (**S**)

Launch Control Center for Silo-Based ICBM (**LCC**)

Strategic Missile-Main Operating Base (**SM-MOB**)

Strategic Missile Base (Troops) (**SMB-T**)

##### ICBM (Mobile) (**ICBM-M**)

Road Area (road-mobile ICBMs) (**RDA**)

Railroad Parking Site (rail-mobile ICBM) (**RRPS**)

Railroad Entrance/Exit (**RRE/E**)

Strategic Missile (Mobile) Dispersal Base (Hardened) (**SMMDB-H**)

Strategic Missile (Mobile) Dispersal Base (Unhardened) (**SMMDB-U**)

Strategic Missile-Main Operating Base (**SM-MOB**)

Strategic Missile Base (Troops) (**SMB-T**)

ICBM Road-Mobile Boundary Coordinates (**RDM-B**) [not targets]

##### SLBM Bases and Forces (**SLBM**)

SSBN Main Operating Base (**SSBN-MOB**)

Naval Base Frequented by SSBNs (dispersal area) (**NB**)

Shipyards Used to Repair/Overhaul SSBNs (dispersal area) (**NY**)

SLBM-Loading Facility (**SLBM-LF**)

SSBN Dispersal Areas (Unhardened) (**SSBN-DA-U**)

SSBN Dispersal Areas (Hardened) (**SSBN-DA-H**)

SSBN At-Sea Dispersal Areas (**SSBN-ASDA**)

##### Strategic Air Forces (**SAF**)

Strategic Bomber Main Operating Base/Airfield (**SBB**)

Aerial Refueling Main Operating Base (**AR-MOB**)

Former Strategic Bomber Main Operating Base/Airfield (**FSBB**)

Strategic Bomber Dispersal Base (**SBDB**)

Strategic Bombers Arctic Staging Base (**AS**)

Strategic Bomber Units (**SBU**)

Heavy Bomber Flight Test Center (**HBFTC**)

Heavy Bomber Training Unit (**HBTU**)

##### Non-Strategic Nuclear Navy (**NSNN**)

Non-Strategic Nuclear Navy-Main Operating Base (**NSNN-MOB**)

Naval Base Frequented by SSGNs and Nuclear-Capable Surface Ships  
(dispersal area) (**NB**)

Shipyards Used to Overhaul SSGNs and Nuclear-Capable Surface Ships  
(dispersal area) (**NY**)

Cruise Missile-Loading Facility (**CM-LF**)

##### Non-Strategic Nuclear Air Forces (**NSNAF**)

Medium Range Bomber Main Operating Base (**MRBB**)

Tactical Air Forces/Frontal Aviation Base (**FAB**)

Air Force Bombers Units (**AFBU**)  
Non-Strategic Nuclear Naval Aviation (**NSNNA**)  
    Naval Aviation Main Operating Base (**NA**)  
    Naval Aviation Unit (**AAU**)  
Non-Strategic Nuclear Army (**NSNA**)  
    Non-Strategic Nuclear Army-Main Operating Base (**NSNA-MOB**)  
Nuclear Warhead Storage (**NWHS**)  
    Nuclear Warhead Storage and Maintenance Facility,  
        General/Possible/Unknown Use (**NWHSF**)  
    Nuclear Warhead Storage and Maintenance Facility (SRF) (**NWHSF-SRF**)  
    Nuclear Warhead Storage and Maintenance Facility (National Level)  
        (**NWHSF-NL**)  
    Nuclear Warhead Storage-Main Operating Base (**NWHS-MOB**)  
    Nuclear Weapons Storage Facilities (At Airfields During Alert) (**NWHSF-A**)  
    Nuclear Weapons Storage Facilities (Primarily Naval) (**NWHSF-N**)  
    Nuclear Weapons Storage Facilities (At Production Sites) (**NWHSF-P**)  
    Warhead Storage Site Boundary Coordinates (**WHS-B**) [not targets]  
Ground Forces Nuclear-Capable Units (**GFNU**)  
    Nuclear-Capable Missile Brigade Site (**NMBS**)  
    Nuclear-Capable Artillery Division Site (**NADS**)  
ABM Forces (**ABM**)  
    Anti-Ballistic Missile Silo (**ABM-S**)  
    Anti-Ballistic Missile Tracking Radar (**ABM-TR**)  
    Anti-Ballistic Missile-Main Operating Base (**ABM-MOB**)  
    Anti-Ballistic Missile Launcher (Dismantled) (**ABM-L-C**)  
Strategic Missile Test Launch Facilities (**SMTLF**)  
    Missile (ICBM) Test Silo (**MTS**)  
    Missile Soft Site Launcher (**MSSL**)  
    Missile Test Site Base (**MTSB**)  
    Missile Test Site (Troops) (**MTS-T**)  
Strategic Forces Storage Facilities (**SFSF**)  
    ICBM Storage Facility (**ICBM-SF**)  
    SLBM Storage Facility (**SLBM-SF**)  
    Strategic Bomber Storage Facility (**SB-SF**)  
Strategic Forces Maintenance Facilities (**SFMF**)  
    ICBM Maintenance Facility (**ICBM-MF**)  
    ICBM Mobile Launcher Repair Facility (**ICBM-MLRF**)  
    SLBM Maintenance Facility (**SLBM-MF**)  
    Strategic Bomber Maintenance Facility (**SB-MF**)  
Strategic Forces Conversion/Elimination Facilities (**SFEF**)  
    ICBM Conversion/Elimination Facility (**ICBM-EF**)  
    SLBM Conversion/Elimination Facility (**SLBM-EF**)  
    Strategic Bomber Conversion/Elimination Facility (**SB-EF**)  
Nuclear Forces Transportation Unit Locations (**NFTU**)

Strategic Missile Transport Troops (**SMTT**)  
 Air Forces Nuclear Transport Unit (**AFNT**)  
 Nuclear Forces Training Facilities (**NFTF**)  
 ICBM Silo Training Launcher (**ICBM-STL**)  
 Missile Training Facility (**MTF**)  
 Missile Static Display (**MSD**)  
 12th Main Directorate (12th GUMO) Training Center (**GTC**)  
 Air Forces Nuclear Training Centers (weapon delivery) (**AFNTC**)

Other Military Targets-Conventional Military Forces (**OMT**)

Airfields (**AF**)

Air Defense Base (**ADB**)  
 Air Force Base (**AFB**)  
 Aviation Sports Club [Aviation Training Base] (**ASC**)  
 Civilian Airport (**CIV**)  
 Frontal Aviation Base (**FAB**)  
 Heliport (**HELO**)  
 International Airport (**IAP**)  
 Medium Range Bomber Main Operating Base (**MRBB**)  
 Military Airfield (**MIL**)  
 National Civil Leadership (**NCL**)  
 National Military Leadership (**NML**)  
 Naval Aviation (**NA**)  
 Unknown Type (**UNKN**)

Air Force Units, Non-Nuclear (**AFUC**)

Air Forces Air Defense Units (**AFAD**)  
 Air Forces Base (**AFB**)  
 Air Forces Bomber Unit (**AFBU**)  
 Air Forces Composite Unit (**AFCU**)  
 Air Forces Fighter Unit (**AFFU**)  
 Air Forces Ground Attack Units (**AFGA**)  
 Air Forces Reconnaissance Unit (**RCON**)  
 Air Forces Transportation Unit (**AFTU**)  
 Air Forces Special Purpose Unit (**AFSPU**)  
 Aviation Maintenance Facility (**AMF**)  
 Flight Training Facilities (**FTF**)

Naval Aviation Units, Non-Nuclear (**NAUC**)

Naval Aviation Base (**NAB**)  
 Naval Aviation Unit (**NAU**)

Helicopter Units (**HU**)

Combat Helicopter Unit (**CHU**)  
 Helicopter Training Unit (**HTU**)

Space Related Facilities (**SPACE**)

Space Launch Facilities (**SLF**)

- Anti-Satellite Systems (**ASS**)
- Air Defense Missiles (**ADM**)
  - Air Defense Missile Base (**ADMB**)
  - Surface-to-Air Missile Site (**SAM-S**)
  - Surface-to-Air Missile-Radar (**SAM-R**)
  - Tactical Surface-to-Surface Missiles (**TSM**)
  - Missile Brigade Site (**MBS**)
- Naval Ship Facilities (**NSF**)
  - Navy Base (**NB**)
  - Navy Shipyard (**NY**)
  - Shipping Dock/Pier (**SD**)
  - Ship Anchorage (**SA**)
- Ground Forces Sites (**GFS**)
  - Artillery Unit (**ARTY**)
  - Airborne Unit (**ABRN**)
  - Battle Tank Unit (**BTU**)
  - Armored Vehicle Unit (**TAAS**)
  - Communication/Signal Unit (**COM**)
  - Electronics/Intl/Countermeasures Unit (**ELEC**)
  - Federal Border Service Troop Site (**FBST**)
  - Material Support Unit (**MAT**)
  - Motorized Rifle Unit (**MRU**)
  - Motorized Transport Unit (**MTU**)
  - MVD Internal Troop Site (**MVDS**)
  - Nuclear, Biological and Chemical Unit (**NBC**)
  - Reconnaissance Unit (**RCON**)
  - Rocket Launcher Unit (**RLU**)
  - Security Units (**SCTY**)
  - Spetnaz Unit (**SPTZ**)
  - Weapon Arsenals (Conventional Weapons/Munitions Storage) (**WAS**)
  - Medical Unit (**MED**)
- Naval Shorebased Troops (**NSTS**)
  - Naval Infantry Unit (**NIU**)
- Chemical Weapons (**CW**)
  - Chemical Weapon Storage Site (**CWSS**)
- Conventional Forces Training (**CFT**)
  - Ministry of Defense Academy (**MOD-A**)
  - Ground Forces Training Site (**GFTS**)
  - Chemical Weapons Training Facility (**CWTF**)
  - Chemical Weapons Defense Academy (**CWDA**)
- Leadership-Command, Control, and Communications (**L-C3**)
  - National Government Leadership/Support (**NGL**)
    - Executive Leadership Facility (**ELF**)

Executive Leadership Facility Underground (**ELF-UG**)  
 Legislative Leadership Facility (**LLF**)  
 Legislative Leadership Facility Underground (**LLF-UG**)  
 National-Level Military Leadership/Support (**NML**)  
   National Command Authority Underground Facility (**NCA-UG**)  
   National Command Authority Deep Underground Facility (**NCA-DUG**)  
   National Military Leadership Facility (**NMLF**)  
   National Military Leadership Facility Underground (**NMLF-UG**)  
   National Military Leadership Facility Deep Underground (**NMLF-DUG**)  
   Strategic Missile Threat and Strike Analysis Center (**SMAC**)  
 Intermediate-Echelon Strategic Leadership (**IESL**)  
   SRF Headquarters (**SRF-HQ**)  
   SRF Army Headquarters (**SRF-AHQ**)  
   SRF Division Headquarters (**SRF-DHQ**)  
   SRF Division Command Center (**SRF-DCC**)  
   Strategic Missile Command and Launch Control Facility (**SMLCF**)  
   Navy Fleet Headquarters (**NF-HQ**)  
   SSBN (RPSKN) Flotilla and Division Headquarters (**SSBN-HQ**)  
   Long Range Bomber Aviation Headquarters (**LRA-HQ**)  
 Intermediate-Echelon Non-Strategic Nuclear Leadership (**IENSL**)  
   Military District Headquarters (**MD-HQ**)  
   Navy Fleet Headquarters (**NF-HQ**)  
   Flotilla and Division Headquarters, SSNs (**SSN-HQ**)  
   Flotilla and Division Headquarters, Diesel Submarines (**SS-HQ**)  
   Flotilla and Division Headquarters, Surface Ships (**SHIP-HQ**)  
   Air Forces (Air Army and Military District Air Forces Headquarters)  
     (**AFN-HQ**)  
   Ground Forces (Independent Army, Combined-Arms Army, and Army  
     Corps) Headquarters (**GF-HQ**)  
 Intermediate-Echelon Non-Nuclear Leadership (**IENNL**)  
   Air Forces (Air Defense Army and Independent Air Defense Corps)  
     Headquarters (**AF-HQ**)  
   Airborne Forces Headquarters (**ABF-HQ**)  
   Ground Forces Headquarters (**GF-HQ**)  
 Intelligence Leadership (**INTLL**)  
   Intelligence Facility Headquarters (**INTEL-HQ**)  
 Telecommunications and Electronic Warfare (**TE**)  
   Military Communication Station/Fixed Site (**MCSS**)  
   Naval Communication Shore Station (**NCSS**)  
   Fixed-Site VLF Stations for Submarine Communication (**VLF-S**)  
   Low Frequency Transmitter (Non-Public) (**LF**)  
   Very Low Frequency Transmitter (Non-Public) (**VLF**)  
   Radio Transmission Tower (Unknown) (**UNKN**)  
 Satellite and Space Communication Systems (**SCS**)

- Earth Station for Satellite Reception (**ES**)
- Non-Communication Electronic Installations (**NCEI**)
  - Radar Installation (**RADAR**)
  - Radar Collocated with SAM Site (**RADAR-SAM**)
  - Missile Strike Warning System (Early Warning Radar) (**RADAR-MSWS**)
  - Space Surveillance Radar (**RADAR-SS**)
  - Air Traffic Control/Navigation Aid (**ATC/NAV**)
  - Meteorological Radar (**RADAR-MET**)
- National-Level War Support Industry Leadership (**NWSL**)
  - Atomic Energy Leadership Institution (**AELI**)
  - Aerospace Leadership Institution (**ASLI**)
  - Defense Industry Leadership Institution (**DILI**)
  - Electronics and Telecommunications Leadership Institution (**ETLI**)
  - Chemical Industry Leadership Institution (**CILI**)
  - Shipbuilding Leadership Industry (**SLI**)
  - Internal Security Leadership Institution (**ISLI**)
  - Mining and Metallurgy Leadership Institution (**MMLI**)
- National-Level Civilian Leadership/Support (**NCL**)
  - Foreign and Domestic Affairs Institution (**FDAI**)
  - Fuels and Energy Institution (**FEI**)
  - Construction and Labor Institution (**CLI**)
  - Federal Resources Institution (**FRI**)
  - Economic, Financial and Banking Institution (**EFBI**)
  - Communications, Media and Press Institution (**CMPI**)
  - Industrial Equipment Institution (**IEI**)
  - Transportation Institution (**TI**)
  - Food and Health Institution (**FHI**)
  - Judiciary Institution (**Jl**)
  - Science, Technology and Education Institutions (**STEI**)
- Leadership Policy, Planning and Training Institutes (**LPPTI**)
  - MOD Institute (**MODI**)
  - SRF Institute (**SRFI**)
- War Support Industry-Urban/Industrial (**WSI**)
  - Strategic Missile Production Facilities (**SMPF**)
    - Missile Production Facility (**MPF**)
    - Missile Launcher Production Facility (**MLPF**)
    - Missile Component Production Facility (**MCPF**)
  - Strategic Aviation Production, Repair and Elimination Facilities (**SAPF**)
    - Strategic Aviation Factory (**SAF**)
    - Heavy Bomber Repair Facility (**HBRF**)
    - Heavy Bomber Conversion/Elimination Facility (**HBC&EF**)
  - Strategic Propulsion Production Facilities (**SPPF**)
    - Strategic Propulsion (Aircraft and Rocket Engines) Factory (**SPF**)

Naval Propulsion System Factory (**NPSF**)

Strategic Forces Research & Development Facilities (**SFR&DF**)

- Missile Design Bureau (**MDB**)
- Missile Design Institute (**MDI**)
- Missile Launcher Design Bureau (**MLDB**)
- Missile Testing Institute (**MTI**)
- Space Design Bureau (**SDB**)
- Naval Design Bureau (**NDB**)
- Naval Research Institute (**NRI**)
- Naval Shipyards (excludes major repair/overhaul yards) (**NY**)
- Aviation Design Bureau (**AvDB**)
- Aviation Research Institute (**AvRI**)
- Propulsion and Guidance Technology Institute (**PTI**)
- Propulsion (Aircraft and Rocket Engines) Design Institute (**PDI**)
- Propulsion (Aircraft and Rocket Engines) Design Bureau (**PDB**)

Nuclear Weapons Support (other than strategic forces specific) (**NUC**)

- Nuclear Warhead Research, Design and Testing (**NWD&T**)
- Nuclear Warhead Production Enterprise (**NWPE**)
- Nuclear Warhead Component Production (**NWCP**)
- Nuclear Warhead Assembly, Disassembly and Maintenance (**NWAD&M**)
- Basic and Applied Nuclear Research and Development (**B&ANR&D**)
- Research/Test Reactor (**R/TR**)
  - a. Atomic Energy Associated Facilities Production and Storage
  - Fissile Material Storage Facility (**FMSF**)
  - Nuclear Service Ships-Icebreaker Fleet (**INSS**)
  - Nuclear Service Ships-Naval Fuel and Waste (**NSSNF\W**)
  - Nuclear Waste Storage Facility (**NWSF**)
  - Strategic Materials Production Facility (**SMPF**)
  - b. Atomic Energy Feed and Moderator Materials Production
  - Uranium Enrichment Facility (**UEP**)
  - Chemical Separation Facility (**CSF**)
  - Production Reactor (**PR**)
  - Uranium Mining and Milling (**UMM**)
  - Uranium Conversion Facility (**UCF**)
    - c. Nuclear Project Research, Design and Consulting
    - d. Nuclear Power Plant Construction and Support
    - Nuclear Reactor Manufacturer (**NRM**)
    - Nuclear Power Plant Support Facility (**NPPSF**)
      - e. Population Centers (Residences) of Nuclear Weapon Support Scientists
      - Population Center for NWRD&T Scientists (**PPL-NWRD&T**)
      - Population Center for Nuclear Weapon Production Enterprise (**PPL-NWPE**)
      - Population Center for AEF&P (**PPL-AEF&P**)

Satellite and Space Related Technologies (**SSRT**)

- Space Launch Control Facility (**SLCF**)

Missile Launch Complex (**MLC**)  
Payload Processing and Assembly Facility(**PPAF**)  
Satellite Design and Manufacturing Facility (**SDMF**)  
Space Research Institute (**SRI**)  
Commercial Space Service Organization (**CSSO**)  
Conventional Forces Production Facilities (**CFPF**)  
SAM Production Facility (**SAM-PF**)  
Conventional Missile Production Facility (**CMPF**)  
Conventional Aviation Factory (**CAF**)  
Aviation Component Production Plant (**ACPP**)  
Navigation and Guidance Systems Production Facility (**NGPF**)  
Shipyards (**NY**)  
Armored Vehicle Production Facility (**ArVPF**)  
Conventional Ordnance Production Facility (**COPF**)  
Conventional Forces Research and Development Facilities (**CFR&DF**)  
Aviation Design Bureau (**AvDB**)  
Aviation Research Institute (**AvRI**)  
Anti-Satellite Design Bureau (**ASDB**)  
Conventional Munitions Design Bureau (**CMDB**)  
Missile Design Bureau (**MDB**)  
Air Defense Systems Development (**ADSD**)  
Armored Vehicle Design Bureau (**ArVDB**)  
Armored Vehicle Research Institute (**ArVRI**)  
Conventional Ordnance Development Facility (**CODF**)  
Electricity Power Generation, Transmission, and Control Facilities (**EP**)  
Electricity Transmission Substation (**ETS**)  
Geothermal Power Plants (**GPP**)  
Hydroelectric Power Plant (**HPP**)  
Nuclear Power Plant (**NPP**)  
Solar Power Plants (**SPP**)  
Thermal (and Other) Power Plant (**TPP**)  
Wind Generator Power Plants (**WPP**)  
Transportation (supporting dispersal)  
Oil and Gas Production, Transmission, and Storage Facilities  
Oil Refinery (**OR**)  
Oil/Gas Pipeline (**PL**)  
Oil Pipeline (**OPL**)  
Gas Pipeline (**GPL**)  
Gas and Oil Pipeline (**G&OPL**)  
Gas Compressor Station (**GCS**)  
Oil or Gas Pipeline Compressor Station (**O/GCS**)  
Underground Gas Storage Facility (**UGS**)  
Oil Storage Tank (**OST**)  
Oil Tanker Terminal (**OTT**)

LNG Tanker Terminal (**LN GTT**)  
 Natural Gas Processing Plant (**NGPP**)  
 Military Electronics Plants (**MEP**)  
 Industry, Aluminum (**IA**)  
     Aluminum Production (**AP**)  
 Industry, Ferrous Metal Production (**FMP**)  
     Pig Iron and Steel Production, Raw (**I&SP**)  
 Metals and Alloys Production Plants (**M&AP**)  
     Graphite Applied R&D Institute (**GR&DI**)  
 Chemical Weapons Support Facilities (**CWSF**)  
     Chemical Weapons Research Institute (**CWRI**)  
     Chemical Weapons Production Facility (**CWPF**)  
     Chemical Weapons Test Site (**CWTS**)  
     Chemical Weapons Training Facility (**CWTF**)  
 Biological Weapons Support Facilities (**BWSF**)  
     Biological Weapons Research Institute (**BWRI**)  
     Biological Weapons Production/Standby Production Facility (**BWPF**)  
     Biological Weapons Storage Site (**BWSS**)  
     Biological Weapons Test Site (**BWTS**)  
     Biological Weapons Component Production Facility (**BWCPF**)  
 Industrial Sector Government Agencies (**ISGA**)  
 Chemical Technology Institutes (**CTI**)  
 Naval Ship Facilities (**NSF**)  
     Shipyards Used to Build and Overhaul Commercial Vessels (**NY**)  
     Population Center Supporting Naval Ship Facilities (**PPL-NSF**)  
 Bridges (**BRDG**)  
     Road Bridge, four lanes (**RDB4**)  
     Road Bridge, two lanes (**RDB2**)  
     Road Bridge, one lane (**RDB1**)  
     Railroad, Bridge (**RRB**)  
     Combined Railroad and 3 Lane Road Bridge (**R&RDB3**)

## APPENDIX D

### *Nuclear Weapons Effects Equation List*

NRDC has made use of two comprehensive sources of the equations that approximate the principal effects of a nuclear explosion: the “Help” files associated with the U.S. Department of Defense computer codes “BLAST” and “WE” (i.e., Weapons Effects). Most other general sources of information on the effects of nuclear explosion, for example Glasstone and Dolan’s *The Effects of Nuclear Weapons*, only provide summary information and graphs. The equations from the BLAST and WE codes are given in Sections 1-7, below. We transcribed these nuclear weapons effects equations, corrected presumably typographic errors, and incorporated them into NRDC’s nuclear conflict computer model. The simple fallout model presented in Section 5 below, is not that used in the Lawrence Livermore computer code KDFOC3, but is consistent with KDFOC3 within the scope of its much simpler phenomenology.

NRDC obtained versions 2.1 of BLAST and WE (both dated December 24, 1984) from the Internet site of the Federation of American Scientists ([www.fas.org](http://www.fas.org)). They were produced under contract to the Defense Nuclear Agency (DNA—now the Defense Threat Reduction Agency) by Horizons Technology.

Section 8, below, provides a description of the methodology and formulas used to calculate damage probability to a target, given the target’s physical vulnerability number and the parameters of the nuclear attack.

#### **Contents:**

1. Free-Air Equations for Blast
  - 1.1 Altitude Scaling Factors
  - 1.2 Overpressure, Dynamic Pressure, and Blast Wave Time of Arrival
  - 1.3 Dynamic Pressure from Overpressure
  - 1.4 Rankine-Hugoniot Factors
2. Air Burst Equations for Blast
  - 2.1 Overpressure, Dynamic Pressure, and Blast Wave Time of Arrival
  - 2.2 Overpressure Total Impulse
  - 2.3 Dynamic Pressure Total Impulse
  - 2.4 Overpressure Partial Impulse
  - 2.5 Dynamic Pressure Partial Impulse
  - 2.6 Time-Dependent Overpressure
  - 2.7 Time-Dependent Dynamic Pressure
  - 2.8 Overpressure Positive Phase Duration
  - 2.9 Dynamic Pressure Positive Phase Duration
  - 2.10 Mach Stem: Formation Range and Triple Point Height
3. Initial Radiation Calculations: Total Dose, Neutron Dose, and Gamma Doses
4. Thermal Equations
5. Fallout Equations
  - 5.1 One-Hour Dose Rate and Debris Arrival Time
  - 5.2 Maximum Biological Dose Rate
  - 5.3 t-Hour Dose Rate Given One-Hour Dose Rate
  - 5.4 One-Hour Dose Rate Given t-Hour Dose Rate

- 5.5 Total Fallout Dose
- 6. Cratering Equations
  - 6.1 Crater Dimensions and Ejecta Thickness
  - 6.2 Apparent Crater Volume for Two or Three Material Layers
- 7. Nuclear Weapon and Material Types
  - 7.1 Nuclear Weapon Types (for Initial Radiation Equations)
  - 7.2 Material Types and Radiation Types (for Section 6 Cratering Equations)
- 8. Mathematics of Vulnerability to Nuclear Weapons

**1. Free-Air Equations for Blast**

INPUT	OUTPUT
ALT—Altitude (m); model limits: 0 to 25,000	SP—Altitude scaling factor for pressure
Y—Weapon Yield (kT); model limits: 0.1 to 25,000	SD—Altitude scaling factor for distance
RANGE—Range (m); model limits: (16 · Y <sup>3</sup> · SD) to (4000 · Y <sup>3</sup> · SD) where Y <sup>3</sup> = Y <sup>1/3</sup> and SD is the altitude scaling factor.	ST—Altitude scaling factor for time
	C—Altitude-dependent speed of sound (m/s)
	PFREE—Free-air peak overpressure (Pa)
	QFREE—Free-air dynamic overpressure (Pa)
	TAFREE—Free-air time of arrival (s)

**1.1 Altitude Scaling Factors (SP, SD and ST):** For 0 ≤ ALT < 11,000, the altitude scaling subfactors are:

$$T = 1 - (2 \cdot 10^9)^{-0.5} \cdot ALT \quad \text{[1] and [2]}$$

$$P = T^{5.3}$$

For 11,000 ≤ ALT < 20,000, the altitude scaling subfactors are:

$$T = 0.7535 \cdot [1 + (2.09 \cdot 10^{-7}) \cdot ALT] \quad \text{[3] and [4]}$$

$$P = 1.6^{0.5} \cdot [1 + (2.09 \cdot 10^{-7}) \cdot ALT]^{-754}$$

For 20,000 ≤ ALT the altitude scaling subfactors are:

$$T = 0.684 \times [1 + (5.16 \times 10^{-6}) \cdot ALT] \quad \text{[5] and [6]}$$

$$P = 1.4762 \times [1 + (5.16 \times 10^{-6}) \cdot ALT]^{-33.6}$$

The altitude scaling factors for pressure, distance and time are

$$SP = P \text{ [7]; } SD = SP^{-1/3} \text{ [8]; } ST = SD \cdot T^{-0.5} \text{ [9]}$$

The altitude-dependent speed of sound is (rule of thumb: C increases 1.8% for each 10°C rise above 15°C):

$$C = (340.5)SD / ST \text{ [10]}$$

**1.2 Overpressure, Dynamic Pressure, and Blast Wave Time of Arrival:** Scale the range by the altitude scaling factor for distance and also the weapon yield:

$$R = (\text{RANGE}) / (\text{SD} \cdot Y^{1/3}) \quad [11]$$

The Defense Nuclear Agency (DNA) 1-kiloton free-air overpressure standard is given by the expression:

$$\Delta P_{DNA} = \frac{3.04 \cdot 10^{11}}{R^3} + \frac{1.13 \cdot 10^9}{R^2} + \frac{7.9 \cdot 10^6}{R \left( \ln \left[ \frac{R}{445.42} + 3 \exp \left[ \frac{-1}{3} \sqrt{\frac{R}{445.42}} \right] \right] \right)^{1/2}} \quad [12]$$

The free-air peak overpressure is simply:  $\Delta P_{FREE} = \Delta P_{DNA}$  [13]

The free-air peak overpressure at altitude is:  $\Delta P_{FREE} = \Delta P_{FREE} \cdot SP$  [14]

The shock strength, xi, is:  $xi = (\Delta p_{FREE} / 101,325) + 1$  [15],

For  $t=10^{-12}(xi)^6$  [16], and  $z = \ln(xi) - \frac{0.47 \cdot t}{100 + t}$  [17],

The gamma,  $g_s$ , behind the shock is:  $g_s = 1.402 - \frac{3.4 \cdot 10^{-4} \times z^4}{1 + 2.22 \cdot 10^{-5} \times z^6}$  [18].

The shock mu,  $\mu_s$ , is:  $\mu_s = (g_s + 1)/(g_s - 1)$  [19].

The mass density ratio across the shock front is:  $n = \frac{1 + \mu_s \cdot xi}{5.975 + xi}$  [20].

The free-air peak dynamic pressure is:  $q_{FREE} = 0.5 \cdot \Delta p_{FREE} (n-1)$  [21].

The free-air peak dynamic pressure at altitude is:  $Q_{FREE} = (q_{FREE}) \cdot SP$  [22].

The scaled free-air blast wave time of arrival is:

$$ta_{FREE} = \frac{R^2(6.7 + R)}{7.12 \cdot 10^6 + 7.32 \cdot 10^4 R + 340.5R^2} \quad [23].$$

The free-air blast wave time of arrival, unscaled for altitude and weapon yield, is

$$TAFREE = (ta_{FREE}) \cdot ST \cdot Y^{1/3} \quad [24]$$

**1.3 Dynamic Pressure from Overpressure**

<b>INPUT</b>	<b>OUTPUT</b>
ALT—Altitude (m); model limits: 0 to 25,000	QFREE—Free-air dynamic pressure (Pa)
PFREE—Free-air peak overpressure (Pa); model limits: $1374 \cdot 53 \cdot SP$ to $7.91151 \cdot 10^7 \cdot SP$ (SP = altitude scaling factor for pressure)	

First, compute the altitude scaling factor for pressure (SP). Next, scale the free-air peak overpressure by SP:

$$\Delta P_{FREE} = (PFREE)/SP \text{ [25]}$$

Then, compute the free-air peak dynamic pressure, using Equations [15]–[21]

**1.4 Rankine-Hugoniot Factors** (Inputs and limits match FREE-AIR calculation dynamic pressure from overpressure if that calculation is selected; otherwise, they match overpressure, dynamic pressure and time of arrival from range)

<b>INPUT</b>	<b>OUTPUT</b>
ALT—Altitude (m); model limits: 0 to 25,000	$R_n$ —Normal reflection factor
Y—Weapon Yield (kT); model limits: 0.1 to 25,000	UC—Shock Mach number
RANGE—Range (m); model limits: $(16 \cdot Y3 \cdot SD)$ to $(4000 \cdot Y3 \cdot SD)$ where $Y3 = Y^{1/3}$ and SD is the altitude scaling factor	VC—Peak particle Mach number

If the inputs are weapon yield, altitude, and range then first do the equations described for the calculation **overpressure, dynamic pressure, and blast wave time of arrival**; otherwise, do the equations described for the calculation **dynamic pressure from overpressure**; the shock gamma is found in Equation [18] and the mass density ratio in Equation [20].

The normal reflection factor is:  $R_n = 2 + (g_s + 1)(n - 1)/2$  [26].

The peak particle Mach number is: 
$$VC = \left[ \frac{\Delta p_{FREE} \left(1 - \frac{1}{n}\right)}{142,000} \right]^{0.5} \text{ [27].}$$

The shock front Mach number is:  $UC = \frac{VC}{1 - \frac{1}{n}}$  [28].

## 2. Air-Burst Equations for Blast

### 2.1 Overpressure, Dynamic Pressure, and Blast Wave Time of Arrival:

INPUT	OUTPUT
Y—Weapon Yield (kT); model limits: 0.1 to 25,000	PAIR—Air-burst peak overpressure (Pa)
HOB—Height of Burst (m); model limits: 0 to (4,000 · Y3)	QAIR—Air-burst peak dynamic pressure (Pa)
GR—Ground range (m); model limits: LM to (4000 · Y3)	TAAIR - Air-burst time-of-arrival (s)

(where Y3 = Y<sup>1/3</sup> and LM = 0 if HOB = (25 · Y3); otherwise LM=20 · Y3)

(note: all the trig functions use radians)

The scaled ground range is:  $SGR = GR/Y^{1/3}$  [1]

The scaled height of burst is:  $SHOB = H/Y^{1/3}$  [2]

The scaled slant range is:  $SR = (SGR^2 + SHOB^2)^{1/2}$  [3]

The DNA Standard 1-kilton free-air overpressure is given by the expression:

$$\Delta p_{DNA} = \frac{3.04 \cdot 10^{11}}{SR^3} + \frac{1.13 \cdot 10^9}{SR^2} + \frac{7.9 \cdot 10^6}{SR \left[ \ln \left[ \frac{SR}{445.42} + 3 \times \exp \left( \frac{-1}{3} \times \sqrt{\frac{SR}{445.42}} \right) \right] \right]^{1/2}} \quad [4]$$

$$\alpha = \tan^{-1}(SHOB / SGR) \text{ (radians) [5].}$$

The free-air peak overpressure is:  $\Delta p_{FREE} = \Delta p_{DNA}$  [6]

$$T = \frac{340}{\Delta p_{FREE}^{0.55}}, U = \left( \frac{7782}{\Delta p_{FREE}^{0.7}} + 0.9 \right)^{-1} \quad [7] \text{ \& [8]}$$

$$W = \left( \frac{7473}{\Delta p_{FREE}^{0.5}} + 6.6 \right)^{-1}, V = \left( \frac{647}{\Delta p_{FREE}^{0.8}} + W \right)^{-1} \quad [9] \text{ \& [10]}$$

The regular/Mach region merge angle:  $\alpha_m = \tan^{-1} \left( \frac{1}{T + U} \right)$  (radians) [11].

The width of the merge region:  $\beta = \tan^{-1}\left(\frac{1}{T + V}\right)$  (radians) [12].

$$s = (\alpha - \alpha_m) / \beta; s_o = \text{maximum}[\text{minimum}(s, 1), -1] \text{ [13] \& [14]}$$

The regular/Mach region switching parameter, used to merge the  $\Delta p_{MACH}$  and the  $\Delta p_{REG}$  terms, is given by the expression:  $\sigma = 0.5 \times [\sin(0.5 \cdot \pi \cdot s_o) + 1]$  [15].

There are 3 cases:

for  $\sigma = 0$ , do Eqs. [16]–[19]

for  $0 < \sigma < 1$ , do Eqs. [16]–[29]

for  $\sigma = 1$ , do Eqs. [20]–[29]

*Mach Reflection Region:*

$$A = \text{minimum}[3.7 - 0.94 \cdot \ln(\text{SGR}), 0.7] \text{ [16]}$$

$$B = 0.77 \cdot \ln(\text{SGR}) - 3.8 - 18/\text{SGR} \text{ [17]}$$

$$C = \text{maximum}(A, B) \text{ [18]}$$

Use  $\text{SGR}/2^{(1/3)}$  in place of SR in Equation [4] and compute  $\Delta p_{DNA}$ :

$$\Delta p_{MACH} = \frac{\Delta p_{DNA}}{1 - C \times \sin(\alpha)} \text{ [19]}$$

*Regular Reflection Region:* The incident shock strength, xi, is:  $xi = \Delta p_{FREE}/101,325 + 1$  [20]

$$t = 10^{-12} \cdot (xi)^6, \quad z = \ln(xi) - \frac{0.47 \times t}{100 + t} \text{ [21] \& [22]}$$

$$\text{The gamma, } g_s, \text{ behind the shock is: } g_s = 1.402 - \frac{3.4 \cdot 10^{-4} \times z^4}{1 + 2.22 \cdot 10^{-5} \times z^6} \text{ [23]}$$

$$\text{The shock mu, } \mu_s, \text{ is: } \mu_s = (g_s + 1)/(g_s - 1) \text{ [24]}$$

$$\text{The mass density ratio across the shock front is given by: } n = \frac{1 + \mu_s \times xi}{5.975 + xi} \text{ [25]}$$

$$\text{The normal reflection factor: } R_n = 2 + (g_s + 1)(n - 1)/2 \text{ [26]; } f = \Delta p_{FREE}/75,842 \text{ [27]}$$

$$D = \frac{f^6 (1.2 + 0.07 \cdot f^{0.5})}{f^6 + 1} \text{ [28]; } \Delta p_{REG} = \Delta p_{FREE} [(R_n - 2) \sin^D(\alpha) + 2] \text{ [29]}$$

All three cases (i.e., for different values of  $\sigma$ ) continue from here. Merging the regular and Mach region overpressure terms by means of the switching parameter,  $\sigma$ , gives the air-burst peak overpressure:

$$\text{PAIR} = (\Delta p_{REG})\sigma + (\Delta p_{MACH})(1 - \sigma) \text{ [30]}$$

Use PAIR in place of  $\Delta p_{\text{FREE}}$  and do Equations [20] through [25],  $n_q = n$  [31]

The air-burst dynamic pressure [sin() uses radians] is:

$$Q_{\text{AIR}} = 0.5PAIR(n_q - 1)[1 - \sigma \sin^2(\alpha)] \quad [32]$$

To determine the air-burst time of arrival first requires the computation of the scaled Mach stem formation range:  $x_m = SHOB^{2.5} / 5822 + 2.09 \cdot SHOB^{0.75}$  [33]

Then a scaling factor for the slant range is found: for  $SGR \leq x_m$ ,  $v = 1$ ; for  $SGR > x_m$ ,  $v = 1.26 - 0.26(x_m/SGR)$  [34]

Use the scaled range,  $R = SR/v$ , in the free-air time-of-arrival equation to compute the scaled air-burst time of arrival:

$$ta_{\text{AIR}} = \frac{R^2(6.7 + R)}{7.12 \cdot 10^6 + 7.32 \cdot 10^4 \times R + 340.5 \times R^2} \quad [36]$$

The unscaled air-burst time of arrival is then:  $TAAIR = ta_{\text{AIR}} Y^{(1/3)} v$  [37]

## 2.2 Overpressure Total Impulse

INPUT	OUTPUT
Y—Weapon yield (kT); model limits 0.1–25,000	IPTOTAL—Overpressure total impulse (Pa-s)
HOB—height of burst (m); model limits 0–4000 · Y <sup>3</sup>	
GR—Ground Range (m); model limits LM to 4000 · Y <sup>3</sup> (where LM = 0 if HOB = 25 · Y <sup>3</sup> m; otherwise LM = 20 · Y <sup>3</sup> m)	

The scaled ground range is:  $SGR = \text{maximum}(GR/Y^{(1/3)}, 10^{-7})$  [1]

The scaled height of burst is:  $SHOB = \text{maximum}(H/Y^{(1/3)}, 10^{-7})$  [2]

The scaled slant range is:  $SR = [SGR^2 + SHOB^2]^{0.5}$  [3]

Compute the scaled Mach stem formation range and the air-burst time-of-arrival by doing Equations [33] through [36] in section 2.1, above, and then determine the peak air-burst overpressure by doing Equations [4] through [32] in section 2.1, above.

Next, calculate the following time-independent waveform, parameters:

$$s = 1 - \frac{1}{1 + \frac{1}{4.5 \cdot 10^{-8} \times SHOB^7}} - \frac{\left[ \frac{5.958 \cdot 10^{-3} SHOB^2}{1 + 3.682 \cdot 10^{-7} (SHOB)^7} \right]}{\left[ 1 + \frac{(SGR)^{10}}{3.052 \cdot 10^{14}} \right]} \quad [4]$$

$$f = s \left[ \frac{2.627(ta_{AIR})^{0.75}}{1 + 5.836ta_{AIR}} + \frac{2341(ta_{AIR})^{2.5}}{1 + 2.541 \cdot 10^6 (ta_{AIR})^{4.75}} - 0.216 \right] + 0.7076 - \frac{3.077}{10^{-4}(ta_{AIR})^{-3} + 4.367} \quad [5]$$

$$g = 10 + s \left[ 77.58 - \frac{154(ta_{AIR})^{0.125}}{1 + 1.375(ta_{AIR})^{0.5}} \right] \quad [6]$$

$$h = s \left[ \frac{17.69ta_{AIR}}{1 + 1803(ta_{AIR})^{4.25}} - \frac{180.5(ta_{AIR})^{1.25}}{1 + 99,140(ta_{AIR})^4} - 1.6 \right] + 2.753 + \frac{56ta_{AIR}}{1 + 1.473 \cdot 10^6 (ta_{AIR})^5} \quad [7]$$

The following factor is used in the computation of the overpressure positive phase duration:

$$t_o = \frac{\ln(1000 \cdot ta_{AIR})}{3.77} \quad [8]$$

The scaled overpressure positive phase duration on the surface is given by:

$$dp_{SURF} = 10^{-3} \left[ 155 \exp(-20.8 \cdot ta_{AIR}) + \exp(-t_o^2 + 4.86t_o + 0.25) \right] \quad [9]$$

The unmodified scaled overpressure positive phase duration is:

$$dp_{UNMOD} = dp_{SURF} \left[ 1 - \left[ 1 - \frac{1}{1 + 4.5 \cdot 10^{-8} (SHOB)^7} \right] \times \left[ 0.04 + \frac{0.61}{1 + \frac{(ta_{AIR})^{1.5}}{0.027}} \right] \right] \quad [10]$$

The scaled overpressure positive phase duration for all heights of burst is:

$$dp_{\Delta p} = dp_{UNMOD} \left[ 1.16 \exp \left( \frac{\left| \frac{SHOB}{0.3048} - 156 \right|}{1062} \right) \right] \quad [11]$$

The equations on the following pages (Equations [12] through [19]) are primarily for double-peak overpressure waveforms. For single-peak waveforms the parameter dt is assumed to be zero.

If  $SGR < x_m$  or  $SHOB > 116$  then skip to Equation [20].

The approximation to the points where the two peaks are equal for

$$x_e = \frac{138.3}{1 + \frac{45.5}{SHOB}} \quad [12]$$

$$e = \max \left[ \min \left( \left| \frac{SGR - x_m}{x_e - SGR} \right|, 50 \right), 0.02 \right] \quad [13], \quad w = \frac{0.583}{1 + \frac{2477}{SHOB^2}} \quad [14]$$

The first peak to second peak ratio is given by:  $d = 0.23 + w + 0.27e + e^5(0.5-w)$  [15]

$$a = (d - 1) \left[ 1 - \frac{1}{1 + e^{-20}} \right] \quad [16]$$

The approximate time separation between the peaks is:

$$dt = \max \left[ \frac{SHOB}{8.186 \cdot 10^5} \times [SGR - x_m]^{1.25}, 10^{-12} \right] \quad [17]$$

$$v_o = \frac{SHOB^6}{2445 \left[ 1 + \frac{(SHOB)^{6.75}}{3.9 \cdot 10^4} \right] (1 + 9.23e^2)} \quad [18], \quad c_o = \frac{\left[ 1.04 - \frac{1.04}{1 + \frac{3.725 \cdot 10^7}{(SGR)^4}} \right]}{(a + 1) \left[ 1 + \frac{9.872 \cdot 10^8}{(SHOB)^9} \right]} \quad [19]$$

Using the time-independent parameters computed in the previous equations (Equations [4] through [19]), the following equations represent overpressure versus time. For any time t such that:

$$ta_{AIR} \leq t \leq ta_{AIR} + dp_{\Delta p}, \text{ first set the waveform positive phase duration: } dp = dp_{\Delta p}. \quad [20]$$

Then, using f, g and h from Equations [5], [6] and [7] respectively, for any time t since the burst,

$$b = \left[ f \left[ \frac{ta_{AIR}}{t} \right]^g + (1 - f) \left[ \frac{ta_{AIR}}{t} \right]^h \right] \times \left[ 1 - \frac{t - ta_{AIR}}{dp} \right] \quad [21]$$

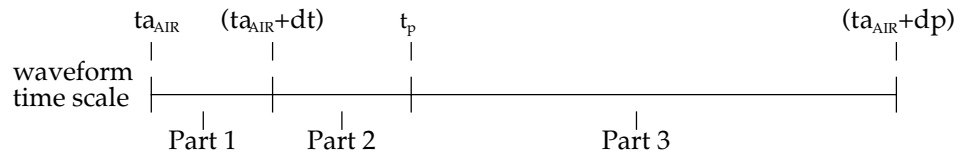
If  $SGR = x_m$  and  $SHOB = 116$ , then do Equations [23] through [26]; otherwise, the overpressure at time t is given by:  $\Delta p_t = (PAIR) \cdot b$  [22]

$$g_a = \max \left[ \min \left[ \frac{t - ta_{AIR}}{dt}, 400 \right], 0.0001 \right] \quad [23], \quad v = 1 + \frac{v_o g_a^3}{g_a^3 + 6.13} \quad [24]$$

$$c = c_o \left[ \frac{1}{g_a^{-7} + 0.923g_a^{1.5}} \right] \times \left[ 1 - \left[ \frac{t - ta_{AIR}}{dp} \right]^8 \right] \quad [25]$$

The overpressure at time t is then given by:  $Dpt = (PAIR)(1+a)(b \cdot v + c)$  [26]

The overpressure total impulse is now found by numerically integrating the above equations (either Equations [21] and [22], or Equations [21], and [23] through [26]). The technique used by the programs BLAST and WE to do the numerical integration is the Gauss-Legendre Quadrature. The waveform is partitioned into 2 or 3 parts (depending on whether the waveform is single-peaked or double-peaked). The time parts are as illustrated below:



where  $t_p = (13ta_{AIR} + dt + dp)/14$ . If the waveform is single-peaked assume  $dt$  is zero and ignore Part 1. Part 1 is numerically integrated using a 4-point Gauss-Legendre Quadrature. Parts 2 and 3 are each integrated using an 8-point Gauss-Legendre Quadrature with time in log-space [that is,  $\ln(t)$  is the independent variable, not  $t$ ]. The overpressure total impulse is then

$IPTOTAL = (\text{sum})Y^{1/3}$  [27], where  $\text{sum} = \text{Gauss-Legendre Quadrature sum}$ .

### 2.3 Dynamic Pressure Total Impulse

Y—Weapon yield (kT); model limits 0.1–25,000

HOB—Height of burst (m); model limits 0 – 750 · Y3

GR—Ground range (m); model limits LM to 4000 · Y3

LM = maximum(1.3 · XM, 80 · Y3), XM · Mach stem formation range

IQTOTAL—Dynamic pressure total impulse (Pa-s)

(All trig functions use radians)

The dynamic pressure waveform is a function of the overpressure waveform; consequently, many of the equations from section 2.2 OVERPRESSURE TOTAL IMPULSE are needed. To begin, do Equations [1] through [8] from that section.

Then,  $SHOB_o = SHOB/0.3048$  [1],  $SGR_o = SGR/0.3048$  [2],  $SHOB_x = \text{abs}(SHOB_o - 200) + 200$  [3],  $SGR_x = SGR_o - 1000$  [4],  $dp_o = 0.3 + 0.42 \cdot \exp(-SHOB_x/131)$  [5]

$$dp_x = \begin{cases} dp_o + 4.4 \cdot 10^{-5} SGR_x, & SGR_x > 0 \\ dp_o + SGR_x \left[ \frac{1}{2361} - \frac{|SHOB_x - 533|^2}{7.88 \cdot 10^7} \right], & SGR_x \leq 0 \end{cases} \quad [6]$$

The scaled dynamic pressure positive phase duration is:

$$dp_q = \begin{cases} dp_x, SHOB_0 \geq 200 \\ dp_x [1 + 0.2 \sin(SHOB_0 \cdot \pi / 200)], SHOB_0 < 200 \end{cases} \quad [7]$$

where the  $\sin()$  argument is in radians. Next, the waveform parameters in Equations [12] through [19] from section 2.2 OVERPRESSURE TOTAL IMPULSE need to be computed. The remaining dynamic pressure waveform parameters appear below:

$$\delta_o = \max \left[ \frac{(SHOB_0)^{1.52}}{16,330} - 0.29, 0 \right] \quad [8]$$

The dynamic pressure waveform decay exponent is:

$$\delta = 2.38 \exp \left[ -7 \cdot 10^{-7} |SHOB_0 - 750|^{2.7} - 4 \cdot 10^{-7} (SGR_0)^2 \right] + \delta_o \quad [9]$$

The dynamic pressure waveform multiplier is:  $q_o = 0.5 \{1 - \sigma [\sin(\sigma)]^2\}$  [10]

where  $\sigma$  is from Equation [15], and  $\alpha$  is from Equation [5] (both equations are found in section 2.1 PEAK PRESSURES & BLAST WAVE TIME OF ARRIVAL) and  $\sin()$  is in radians.

Using the time-independent parameters computed in the previous equations (Equations [12] through [19] from the HELP section OVERPRESSURE TOTAL IMPULSE), the following equations represent dynamic pressure versus time. For any time  $t$  such that:  $ta_{AIR} \leq t \leq ta_{AIR} + dp_q$ , first set the waveform positive phase duration:  $dp = dp_q$ . [20] Next, do Equations [21] through [26] from section 2.2 OVERPRESSURE TOTAL IMPULSE as needed to compute  $\Delta p_t$ .

Do Equations [20] through [25] from section 2.1 PEAK PRESSURES & TIME-OF-ARRIVAL using  $\Delta p_t$  in place of  $\Delta p_{FREE}$ .  $n_q = n$  [12].

The dynamic pressure at time  $t$  is given by:

$$q_t = 0.5 \Delta p_t (n_q - 1) \left[ \frac{\Delta p_t}{PAIR} \right]^\delta \quad [13]$$

The dynamic pressure total impulse is not found by numerically integrating Equation [13] above (which requires Equations [21] and [22], or Equations [21], and [23] through [26] from section 2.2 OVERPRESSURE TOTAL IMPULSE).

#### 2.4) Overpressure Partial Impulse

Y—Weapon yield (kT); model limits 0.1–25,000

HOB—Height of burst (m); model limits 0–4000 · Y3

GR—Ground range (m); model limits LM–4000 · Y3

TIME—Time after time of arrival (s); model limits 0–DPP

where LM = 0 if HOB = 25 Y3 (meters); otherwise LM = 20 Y3 (meters); DPP = overpressure positive phase duration

IPPART—Overpressure partial impulse (Pa-s)

The equations needed to compute the overpressure partial impulse are almost identical to those used in the calculation of overpressure total impulse (whose equations are found in section 2.2 OVERPRESSURE TOTAL IMPULSE). The only difference is that the upper limit for the integration of the waveform has changed. The upper limit should be:  $ta_{AIR} + (TIME) / Y^{1/3}$  [1]

The overpressure partial impulse is given by:  $IPPART = (sum)Y^{1/3}$  [2], where sum = Gauss-Legendre Quadrature sum.

### 2.5 Dynamic Pressure Partial Impulse

Y—Weapon Yield (kT); model limits 0.1–25,000

HOB—Height of burst (m); model limits 0–750 Y3

GR—Ground range (m); model limits LM-4000 Y3

TIME—Time after time of arrival (s); model limits 0-DPQ

where LM = maximum(1.3 XM, 80 Y3), XM = Mach stem formation range, and

DPQ = dynamic pressure positive phase duration

IQPART—Dynamic pressure partial impulse (Pa-s)

The equations needed to compute the overpressure partial impulse are almost identical to those used in the calculation **dynamic pressure total impulse** (whose equations can be found in section 2.2 DYNAMIC PRESSURE TOTAL IMPULSE). The only difference is that the upper limit for the integration of the waveform has changed. The upper limit should be:

$$ta_{AIR} + (TIME) / Y^{1/3} \text{ [3]}$$

The dynamic pressure partial impulse is given by:  $IQPART = (sum)Y^{1/3}$  [4], where sum = Gauss-Legendre Quadrature sum.

**2.6 Time-Dependent Overpressure:** Inputs and limits are the same as the calculation-overpressure partial impulse.

PT—Time-dependent overpressure (Pa)

The time-dependent overpressure is computed as in the calculation **overpressure total impulse**. Those equations can be found in section 2.2 OVERPRESSURE TOTAL IMPULSE). It is not necessary to do the equations related to the integration of the overpressure waveform.

The time-dependent overpressure for the given time,  $t = (TIME)/Y^{1/3}$  [5]

is found in Equation [22] (for single-peak waveforms) or Equation [26] (for double-peak waveforms) in section 2.2 OVERPRESSURE TOTAL IMPULSE.

$$PT = \Delta p_t \text{ [6]}$$

**2.7 Time-Dependent Dynamic Pressure: Inputs and limits are the same as the calculation dynamic pressure partial impulse.**

QT—Time-dependent dynamic pressure (Pa)

The time-dependent dynamic pressure is computed as in the calculation dynamic pressure total impulse (whose equations can be found in the HELP section DYNAMIC PRESSURE TOTAL IMPULSE). It is not necessary to do the equations related to the integration of the dynamic pressure waveform.

The time-dependent dynamic pressure for a given time,  $t = (\text{TIME})/Y^{1/3}$  [7] is found in Equation [13] in section 2.3 DYNAMIC PRESSURE TOTAL IMPULSE.

$$QT = q_t \text{ [8]}$$

### 2.8 Overpressure Positive Phase Duration

Y—Weapon yield (kT); model limits 0.1–25,000

HOB—Height of burst (m); model limits 0–4000 Y3

GR—Ground range (m); model limits LM-4000 Y3

where LM = 0 if HOB = 25 Y3 m; otherwise LM = 20 Y3 (meters).

DPP—Overpressure positive phase duration (s)

First, compute the scaled ground range (SGR) and scaled height of burst (SHOB) as shown in Equations [1] and [2] from section 2.2 OVERPRESSURE TOTAL IMPULSE. The scaled overpressure positive phase duration can then be computed using Equations [8] through [11] from the same section. The unscaled overpressure positive phase duration is given by:  $DPP = (dp_{\Delta p})Y^{1/3}$  [9].

### 2.9 Dynamic Pressure Positive Phase Duration

Y—Weapon yield (kT); model limits 0.1–25,000

HOB—Height of burst (m); model limits 0–750 Y3

GR—Ground range (m); model limits LM-4000 Y3

where LM = maximum(1.3 XM, 80 Y3), and XM = Mach stem formation range

DPQ—Dynamic pressure positive phase duration (s)

First, compute the scaled ground range (SGR) and scaled height of burst (SHOB) as shown below. The scaled ground range is:  $SGR = \text{maximum}(GR/Y^{1/3}, 10^{-7})$  [10]

The scaled height of burst is:  $SHOB = \text{maximum}(H/Y^{1/3}, 10^{-7})$  [11]

The scaled dynamic pressure positive phase duration can then be computed using Equations [1] through [7] from section 2.3 DYNAMIC PRESSURE TOTAL IMPULSE.

The unscaled dynamic pressure positive phase duration is given by:

$$DPQ = (dp_q)Y^{1/3} \text{ [12].}$$

### 2.10 Mach Stem: Formation Range and Triple Point Height

Y—Weapon yield (kT); model limits 0.1–25,000

HOB—Height of burst (m); model limits 0–800 Y3

GR—Ground range (m); model limits LM-4000 Y3

where Y3 =  $Y^{1/3}$ , LM = maximum(XM, 20 · Y3), XM = Mach stem formation range

XM—Mach stem formation range (m)

HTP—Height of triple point (m)

The scaled ground range is:  $SGR = GR/Y^{1/3}$  [1]. The scaled height of burst is:  $SHOB = H/Y^{1/3}$  [2]. The scaled Mach stem formation range is:  $x_m = SHOB^{2.5}/5822 + 2.09SHOB^{0.75}$  [3] and the unscaled formation range is:  $XM = x_m Y^{1/3}$  [4].

$$S = (5.98 \cdot 10^{-5} SHOB^2 + 3.8 \cdot 10^{-3} SHOB + 0.766)^{-1} \quad [5]$$

$$h = 0.9x_m - 3.6 \cdot SHOB \quad [6].$$

The unscaled height of the triple point is:

$$HTP = S \left\{ h + \left[ h^2 + (SGR - 0.9x_m)^2 - x_m^2 / 100 \right]^{0.5} \right\} \times Y^{1/3} \quad [7]$$

### 3. Initial Radiation Calculations: Total Dose, Neutron Dose, and Gamma Dose

Y—Yield(kT); model limits 0.1–25,000

AIR—Air Density Ratio; model limits  $0.6 \leq AIR \leq 1.0$

H—Height of burst (m); model limits  $1.5/AIR \leq H \leq 10,000/AIR$

GR—Ground range (m); model limits  $x/AIR \leq GR \leq y/AIR$

where, for neutron and secondary gamma doses doses,  $x = [\text{maximum}(0, 10^4 - H^2)]^{1/2}$ ; for all other doses,

$$x = \{\text{maximum}[0, (150 \text{ maximum}[1, Y^{1/3}]^2 - H^2)]^{1/2}\}; y = (10^8 - H^2)^{1/2}$$

FF—Fission fraction; model limits  $0.0 \leq FF \leq 1.0$

WT—Weapon type; model limits 1–13

N—Neutron component of total dose (rad(tis))

SG—Secondary-gamma component of total dose (rad(tis))

FFG—Fission-fragment-gamma component of total dose (rad(tis))

TD—Total dose (rad(tis))

DS—Total dose (rad(sil))

N/G—Neutron-to-gamma dose ratio

(all trig functions use radians)

The component doses are:

$$N = D_n C_n YAIR^2 \quad [1]$$

$$SG = D_g C_g YAIR^2 \quad [2]$$

$$FFG = D_{ff} C_f H_e Yff \quad [3]$$

And the total dose (in tissue) is the sum of components,

$$TD = N + SG + FFG \quad [4]$$

Common factors: The slant range is:  $SR = (GR^2 + H^2)^{1/2}$  [5]

Air-density scaled slant range:  $SR_o = (AIR)(SR)$  [6]

Air-density scaled height of burst:  $H_o = (AIR)(H)$  [7]

Height of burst switching parameter for  $C_g$  and  $C_n$ :  $s = \text{minimum}\{1, \text{maximum}[-1, (H_o - 277)/50]\}$  [8]

$$\sigma = 0.5 [1 + \sin(s \pi/2)] \quad [9]$$

Neutron Dose Yield-scaled factor:  $D_n = [a/(SR_o)^c] \exp[b(SR_o)]$  [10]

where  $a = 10^6 a'$ ,  $b = -(500 + b')/105$ ,  $c = 1 + c'/1000$  [11], [12], and [13]

and the coefficients  $a'$ ,  $b'$  and  $c'$  for  $D_n$  are as follows:

WT	a'	b'	c'
1 & 3	253	71	138
2	98	49	225
4, 7 & 11	394	31	261
5	347	52	147
6	177	67	152
8	450	24	323
9	753	-13	482
10	272	13	933
12	300	-13	492
13	1431	-2	63

Secondary-Gamma Dose Yield-Scaled Factor:  $D_g = [a/(SR_o)^c] \exp[b(SR_o)^d]$  [14]

where for WT = 10: a = 13.5, b = -0.344, c = -1.537, d = 0.5173 [15-18]

and for all other WT's: a =  $\text{antilog}_{10}(a'/100)$ , [19] b =  $-(193+b')/10^4$ , [20]

c =  $c'/1000$ , [21] d = 0.8 [22]

and the coefficients a', b' and c' for  $D_g$  are as follows:

COEFFICIENTS FOR $D_g$			
WT	a'	b'	c'
1	357	32	-188
2	605	0	793
3 & 6	433	27	68.8
4, 5, 7, 9, & 11	542	14	439
8	490	18	297
12	604	7	633
13	722	8	651

Fission-fragment-gamma Dose Yield-scaled factor:

$$D_{ff} = 1.42 \cdot 10^7 / (SR_x)^{0.9516} \times \exp[-(SR_x)^{0.774} / 32.7] \quad [23]$$

where  $SR_x = \text{Sgn}(SR - 140)|SR - 140|^p + 140$  [24]

$\text{Sgn}(x) = -1$ , for  $x < 0$ ; 0 for  $x = 0$ ; +1 for  $x > 0$  [25]

and  $p = \text{AIR}(0.264 - \text{AIR}/12.6) + 0.815$  [26]

Secondary Gamma Dose Height of Burst Correction Factor:  $C_g = a + \exp\{b+c[1-\exp(4 \times 10^{-5}(SR_o))]\}$  [27]

where  $H_x = \text{minimum}(1000, H_o)$ ; for WT = 13,  $C_{g\text{max}} = 1.1$ ,  $a_o = 0.002$  [28-30]

$$b = -2.12 + \exp(H_x^{0.903} / 204) + 0.977(1 - \sigma) \quad [31]$$

and for all other WT's:  $C_{g\text{max}} = 1$ ,  $a_o = 0.0035$ , [32-33]

$$b = b' / 100 + \exp[H_x^{0.88} / (b' + 192)] + (1 - \sigma)\pi / 6 \quad [34]$$

and then for all WT's:  $x = 0.9 - a'/1000$ ,  $t_1 = a_o H_o^x$ ,

$$t_2 = a_o 277^x + 0.00011 H_o^{(1+a'/100)} \quad [35-37]$$

$$a = \text{minimum}[C_{g\text{max}}, 0.31 + (1 - \sigma)t_1 + \sigma t_2], c = c' + (\sigma/c'')\text{maximum}(0, H_x - 277)^{1.4} \text{ [38-39]}$$

and the coefficients  $a', a'', b', b'', c'$  and  $c''$  for  $C_g$  are as follows:

COEFFICIENTS FOR $C_g$						
WT	$a'$	$a''$	$b'$	$b''$	$c'$	$c''$
1, 3 & 4	59	9	8	5	98	108
2, 6 & 10	61	9	34	13	108	142
5	50	11	-25	1	90	92
7 & 12	42	12	-4	2	100	93
8, 9 & 11	44	11	-43	0	86	87
13	-87	12	0	0	62	84

*Fission fragment Gamma Dose Correction Factor:* Based on ATR 4.1 DTA as modified by SAI for yields below 1 MT: The yield-scaled height of burst:

$$SH = \text{minimum}(H/Y^{1/3}, 250), s_f = \sin[1.16 \log(Y) - 1.39], z = (\log(Y) - 1.4)/3.5 \text{ [40-42]}$$

$$C_f = 0.5 \left[ z + (z^2 + 0.044)^{1/2} \right] (AIR) \left[ 1 - \frac{SH}{125} \right] + 0.038 \text{Log}(Y) - 0.22 + \text{ [43]}$$

$$\left[ \frac{GR}{1000} - 0.65 \log(Y) - 0.4 \right] 0.075 \left[ s_f + 2|s_f|(AIR - 0.9) \right]$$

$$C_f = \text{antilog}_{10}(C_f). \text{ [44]}$$

*Fission Fragment Gamma Dose Hydrodynamic Enhancement Factor:* For Y less than 1 do only Equation [45] otherwise do Equations [46-52]:

$$H_e = 1 \text{ [45]}. \text{ Otherwise for Y greater than or equal to 1: } A_H = \text{antilog}_{10}[a(\log_{10} Y)^b] \text{ [46]}$$

where  $a = 0.1455 \text{ AIR} - 0.0077 \text{ [47]}$ ;  $b = 2.55 - 0.35 \text{ AIR} \text{ [48]}$

$$B_Y = 1 - [1 + c(\log_{10} Y)^{2.6}] \exp[-d(\log_{10} Y)^{2.6}] \text{ [49]}, \text{ where } c = 0.05875 \text{ AIR} + 0.004 \text{ [50]}$$

$$d = 0.04 \text{ AIR} - 0.03 \text{Sgn}(\text{AIR} - 0.6) |\text{AIR} - 0.6|^{1.3} \text{ [51]}$$

$$H_e = \text{minimum}\{A_H \exp[B_Y(SR/1000)], \exp[(-0.26 + 2.563 \text{ AIR})(SR/1000)]\} \text{ [52]}$$

*Neutron Dose Height of Burst Correction Factor:*  $C_n = a + b \exp[-c(SR_o^d)] \text{ [53]}$

where

$$t_1 = 0.205 + 2.2 \cdot 10^{-3} H_o^{0.839}, t_2 = 0.4514 + H_o^{1.636} / 637^2,$$

$$a = \text{minimum}[1, (1 - \sigma)t_1 + \sigma t_2] \text{ [54-56]}$$

$$t_3 = 0.388 + 0.116 H_o^{0.27}, t_4 = 0.9176 + H_o^{3.726} / 1.78 \cdot 10^{10}, b = (1 - \sigma)t_3 + \sigma t_4 \text{ [57-59]}$$

$$c = 8 \cdot 10^{-4} + 0.0728 / (H_o^{1.23} + 23.6), d = 0.9 \text{ [60-61]}$$

If  $H_o$  is greater than 1 do Equation [62]:  $d = 0.9 + \ln(H_o)/25 \text{ [62]}$

The neutron dose/gamma-ray dose ratio,  $N/G = N/[(SG) + (FFG)] \text{ [63]}$

The total dose (in silicon) is:  $DS = FFG + SG + f_n N$  [64]

for WT not 10 nor 13,  $f_n = 0.015$  [65], for WT = 10  $f_n = \exp[(SR)/800]/250$  [66],

for WT = 13  $f_n = \exp[-(SR)/234.7]/20 + \exp[-(SR)/4329]/25$  [67]

#### 4. Thermal Equations

If the quantity calculated is *transmittance*, then it includes both direct and scattered thermal radiation.

##### Calculation: Thermal Fluence

Y—Yield (kT); model limits 0.1–25,000

H—Height of burst (m); model limits 0–1500 · Y<sup>1/3</sup>

GR—Ground range (m); model limits  $x \neq GR \leq 2200 \cdot Y^{1/3}$

where  $x = \max\{[(100 \cdot Y^{1/3})^2 - H^2], 0\}^{1/2}$

VIS—Visibility (m); model limits 10,000 ≤ VIS ≤ 80,000

FLUE—Thermal fluence to ten times the time of second maximum of the thermal output (cal/cm<sup>2</sup>)

The slant range is:  $SR = (H^2 + GR^2)^{1/2}$  [1], The transition height of burst is  $H_T = 4 \cdot Y^{1/3}$  [2].

Surface Burst Equations:  $A_1 = 0.32 \left[ 1 - \exp(-12Y^{-VIS/17000}) \right]$  [3]

$B_1 = -(\log_{10} Y)^2 / 275 + 0.0186 \log_{10} Y - 1/40$  [4],  $A_2 = [(30 \cdot Y^{-0.26})^4 + 1350]^{-1/4}$  [5],

$B_2 = -(1.457 / VIS + 9.3 \cdot 10^{-6})$  [6]

$F_5 = A_1 \exp(B_1 \cdot SR) + A_2 \exp(B_2 \cdot SR) + 0.006$  [7]

Air Burst Equations:  $A_3 = H^{3/2} / (5 \cdot 10^7) + 97 / (281 + Y^{1/2})$  [8],

$B_3 = (0.139 / H) [\exp(-8 \cdot H / VIS) - 1]$  [9]

$F_A = A_3 \exp(B_3 \cdot SR)$  [10]

Transition Region Equations: For  $H \geq H_T$ ,  $F = F_A$ , for  $0 \leq H < H_T$ ,

$F = F_A (H / H_T) + F_5 (1 - H / H_T)$  [11]

$Q = 8 \cdot 10^6 Y / SR^2$  [12]

#### 5. Fallout Equations

##### 5.1 One-Hour Dose Rate and Debris Arrival Time

Y—Yield (kT); model limits 0.1–25,000

H—Height of Burst (m); model limits 0–4000

DW—Downwind ground range (m); model limits 0–10<sup>6</sup>

CW—Crosswind ground range (m); model limits 0–40,000

W—Effective wind speed (kn); model limits 1–40

SY—Crosswind shear (kn/kft); model limits 0–10

FF—Fission fraction; model limits 0–1

DH+1—One-hour dose rate (roentgen/hr)

T0—Debris arrival time (hours)

MBD—Max. biological dose (roentgen)

$\hat{H} = H / 0.3048$  [1], for  $\hat{H} = 0$ , do Equation [2]: AF = 1 [2]. For  $\hat{H} > 0$ , do Eqs. [3] and [4]:

$z = 0.01 \cdot \hat{H} / Y^{0.4}$  [3], For  $z > 1$ , AF = 0. [4a] If  $z = 1$ , AF =  $0.5(1-z)^2(2+z) + 0.001 \cdot z$  [4b]

$Y_m = Y / 1000$  [5]

$$\text{Cloud radius (nautical miles), for } Y = 1: \sigma_0 = Y_m^{1/3} \exp\left(0.56 - \frac{3.25}{\left[4 + (\ln Y_m + 5.4)^2\right]}\right) \quad [6a],$$

and for  $Y < 1$ ,  $\sigma_D = 0.1 \cdot Y^{0.2665}$  [6b]

Cloud height (kilofeet), for  $Y = 1$ :

$$h_0 = 44 + 6.1 \ln Y_m - 0.205 \cdot \left[ \ln Y_m + 2.42 \right] \cdot \left| \ln Y_m + 2.42 \right| [7a].$$

For  $Y < 1$ ,  $h_0 = 6 \cdot Y^{0.25}$  [7b].

Cloud duration (hours):

$$T = 1.057 \cdot h_0 (0.2 - h_0 / 1440) \left[ 1 - \exp(-h_0^2 / 625) / 2 \right] [8]$$

Cloud thickness (kilofeet):  $\sigma_h = 0.18 \cdot h_0$  [9]

Effective particle distance (nautical miles):  $L_0 = W \cdot T_0$  [10]

Change in fallout distribution:  $\sigma_x = \sigma_0 \left[ \left( L_0^2 + 8\sigma_0^2 \right) / \left( L_0^2 + 2\sigma_0^2 \right) \right]^{1/2}$  [11]

A modified form of  $L_0$ :  $L = \left[ L_0^2 + 2\sigma_x^2 \right]^{1/2}$  [12]

Constant for symmetry,  $N = \left( L_0^2 + \sigma_x^2 \right) / \left( L_0^2 + 0.5\sigma_x^2 \right)$  [13]

Downwind distance (nautical miles),  $d = DW / 1853$  [14]

Crosswind distance (nautical miles),  $c = CW / 1853$  [15]

Area reduction factors:  $\alpha_1 = (1 + 0.001 \cdot h_0 \cdot W / \sigma_0) - 1$  [16]

$$\alpha_2 = \left\{ 1 + \frac{0.001 h_0 W}{\sigma_0 [1 - \Phi(2d / W)]} \right\}^{-1} [17]$$

Where  $\phi(u)$ , the cumulative normal distribution function, is approximated by the expression:  $\phi(u) = [1 + \exp(-1.5976u - 0.0706 u^3)]^{-1}$  [18]

The crosswind spread parameter,  $\sigma_y = \{\sigma_0^2 R + 2(P\sigma_x)^2 + (PQL_0)^2\}^{1/2}$  [19]

where  $P = (SY)T_1\sigma_h/L$  [20],  $Q = |d + 2\sigma_x| / L$  [21], and  $R = \text{minimum}[4, 1+8Q]$  [22]

The crosswind transport function:  $F_1 = \frac{\exp\left[-\left(c / \{\alpha_2\sigma_y\}\right)^2 / 2\right]}{\sigma_y[2\pi]^{1/2}}$  [23]

The downwind transport function:  $F_2 = \Phi\left(\frac{L_0 d}{L\alpha_1\sigma_x}\right)$  [24]

The deposition function,  $F_3 = \frac{\exp\left(-\left|\frac{d}{L}\right|^N\right)}{L \cdot \Gamma\left(1 + \frac{1}{N}\right)}$  [25], where the gamma function is

approximated by the expression:  $\Gamma(u) = 0.994 - 0.446(u-1) + 0.455(u-1)^2$ ,  $1 \leq u \leq 2$  [26]

$F = F_1 \cdot F_2 \cdot F_3$  [27]

The one-hour dose rate,  $DH+1 = 1,510 \cdot (Y) \cdot (FF) \cdot (AF) \cdot (F)$  [28]

The debris arrival time,  $T_0 = \left\{0.25 + \frac{(L_0 Q T_i)^2 + 2\sigma_x^2}{L_0^2 + 0.5\sigma_x^2}\right\}^{1/2}$  [29]

The maximum biological dose can be found using the equations on the following pages:

### 5.2 Maximum Biological Dose Rate

$T_0$ —Debris arrival time (hr); model limits 0.5–550

$DH+1$ —One-hour dose rate (roentgen/hr); model limits 0– $10^9$

$MBD$ —Max. biological dose (roentgen)

$z = \ln(T_0)$  [30],  $MBD = (DH + 1)\left(2.737 - 0.7809z_0 + 2z_0^2 / 29 - z_0^3 / 617\right)$  [31]

### 5.3 t-Hour Dose Rate Given One-Hour Dose Rate

$T$ —measurement time (hr); model limits 0.1–5000

$DH+1$ —One-hour dose rate (roentgen/hr); model limits 0–10

$DT$ —t-hour dose rate (roentgen/hr)

The t-hour dose rate:  $DT = (DH+1)T^{-1.2}$  [32]

**5.4 One-Hour Dose Rate Given t-Hour Dose Rate**

T—Measurement time (hr); model limits 0.1–5000

DT—t-hour dose rate (roentgen/hr); model limits 0–10<sup>9</sup>

DH+1—One-hour dose rate (roentgen/hr)

The one-hour dose rate,  $DH+1 = (DT)T^{1.2}$  [33]

**5.5 Total Fallout Dose**

TI—Initial exposure time (hr); model limits 0.1–5000

TEXP—Exposure duration (hr); model limits 0 to (5000-TI)

DH+1—One-hour dose rate (roentgen/hr); model limits 0–10<sup>9</sup>

FD—Total fallout dose (roentgen)

The fallout total dose:  $FD = 5(DH + 1) \left[ TI^{-0.2} - (TI + TEXP)^{-0.2} \right]$  [34]

**6. Cratering Equations**

*Definitions:*

**Fallback:** Material that was lifted or thrown out by the explosion and has fallen back within the true crater

**True crater:** the approximate boundary between the fallback material and the rupture zone (the shape of the true crater is disguised by the fallback)

**Apparent crater:** the crater that is visible on the surface, the dimensions being measured between fallback and the original ground surface elevation

**Above-Surface Burst:**  $HOB/Y^{1/3} > 0$  (Bursts of most significance to cratering are for  $HOB < Y^{1/3}(3 \text{ m}/kT^{1/3})$ ); **Contact Burst:**  $HOB \sim 0.5 \text{ m}$ ; **Surface Burst:**  $HOB = 0.$ ;

**Shallow-Buried Burst:**  $0 > HOB/Y^{1/3} > -5\text{m}/kT^{1/3}$ ; **Deep-Buried Burst:**  $HOB/Y^{1/3} < 5 \text{ m}/kT^{1/3}$ .

**INPUT**

Y—Yield (kT); model limits 0.1-25,000

HOB—Height of Burst; model limits  $-40Y^{1/3}$  to  $3Y^{1/3}$

GR—Ground range from burst point (m); model limits  $1.8*CR \leq GR \leq 10,000$  (CR is the apparent crater radius)

T1—Thickness of material layer #1 (m); model limits 0-1000

T2—Thickness of material layer #2 (m); model limits 0-1000

T3—Thickness of material layer #3 (m)

M1, M2 & M3—Geologic material types:  
1=Dry Soil, 2=Wet Soil, 3=Dry Soft Rock,  
4=Wet Soft Rock, 5=Hard Rock

**OUTPUT**

SV—Scaled apparent crater volume (m<sup>3</sup>)

V—Apparent crater volume (m<sup>3</sup>)

CR—Apparent crater radius (m)

CD—Apparent crater depth (m)

EJ—Depth of the ejecta or debris (m)

### 6.1 Crater Dimensions and Ejecta Thickness

The first scaled depth of burial is:  $S_1 = -HOB/Y^{1/3}$  [1].

The second scaled depth of burial is:  $S_2 = -HOB/Y^\alpha$  [2], where  $\alpha$  is the volume scaling exponent.

The volume scaling exponent,  $\alpha$ , varies with material type and burst location. The burst location falls into three regions: air burst, near-surface buried, and deeply buried. The yield also falls into three regions: 1 kT or less, 1 to 20 kT (interpolation region), and greater than 20 kT. Weapons with high radiative output use the 20 kT scaling exponent for all yields. Normal radiative output weapons use an interpolation in the 1 to 20 kT region.

For all material types, and for  $Y < 1$  kT:

$$\alpha_1 = \begin{cases} 1/3, & \text{for } -3 \leq S_1 \leq 0.15 \\ 0.2946 + \frac{\exp[-(S_1) \log_{10}(583)]}{305^{1/2}}, & \text{for } -0.15 \leq S_1 \leq 5 \text{ [3]} \\ 1/3.4, & \text{for } S_1 > 5 \end{cases}$$

For all material types except dry Soil, and for  $Y > 20$  kT:  $\alpha_{20} = 1/3.4$  [4]

For dry soil, and for  $Y > 20$  kT:

$$\alpha_{20} = \begin{cases} 1/3.1, & \text{for } -3 \leq S_1 \leq 0 \\ 1 / [3.4 - 0.3 \exp(-2.2 \cdot S_1)], & \text{for } 0 \leq S_1 \leq 5 \text{ [5]} \\ 1/3.4, & \text{for } S_1 > 5 \end{cases}$$

For  $Y < 1$  kT the scaling exponent is:  $\alpha = \alpha_1$  [6]

For  $Y > 20$  kT the exponent is:  $\alpha = \alpha_{20}$  [7]

and for the interpolation region ( $1 \text{ kT} \leq Y \leq 20 \text{ kT}$ ) do equations [8] and [9]:

For weapons with high radiative output,  $g = 0$ , and for weapons with low radiative output:

$$g = 1 - \text{minimum}\{1, \text{maximum}[0, \log(Y)/\log(20)]\}. \text{ [8]}$$

The interpolated  $\alpha$  scaling exponent is:  $\alpha = \alpha_{20} + g\{\alpha_1 - \alpha_{20}\}$  [9]

The non-deeply-buried scaled crater volume,  $SV$ , for all cases except for  $Y > 20$  and dry soil, is given by:

$$SV = (L/J) \text{antilog}_{10}[K(\exp(F(S_2)+G(S_2)^2)-1)+D(S_2)],$$

where coefficients  $K, F, G, D, L,$  and  $J$  are tabulated below:

Region	F	G	D	K	L
Y = 1, Buried	-1.05	-0.105	0.0573	-0.5	16989
Y = 1, Air	0.258	0.01	0.1	1.9	16989
Y = 20, Buried	-2	-0.3044	0.0707	-0.9059	5663
Y = 20, Air	0.53	0.028	-1/46	1.74	5663

Material Type	Material No.	J
Dry soil*	1	4
Wet soil	2	1
Dry soft rock	3	5
Wet soft rock	4	2
Hard rock	5	8

\* for Y < 1 kT only

The non-deeply-buried scaled crater volume for Y>20 kT and for dry soil is given by:

$$SV = 354 \text{ antilog}_{10}[0.506\{\exp(2.6(S2)+0.486(S2)^2)-1\}+2(S2)/9], \text{ for } -3 \leq S2 \leq 0 \text{ [10]}$$

$$SV = 354 \exp\{[1-\exp(-3.967(S2)^{1.139})]\{4.283-0.0515[5-S2]^{2.068}\}\}, \text{ for } 0 < S2 \leq 5 \text{ [11]}$$

The scaled crater volume for deeply-buried bursts, for all material types is give by:

$$SV = \exp(P + Q(S2) + R(S2)^2) - S, \text{ } 5 < S2 \leq 40 \text{ [12]},$$

where the coefficients P, Q, R and S are given below:

Material type	No.	P	Q	R
Dry soil	1	9.7	0.103	-0.00143
Wet soil	2	12.54	0.029	-0.00078
Dry soft rock	3	9.34	0.131	-0.00231
Wet soft rock	4	10.45	0.089	-0.00134
Hard rock	5	8.72	0.1634	-1/370

S = 0 for all materials but wet soil; S = 503<sup>2</sup>exp[-(S2)/30] for wet soil. [13]

For all Materials and all Yields Except in Interpolation Region: V = (SV)Y<sup>3α</sup> [14]

For all Materials and Yields Within the Interpolation Region:

$$V = (SV_{20})[SV_1/SV_{20}]^{\beta}Y^{3\alpha} \text{ [15]}$$

where SV<sub>1</sub> and SV<sub>20</sub> are scaled volumes computed at 1 and 20 kT.

**6.2 Apparent Crater Volume for Two or Three Material Layers:** Compute a volume for each layer separately, using the full yield, the relevant cratering efficiency, and the single-layer equations above; denote these by V<sub>M1</sub>, V<sub>M2</sub> and V<sub>M3</sub> (if needed). Then compute an average volume from these by the procedure described below:

$$2 \text{ Layers: } V = \hat{V}_A(V_{M1}, V_{M2}, T1), \text{ } 3 \text{ Layers: [16]}$$

$$V = \hat{V}_A(V_{M1}, \hat{V}_A(V_{M2}, V_{M3}, T2), T1) \text{ [17]}$$

$\hat{V}_A(V_U, V_L, T)$  is an approximation to  $V(V_U, V_L, T)$  that satisfies the equation:

$$V_A = (V_L - V_U) \exp\left(\frac{-5.4T}{V_A^{1/3}}\right) + V_U \text{ [18]}$$

where  $V_A$ = average volume,  $V_U$ = upper layer volume,  $V_L$ =lower layer volume, and  $T$ =layer thickness.  $\hat{V}_A$  is computed iteratively by the procedure:

$$V_0 = (V_U V_L)^{1/2}, V_{i+1} = (V_L - V_U) \exp\left(\frac{-5.4 \cdot T}{V_i^{1/3}}\right) + V_U \text{ [19-20]}$$

The apparent crater volume is equal to the fifth term in the series:  $\hat{V}_A = V_5$  [21]

*Radius, Depth and Ejecta Thickness:* The apparent crater radius, CR, and depth, CD are given by:

$$CR = 1.2V^{1/3} \text{ [22]}, CD = 0.5V^{1/3} \text{ [23]}$$

and the minimum ground range for the debris calculation is then 1.8 times the apparent crater radius, CR. The ejecta thickness is given by the expression:  $EJ = kV^{1.62}(GR)^{-3.86}$  [24], where  $k=0.9$  for dry and wet soil materials and  $k=1.17$  for all rock materials.

## 7. Nuclear Weapon, Material and Radiation Types

### 7.1 Nuclear Weapon Types (for Section 3. Initial Radiation)

Type	Description	Yield Range (kT)
1	Gun-assembly fission weapon	0.1 to a few tens
2	Boosted or unboosted fission implosion weapon, old design	1 to a few tens
3	Unboosted fission implosion weapon, contemporary design	less than 1
4	Boosted fission implosion weapon, contemporary design	1 to a few tens
5	Boosted fission implosion weapon, modern design	1 to a few tens
6	Unboosted fission implosion	less than 1
7	Boosted fission implosion	1 to 10
8	Thermonuclear having a single yield	a few tens to 5000
9	Thermonuclear having multiple yields; high yield option	100 to 500
10	Thermonuclear having multiple yields; low yield option	a few tens
11	Tactical (clean) thermonuclear	a few tens to a few hundreds
12	Thermonuclear, very high yield	greater than 5000
13	Enhanced radiation (user familiarity with specific applications is required for meaningful results)	N/A

**7.2 Material Types and Radiation Types (for Section 6. Cratering Equations)**

Layers are specified by entering thicknesses for all but the bottommost layer (which is assumed to have semi-infinite thickness), and values identifying the generic types of geologic material they comprise. The structure of the calculation is such that a three-layer medium is assumed. If only a one- or two-layer calculation is desired, the geologic material type for the unwanted layers must be set to NO LAYER PRESENT.

*Geologic Material Types:*

\*NO LAYER PRESENT     DRY SOFT ROCK  
 DRY SOIL                     WET SOFT ROCK  
 WET SOIL                     HARD ROCK

\*Only for layers #2 and #3

Cratering efficiencies are greater for low-yield weapons than for high (greater than 20 kT). For the cratering calculations using the NORMAL RADIATION weapon radiation output, the program interpolates in the 1 to 20 kT region to provide a smooth transition. If a weapon of less than 20 kT is known to have a high radiative output, the weapon radiation output should be set to HIGH RADIATION. This option attributes to the low yield weapon the low cratering efficiency it would have if it were of a high yield.

For  $Y = 1$  kT,  $SV = C0 + C1*S^2 + C2*S^2^2 + C3*S^2^3 + C4*S^2^4 + C5*S^2^5$ , where the coefficients C0-C5 are given below for the five geologic material types:

	Dry Soil	Wet Soil	Dry Soft Rock	Wet Soft Rock	Hard Rock
C5	5e-5	6e-5	5e-5	5e-5	5e-5
C4	3e-3	3.1e-3	3.1e-3	3e-3	3.1e-3
C3	1.4e-2	1.39e-2	1.39e-2	1.39e-2	1.39e-2
C2	-5.53e-2	-5.55e-2	-5.54e-2	-5.54e-2	-5.54e-2
C1	-0.4412	-0.4408	-0.4409	-0.441	-0.441
C0	3.6233	4.2255	3.5265	3.9244	3.3224
Av. err. (%)	0.63	0.50	0.63	0.56	0.67

**8. Mathematics of Vulnerability to Nuclear Weapons**

Source: Mathematical Background and Programming Aids for the Physical Vulnerability System for Nuclear Weapons; Defense Intelligence Agency (written by Gilbert C. Binninger, Paul J. Castleberry, Jr. and Patsy M. McGrady under the supervision of John W. Burfening of the Physical Vulnerability (Nuclear) Branch of the Targets Division, Defense Intelligence Agency), 1 November 1974, DI-550-27-74.

The 1974 DIA document is noteworthy because it reflects the adoption of the cumulative lognormal function to describe probability of damage as a function of distance from the detonation point, rather than the circular coverage function. The cumulative lognormal function was chosen as the best fit the Hiroshima and

Nagasaki data for the collected probability of damage versus pressure. Distance damage functions are functions describing the probability of damage versus range derived by combining the pressure-damage curves discussed in this section with the pressure versus range curves described above. In addition, weapon delivery error must be included in the calculation.

The lognormal density function with variable  $r$  and parameters  $\alpha$  and  $\beta$  is given by:

$$p(r; \alpha, \beta) = \frac{1}{\sqrt{2\pi}\beta \cdot r} e^{-\frac{1}{2}\left[\frac{1}{\beta} \ln\left(\frac{\alpha}{r}\right)\right]^2} \quad [1]$$

for  $r > 0$  and  $\ln$  is the natural logarithm.  $p(r; \alpha, \beta)$  is a density function over the range  $(0, \infty)$ . The parameter  $\alpha$  is the median of the lognormal density distribution function, or the distance from ground zero where there is a 50% chance of achieving the specified level of damage. In mathematical terms:

$$\int_0^{\alpha} p(r; \alpha, \beta) dr = 1/2 \quad [2]$$

The parameter  $\beta$  is the standard deviation of  $\ln(r)$ .

The cumulative lognormal function is defined as:

$$P(r) = \int_0^r p(r; \alpha, \beta) dr = \int_{z(r)}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy \quad [3]$$

$$z(r) = \frac{1}{\beta} \ln\left(\frac{\alpha}{r}\right) \quad [4]$$

The distance damage function,  $P_d(r)$ , is the complement of  $P(r)$ :

$$P_d(r) = 1 - \int_{z(r)}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy = \int_{-\infty}^{z(r)} \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy \quad [5]$$

$P_d(r)$  is the probability that a target will receive *at least* a specified level of damage, so that  $1-P_d(r)$  is not the probability of survival but the probability of receiving less than the specified level of damage.

The parameters  $\alpha$  and  $\beta$  uniquely determine the distance damage function. Historically, the Defense Intelligence Agency Physical Vulnerability (DIA PV) methodology has used two other quantities to specify the distance damage function: the weapon radius (WR) and the distance damage sigma ( $\sigma_d$ ):

$$WR = \sqrt{\langle r^2 \rangle}, \quad \sigma_d^2 = \frac{\langle r^2 \rangle - \langle r \rangle^2}{\langle r^2 \rangle} \quad [6, 7]$$

Given a uniform distribution of like targets, the WR is the radius of a circle centered at the ground zero (GZ) that contains as many targets *undamaged* to a specified level

inside as there are targets *damaged* to a specified level outside. Thus if the undamaged targets inside the circle are replaced with the damaged targets outside the circle, the circle of radius WR would enclose an area entirely damaged to the specified level. The mean area of effectiveness (M.A.E.) of a weapon is defined as the area over which a weapon on the average achieves at least a specified level of damage, and is equal to  $\pi WR^2$ . Small values of  $\sigma_d$  indicate a relatively rapid fall off of the damage function, and large values of  $\sigma_d$  indicate a more gradual fall off. The WR and  $\sigma_d$  may be expressed in terms of  $\alpha$  and  $\beta$ :

$$WR = \alpha \cdot e^{\beta^2}; \sigma_d^2 = 1 - e^{-\beta^2}; \beta = \sqrt{-\ln(1 - \sigma_d^2)} \text{ and } r_{50} \equiv \alpha = WR(1 - \sigma_d^2) \quad \text{[8-11]}$$

In some cases, two or more weapons effects may significantly contribute toward damaging a target (e.g., personnel casualties may result from blast effects and/or radiation effects). Here the WR has a larger value than it would for either effect alone. For three effects,  $i=1,2,3$ , the combined distance damage function is:

$$P_d(r) = 1 - (1 - P_{d1}(r))(1 - P_{d2}(r))(1 - P_{d3}(r)) \quad \text{[12]}$$

This methodology assumes the independence of effects.

The circular error probability (CEP) is a measure of weapon system accuracy. It is the radius of a circle centered at the desired ground zero (DGZ) within which 50% of the impact points will fall if the distribution of impact points is assumed to be normally distributed about the DGZ:

$$\frac{1}{2} = \int_0^{2\pi} \int_0^{CEP} \frac{1}{2\pi\sigma^2} e^{-r^2/2\sigma^2} r dr d\theta, \quad \text{[13]}$$

implying  $CEP = 1.1774 \times \sigma$

In general, all that is known in a problem is the distance from the aimpoint to the target. The actual distance from the weapon detonation point to the target is uncertain due to inaccuracies in the weapon delivery system, expressed through the CEP parameter. The results of an attack can not be predicted with certainty; all that can be predicted in most cases is what is most likely to happen, or what will happen on average. The PV system calculates an average probability of damage by weighting the probability of damage for each possible detonation point by the probability that the weapon lands at that detonation point:

$$P = \int_0^{2\pi} \int_0^{\infty} P_d(r) \frac{1}{2\pi\sigma^2} \exp\left[-\frac{(r^2 + x^2 - 2rx \cos \theta)}{2\sigma^2}\right] r dr d\theta \quad \text{[14]}$$

where  $P_d(r)$  is the distance damage function, above,  $\sigma$  is related to the CEP as above, and  $x$  is the distance from the aimpoint (or DGZ) to the target.

Average probabilities of damage to area targets are obtained by dividing the area target into small cells which can be treated as point targets, calculating the probability of damage to each cell, weighting these probabilities by the area of the cell or

the portion of the target in the cell, and averaging the results. There are two analytical methods for calculating probabilities of damage to area targets for the special cases of normally-distributed elements in an area target, and for the case where damage to some part of the area target satisfies the damage objective (e.g., breaching a dam at a point).

Some area targets, such as population centers, exhibit a concentration of target elements in the center which tends to become less as the distance from the target center increases. In this case the distribution of target elements (i.e., people) can be well described by a circular normal distribution. The P-95 is defined as the radius of the smallest circle which encompasses at least 95 percent of the population being considered:

$$0.95 = \int_0^{2\pi} \int_0^{P-95} \frac{1}{2\pi\sigma_t^2} e^{-\frac{t^2}{2\sigma_t^2}} t dt d\theta \quad [15]$$

which gives the target sigma,  $\sigma_t$ , as P-95/2.44. Since both the delivery error and target density are normally distributed, the joint density function is also normally distributed. The variance of a joint distribution of independent random variables is the sum of the variances of those random variables, or in terms of an adjusted CEP, CEP<sub>a</sub>:

$$CEP_a = 1.1774\sigma_a = \sqrt{CEP^2 + 0.231 \cdot (P - 95)^2} \quad [16]$$

where CEP is the delivery CEP.

For certain special classes of targets such as bridges, dams, locks, runways, etc., a specified degree of damage to some part of the target satisfies the damage objective. For example, for a bridge the collapse of one span is usually the damage objective. For the Equivalent Target Area (ETA) approximation, the ETA is defined as an area such that the probability of placing the ground zero (GZ) in the area is equal to the probability of doing the desired level of damage to the target. For a rectangular target the ETA is approximated by adding marginal strips around each edge of the target of width equal to the weapon radius for that aspect of the target. Then the probability of damage to a rectangle having a length l and width w is approximately the probability of placing a weapon in a rectangular area of length (l+2WR<sub>l</sub>) and width of (w+2WR<sub>w</sub>) where WR<sub>l</sub> is the weapon radius associated with the length vulnerability number (VN, defined below) and WR<sub>w</sub> is the weapon radius associated with the width VN. This probability may be approximated by:

$$P = 0.25 * \left[ \frac{|b|}{b} \operatorname{erf} \left( \frac{|b|}{\sqrt{2}\sigma_l} \right) - \frac{|a|}{a} \operatorname{erf} \left( \frac{|a|}{\sqrt{2}\sigma_l} \right) \right] \times \left[ \frac{|d|}{d} \operatorname{erf} \left( \frac{|d|}{\sqrt{2}\sigma_w} \right) - \frac{|c|}{c} \operatorname{erf} \left( \frac{|c|}{\sqrt{2}\sigma_w} \right) \right] \quad [17]$$

where erf is the error function, a=x1-WR<sub>l</sub>, b=x2+WR<sub>l</sub>, c=y1-WR<sub>w</sub>, d=y2+WR<sub>w</sub>; (x1,y1),(x2,y2) are the coordinates of the physical bounding rectangle for the target;  $\sigma_d$  is the damage sigma (with values between 0.1 and 0.5), and:

$$\sigma_w = \sqrt{CEP^2 + (1.774\sigma_d^2)^2 WR_w^2}, \quad \sigma_l = \sqrt{CEP^2 + (1.774\sigma_d^2)^2 WR_l^2} \quad [18-19]$$

For the vulnerability number (VN) coding system, a target's susceptibility to blast damage is indicated by a combination of numbers and letters. The vulnerability number (VN) consists of a two-digit number reflecting the target hardness relative to a specified damage level, a letter indicating predominant sensitivity to overpressure (P) or dynamic pressure (Q), and a K factor. The two-digit numerical value scale of the VN is an arbitrary classification describing a target's hardness. It is a linear function of the logarithm of the peak pressure from a 20 kt weapon that would have a 50% probability of damaging a randomly-orientated target to the desired level. The base yield was chosen to be 20 kt instead of the more convenient 1 kt because the original system was developed from the Hiroshima-Nagasaki data assuming that the yields of the Hiroshima and Nagasaki weapons were 20 kt. The appropriate damage sigma for P targets unless otherwise specified is  $\sigma_d=0.20$ . The appropriate damage sigma for Q targets unless otherwise specified is  $\sigma_d=0.30$ . The K factor allows for hardness adjustments to be made to account for the effects of variations in blast wave duration due to different weapon yields. Each VN must also have a specified damage-level criterion, such as "collapse," "24-hour recovery time," "severe damage to contents," "moderate structural damage," etc.

The completely arbitrary coding relationship for P type targets is:

$$p_{50} = 1.1216(1.2)^{PVN}, \text{ or } PVN = 12.63 \log_{10} p_{50} - 0.63 \quad [20-21]$$

Since the peak overpressure at a given range is uncertain to roughly  $\pm 20\%$ , this coding relationship insures that P type target hardnesses are not specified more precisely than justified by the pressure-range data. This scale conveniently allows for the complete pressure range of interest to be coded by a two-digit number.

The dynamic pressure coding scale was chosen using the approximate form of the Rankine-Hugoniot equation,  $q=0.023p^2$ . The scale was defined so that the dynamic pressure required for a 50% probability of damage,  $q_{50}$ , for the VN of interest is equal to  $0.023p_{50}^2$  where  $p_{50}$  is from the numerically equal P VN\*. Therefore, the VN's are "tied" at the 50% probability but not at the other probabilities. The relationship between the QVN and  $q_{50}$  is:

$$q_{50} = 0.02893(1.44)^{QVN}, \text{ or } QVN = 6.31 \cdot \log_{10} q_{50} + 9.72 \quad [22-23]$$

Since the dynamic pressure is only known to within about  $\pm 40\%$ , Q type target hardnesses are also not specified more accurately than justified by the pressure range data.

\* Care should be taken not to use the equation  $q=0.023p^2$  to calculate the peak dynamic pressure corresponding to a given overpressure. For overpressures below about 10 psi the equation  $q=0.023p^2$  is a good approximation to the Rankine-Hugoniot relation  $q=(5/2)(p^2/7p_0+p)$  where  $p_0$  is the ambient atmospheric pressure. This Rankine-Hugoniot relation was derived assuming an ideal shock front. It only fits the available experiment data fairly well for zero heights-of-burst (HOB). The correct determination of the  $q$  given  $p$  or vice versa for a given HOB must be through the horizontal ground range using pressure-range-HOB curves.

The blast wave duration varies with weapon yield. The increased blast duration associated with larger yields may cause targets to fail at lower pressure levels, while at small yields the reduced blast duration may necessitate higher pressures for the target to fail. To account for this yield dependence, the PV system uses K-factors for both P and Q targets. The K-factor is an integer from 0 to 9 which adjusts the base VN to reflect the sensitivity of the target the different pressure-time pulse shapes for yields other than 20 KT. A K factor of 0 indicates a target that is not sensitive to blast wave duration and can be expected to fail at the same pressure regardless of weapon yield. A K factor of 9 indicates a target that is very sensitive to blast wave duration and can be expected to fail at quite different pressures at various yields.

The adjustment factor R is the ratio of the pressure (either overpressure,  $p(Y)$ , or dynamic pressure,  $q(Y)$ , required for a 50% probability of damage at yield Y to the pressure required at 20 KT ( $p(20)$  or  $q(20)$ ). The K factor is related to the adjustment factor, R, in the following manner:

$$R = 1 - \frac{K}{10} \left( 1 - \frac{t_{do}}{t_d} \right) = \frac{p(Y)}{p(Y = 20)} \text{ or } \frac{q(Y)}{q(Y = 20)} \quad [24]$$

where  $t_{do}$  is the positive phase blast wave duration for 20 kt and  $t_d$  is the positive phase blast wave duration for yield Y ( $t_d \approx 0.45(Y^{1/3}/p^{1/2})$  for overpressure,  $t_d \approx 0.105(Y^{1/3}/q^{1/3})$  for dynamic pressure).

The adjustment factor R is used to determine the adjusted VN ( $VN_a$ ) using the PVN and QVN coding relationships:

$$\text{for P VN's, } A = \frac{\log(R)}{\log(1.2)}, VN_a = VN + A; [25]$$

$$\text{for Q VN's, } A = \frac{\log(R)}{\log(1.4)}, VN_a = VN + A. [26]$$

It is often necessary to know not only p50 for a given VN and yield, but also the pressures for other probabilities of damage. The method used to obtain the pressure  $P_a$  for a probability of damage  $a\%$  for the adjusted VN of  $v_2$  is discussed below.

For type P targets, the VN coding relationship gives:  $p_{50}=1.1216(1.2)^{v_2}$ . The analysis of the Hiroshima-Nagasaki and Nevada test data resulted in the adoption of the following relationship between the overpressure required to damage a structure to a given level and the pressure which gives a 50% probability of damage,  $p_{50}$ :

$$p_a = p_{50} e^{0.297b}, \text{ where } a \text{ is given by: } a = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^b e^{-x^2/2} dx \quad [27-28]$$

and b is the probability as expressed as probits-5 (A probit has the magnitude of the standard deviation. Minus 5 probits is defined as a=0%, 5 probits is 50%, and 10 probits corresponds to a=100%). For dynamic pressure:

$$q_{50} = 0.02893(1.44)^{v_2}, \text{ and } q_a = q_{50} e^{1.042b}. [29-30]$$

This was questioned.

## ENDNOTES

### Chapter One

1 George W. Bush, "Remarks to Students and Faculty at National Defense University," Fort Lesley J. McNair, Washington, DC, May 1, 2001.

### Chapter Two

1 There is a modest literature that describes the evolution of the plan and some of the details. Desmond Ball and Jeffery Richelson, eds., *Strategic Nuclear Targeting* (Ithaca: Cornell University Press, 1986); Scott D. Sagan, *Moving Targets: Nuclear Strategy and National Security* (Princeton, NJ: Princeton University Press, 1989); Steven T. Ross, *American War Plans, 1945–1950* (London: Frank Cass, 1996).

2 David Alan Rosenberg, "U.S. Nuclear War Planning, 1945–1960," in Ball and Richelson, eds., *Strategic Nuclear Targeting*, pp. 35–56; Steven T. Ross, *American War Plans: 1945–1950* (London: Frank Cass, 1996).

3 Rosenberg, in Ball and Richelson, p. 54.

4 Desmond Ball, "The Development of the SIOP, 1960–1983," in Ball and Richelson, pp. 57–83; Aaron L. Friedberg, "A History of the U.S. Strategic Doctrine, 1945 to 1980," *Journal of Strategic Studies*, Vol. 3, No. 3 (December 1980), pp. 37–71.

5 Quoted in Ball, p. 64.

6 Quoted in Ball, p. 67.

7 Jeffrey Richelson, "PD-59, NSDD-13 and the Reagan Strategic Modernization Program," *The Journal of Strategic Studies*, Vol. 6, No. 2 (June 1983), pp. 125–146.

8 Richard Halloran, "Pentagon Draws Up First Strategy For Fighting a Long Nuclear War," *New York Times*, May 30, 1982, p.1.

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17 R. Jeffrey Smith, "Clinton Directive Changes Strategy on Nuclear Arms," *The Washington Post*, December 7, 1997, pp. A1 and A8.

18 *Ibid.*

19 *Ibid.*

20 Recent SIOPs (and date of implementation) are:

SIOP-5, January 1, 1976

SIOP-6, October 1, 1983

SIOP-6F, January 1, 1989

SIOP-6G, October 1, 1990

SIOP-6H, October 1, 1991

SIOP-92, October 1, 1991

SIOP-93, June 1, 1992

SIOP-94, October 1, 1993

SIOP-95, October 1, 1994

SIOP-96, October 1, 1995

SIOP-97, October 1, 1996

SIOP-98, October 1, 1997

SIOP-99, October 1, 1998

And, presumably,

SIOP-01, October 1, 2000

21 Jeff Greenfield and George Crile, "Rehearsing Doomsday," CNN Democracy in America, Transcript # 00101500V66, October 15, 2000.

22 "Group Urges U.S. To Reduce Nuclear Warheads," Armed Forces Newswire Service, May 19, 2000.

23 Kenneth McGill, "USSTRATCOM/J53 War Plan Analysis," MSRR/MEL Users Conference, April 1999.

24 *Ibid.*

25 Bruce G. Blair, "Too Many Missiles, Too Many Targets," *Sacramento Bee*, June 25, 2000, p. II.

26 During the last two decades of the Cold War, Pentagon spokesmen frequently employed this phrasing as a kind coded reference to the alleged need to target and severely damage Soviet nuclear

forces and underground command centers, on the grounds that the heirs of Stalin could not be relied upon to value their own population and industry sufficiently to refrain from escalation to nuclear warfare, especially in the event that NATO forces fired first.

27 Eric Schmitt, "Pentagon Feels Pressure to Cut Out More Warheads," *The New York Times*, May 11, 2000, p. 1.

28 George W. Bush, "Remarks to Students and Faculty at National Defense University," Fort Lesley J. McNair, Washington, DC, May 1, 2001.

### Chapter Three

1 Three nuclear warhead types were designed at Lawrence Livermore National Laboratory (W62, B83, and W87) and the remaining six types at Los Alamos National Laboratory (W78, W76, W88, B61-7, B61-11, and W80-0).

2 Bruce G. Blair, "Trapped in the Nuclear Math," *The New York Times*, June 12, 2000, p. A29.

3 DOD, Joint Staff, "Reporting Manual for Joint Resources Assessment Database System (JRADS)," CJCSM 3150.09, 15 March 1999), pp. 2 and A-1.

4 *Ibid.*

5 See "functional classification code" in William M. Arkin and Hans Kristensen, "The Post Cold War SIOP and Nuclear Warfare Planning: A Glossary, Abbreviations, and Acronyms," Natural Resources Defense Council, January 1999.

6 For the National Imagery and Mapping Agency's publicly available database, see: <http://164.213.2.59/gns/html/index.html>.

7 1° (longitude at the equator) = 1,855 meters; 1° (latitude at the equator) = 1,862 meters; and 1° (latitude at the pole) = 1,843 meters.

8 [www.fos.org](http://www.fos.org).

9 Kevin C. Ruffner, ed., *CORONA: America's First Satellite Program* (Washington, D.C.: Center for Study of Intelligence, Central Intelligence Agency, 1995).

10 Oleg Bukharin, Thomas B. Cochran, and Robert S. Norris, "New Perspectives on Russia's Ten

Secret Cities," (Washington, D.C.: Natural Resources Defense Council, October 1999).

11 Ruffner, *CORONA*, pp. xiv–xv.

12 *Ibid.*

13 *Ibid.*

14 *Ibid.*

15 See, for example, Thomas B. Cochran, Robert S. Norris, and Oleg A. Bukharin, *Making the Russian Bomb: From Stalin to Yeltsin* (Boulder: Westview Press, 1995).

16 Oleg Bukharin, Thomas B. Cochran and Robert S. Norris, "New Perspectives on Russia's Ten Secret Cities," (Washington, D.C.: Natural Resources Defense Council, October 1999).

17 See, for example, Thomas Nilsen, Igor Kudrik, and Alexandr Nikitin, *The Russian Northern Fleet*, (Norway: Bellona Report Volume 2, 1996).

18 Mr. Handler was the Greenpeace disarmament campaign coordinator and is currently a graduate student at Princeton University. See his, "The Northern Fleet's Nuclear Submarine Bases," *Jane's Intelligence Review*, December 1993—Europe, pp. 551–556; and "Russia's Pacific Fleet—Submarine Bases and Facilities," *Jane's Intelligence Review*, April—Europe, pp. 166–171.

19 Samuel Glasstone and Philip J. Dolan, eds., *The Effects of Nuclear Weapons*, Third Edition, United States Department of Defense and Department of Energy, 1977.

20 Philip J. Dolan, editor, *Capabilities of Nuclear Weapons: Defense Nuclear Agency Effects Manual Number 1*, Headquarters, Defense Nuclear Agency, Washington, D.C., 20305. Obtained through the Freedom of Information Act, February 13, 1989.

21 Computer code "Blast Effects," developed by Horizons Technology, Inc. (7830 Clairemont Mesa Blvd., San Diego, CA 92111) for the Director, Defense Nuclear Agency, Washington DC 20305, Version 2.1, December 21, 1984.

22 Computer code "Weapon Effects," developed by Horizons Technology, Inc. (7830 Clairemont Mesa Blvd., San Diego, CA 92111) for the Director, Defense Nuclear Agency, Washington DC 20305, Version 2.1, December 21, 1984.

- 23 Harvey, T. F., private communication of KDFOC3 FORTRAN IV source code and 34 pages (entitled 3. USERS MANUAL: INPUT AND ALGORITHMS) of a LLNL report regarding KDFOC3. For another study discussing KDFOC3 see Per Ljung and Kenneth Nyren, "Nuclear Fallout Simulations Using KDFOC3," National Defense Research Establishment (FOA), Department of NBC Defense, Sweden, May 1984 (available from the U.S. Department of Commerce National Technical Information Service)
- 24 Defense Nuclear Agency, *Capabilities of Nuclear Weapons*, DNA EM-1, Part I (July 1, 1972), p. 5-1. Additional nuclear radiation arises from the neutron activation of the earth below an air burst and fallout, which are discussed later in this chapter.
- 25 Another example where the weapon effect of initial radiation depends on the type of nuclear weapon would be a phenomenon termed "hydrodynamic enhancement." Gamma rays produced by fission products emanate from the rising nuclear fireball, and the reduction in air density behind the blast wave allows these gamma rays to travel more efficiently from the fireball to persons in the vicinity of the explosion. This effect is called hydrodynamic enhancement. For "Fat Man" and "Little Boy" the prompt neutrons accounted for most of the harmful dose to Japanese victims of the bombing. But for thermonuclear weapons in the megaton yield range, hydrodynamic enhancement makes the fission product gamma rays a more significant source of initial radiation than the prompt neutrons. DNA EM-1, pp. 5-23.
- 26 "In the report (Hiroshimashi-Nagasaki, p. 31) sent to the Secretary-General of the United Nations by both cities in the autumn of 1976, the total deaths following exposure to the bomb by the end of 1945 totaled 140,000 (+/- 10,000) in Hiroshima and 70,000 (+/- 10,000) in Nagasaki." From *Hiroshima and Nagasaki: The Physical, Medical, and Social Effects of the Atomic Bombings*, (New York: Basic Books, 1981) p. 113.
- 27 John Malik, "The Yields of the Hiroshima and Nagasaki Nuclear Explosions," LA-8819, Los Alamos National Laboratory, September, 1985.
- 28 "The Epicenter of the Atomic Bombs. 2. Re-evaluation of All Available Physical Data with Recommended Values," in the Atomic Bomb Casualty Commission Technical Report, 1969.
- 29 Hiroshima Shiyakusho [Hiroshima City Office], *Hiroshima Genbaku Sensaishi* [Record of the Hiroshima A-bomb War Disaster], Hiroshima, 1971, vol. I.
- 30 Theodore A. Postol, "Possible Fatalities from Superfires Following Nuclear Attacks in or near Urban Areas," reprinted by the International Strategic Institute at Stanford University, Center for International Security and Arms Control from *The Medical Implications of Nuclear War*, (Washington, D.C.: National Academy of Sciences Press, 1986).
- 31 Arthur M. Katz, *Life After Nuclear War: The Economic and Social Impacts of Nuclear Attacks on the United States* (Cambridge, MA: Ballinger Publishing Company, 1982).
- 32 T. Harvey, et al., "Internal Dose Following a Large-Scale Nuclear War," LLNL, 1986.
- 33 DELFIC was developed by the U.S. Defense Nuclear Agency with the "aim to give warranted attention to all phenomena that were considered significant." Reportedly it is the most sophisticated model: it was developed for research purposes and other models use it for calibration. In calculating fallout, it is necessary to convert the quantity of gross fission products produced to a dose rate. The dose rate is calculated one meter above a smooth plane one hour after the detonation and with one kt per km<sup>2</sup> of gross fission products uniformly distributed. KDFOC3 uses a conversion factor of 70 (Sv/hr)(km<sup>2</sup>/kt). DELFIC uses a gross fission conversion factor of K = 54 (Sv/hr)(km<sup>2</sup>/kt). Reference: "Nuclear Fallout Simulation Using KDFOC3," p. 21.
- 34 SEER3 was developed in the early 1970s by Stanford Research Institute as a simplified version of DELFIC (assumes a stabilized cloud without a stem, uses few discs, and incorporates some curve-fitting to DELFIC).
- 35 WSEG10 was first developed by the U.S. Defense Department in 1959. The 1981 improved model [Bridgman, C.J. and Bigelow, W.S., "A New Fallout Prediction Model," *Health Physics*, 43 (1982): 2, 205-218.] uses a gross fission conversion factor of K = 47 (Sv/hr)(km<sup>2</sup>/kt).
- 36 Pertaining to fallout, nuclear weapons have been generally classified into five types depending on the amount of residual radiation produced in the explosion. From least to greatest residual radiation produced in the explosion the types are: minimum residual radioactivity weapon, clean weapon, normal weapon, dirty weapon and salted weapon. A minimum residual radioactive weapon is "designed to have optimum reduction of unwanted effects from fallout, rainout, and burst-site radioactivity." A clean weapon is a "nuclear weapon in which measures have been taken to reduce the amount of residual radioactivity relative to a 'normal' weapon of the same energy yield." A dirty weapon "produces a larger amount of radioactive residues than a 'normal' weapon of the same yield. It is a fission weapon or any other weapon that would distribute relatively large amounts of radioactivity upon explosion, as distinguished from a fusion weapon." A salted weapon "has, in addition to its normal components, certain elements or isotopes that capture neutrons at the time of the explosion and produce radioactive products over and above the usual radioactive debris." KDFOC3 calculates a fission-equivalent yield for the fusion part of the total yield, using a 10 percent fission-equivalent yield for an air burst and 18 percent for buried bursts. These definitions are from Kenneth E. Gould and Kaman Tempo, *Glossary of Terms—Nuclear Weapon Phenomena and Effects*, Prepared for the Director, Defense Nuclear Agency, Washington, DC (Contract No. DNA 001-82-C-0274), February 15, 1985, pp. 163-165.
- 37 "Nuclear Fallout Simulation Using KDFOC3," p. 25.
- 38 *Ibid.*
- 39 General Electric Company—TEMPO. Compilation of Local Fallout Data from Test Detonations 1945-1962. Vol. 1: "Continental US Tests." Vol. 2: "Oceanic U.S. Tests." Washington, D.C.: Defense Nuclear Agency, DNA 1251-1 and -2, 1 May 1979.
- 40 The dose-rate contours given in these volumes are given at H+1 hour, a convention used to facilitate comparison of data with calculations: "The dose-rate contours for the fallout patterns have been drawn to show the gamma dose rate in roentgens per hour, three feet above the ground, in terms of the one hour after burst reference time. The t<sup>-1.2</sup> approximation was used when no actual decay data were available to adjust radiation measurements to the one-hour reference time. It is important to recognize the H+1 hour is used as a reference time, and that only the contours from low yield weapons are complete at one hour after burst. For high-yield weapons, fallout over some parts of the vast areas shown does not commence until many hours after the burst." General Electric Company—Tempo, pp. 2-3.
- 41 General Electric Company—Tempo, p. 63.
- 42 NATO *Target Data Inventory Handbook* (NTDI) (U), Headquarters United States European Command and Defense Intelligence Agency ("produced by the HQ USEUCOM Intelligence Targets Division for the Defense Intelligence Agency"), January 1, 1989 (released under the Freedom of Information Act, with deletions, 1998) and *Physical Vulnerability Handbook-Nuclear Weapons* (U), Defense Intelligence Agency, AP-550-1-2-69-INT (unclassified), January 28, 1974, and "Mathematical Background and Programming Aids for the Physical Vulnerability System for Nuclear Weapons," Defense Intelligence Agency (prepared for the Defense Intelligence Agency, Directorate for Intelligence), DI-550-27-74, November 1, 1974 (unclassified).
- 43 "Global Gridded Upper Air Statistics: 1980-1995," Version 1.1, March 1996, National Climatic Data Center (a part of the National Oceanic and Atmospheric Administration), Asheville, North Carolina.
- 44 The University of Washington Geospatial Data Archive contains GIS boundary data for most of the Russian *rayons* and *gorsoviets* as part of their "Russian Federation Digital Data" archive (<http://wagda.lib.washington.edu/data/russianfed/>).

45 Furthermore, the population within a P-95 circle is assumed to have a log-normal distribution within that circle. In a log-normal distribution, the logarithm of the population has a normal, or Gaussian, distribution peaking at the center and falling off towards the circumference. There are U.S. Department of Defense algorithms (which NRDC possesses) for readily calculating casualties from a nuclear burst based on the log-normal distribution in a P-95 circle.

46 "The Feasibility of Population Targeting," pp. 32-33.

47 Kenneth McGill, "USSTRATCOM/J53 War Plan Analysis," MSRR/MEL Users Conference, April 1999.

#### Chapter Four

1 "Of the Soviet inventory of 1,400 operational ballistic missile silos, 818 have been rebuilt since 1972. Fully one-half of these silos have been totally reconstructed and hardened since 1980." *Soviet Military Power: An Assessment of the Threat 1988*, U.S. Department of Defense, p. 46.

2 The "P" and "L" vulnerability numbers quantify the damage probability in terms of the nuclear explosive effect of peak blast overpressure. L-type numbers have a standard deviation half as large as P-type numbers. This means that the probability of achieving severe damage to a silo decreases more rapidly with the separation between ground zero and silo for L-type silos than for P-type silos.

3 "The VN for severe damage to the installation predicts one of the following: (a) collapse or severe distortion of silo door resulting in severe damage to in-silo missile or critical launch support equipment by debris impact or vented overpressure; (b) collapse or severe distortion of roof or walls of launcher equipment room (silo headworks) resulting in severe damage to critical launch support equipment by debris impact or physical dislocation; or (c) severe damage to in-silo missile by a nuclear effect." NATO Target Data Inventory Handbook, p. 681.

4 "The VN for moderate damage to the installation predicts one of the following: (a) sufficient deformation of launch silo door to

prevent missile launch until door is removed by use of emergency equipment; (b) moderate structural damage to roof of launcher equipment room (silo headworks) which causes sufficient damage to launch support equipment to prevent missile launch until damaged equipment is inspected, tested, or repaired; or (c) sufficient damage by any nuclear effect to in-silo missile airframe, propulsion, or guidance system or to launch support equipment to prevent missile launch until damaged equipment is inspected, tested, calibrated or repaired." NATO Target Data Inventory Handbook, p. 680.

5 Edgar Ulsamer, "The Prospect for Superhard Silos," *Air Force Magazine*, January 1984, pp. 74-77.

6 *Ibid.*

7 "For airburst weapons, the vertical error distribution is expressed in terms of PEH. A distance of 1 PEH from the desired HOB will contain 25 percent of the detonations. A 1 PEH bracket is the vertical distance both above and below the desired HOB within which a single weapon has a 50 percent probability of detonating. The vertical distribution pattern is assumed to be normal about the desired HOB." *Nuclear Weapons Employment Effects Data* December 20, 1995, (Joint Pub 3-12.2, December 20, 1995) p. III-3. Released under FOIA October 4, 2000.

8 Seasonal variations in the ambient winds were modeled by performing fallout calculations using the most probable wind vectors at each silo location for each month of the year.

9 Because the angular resolution of the monthly wind rose data was 45 degrees, calculations for each month were performed at the most probable wind vector angles and for wind vector angles globally offset by  $\pm 15$  degrees.

10 Each of the fallout calculations were performed using an ideal-plane conversion factor of 0.7 to account for the radiation shielding provided by the roughness of a real planar surface (i.e., an open field), and calculations using sheltering factors of 1 (no sheltering), 4 (sheltering typical of single-story residential structures), 7 (sheltering typical of multi-story buildings) and 40 (sheltering

typical of basement environments) were performed for each wind field.

11 Calculations for each of the wind fields and for each of the sheltering factors were performed for fission fractions of 50 percent and 80 percent in order to understand the dependence of fallout casualties over the likely range of fission fractions for U.S. nuclear weapons. Fission fractions of U.S. nuclear weapons are classified. Our range of values for the W88 and W87 warheads is suggested by the known fission fractions of the tests from Operation Castle: Bravo (fission fraction = 66.67 percent); Romeo (fission fraction = 63.6 percent); Union (fission fraction = 72.5 percent); Yankee (fission fraction = 51.9 percent) and Nectar (fission fraction = 79.9 percent). The Castle tests were of early design, multi-megaton weapons. Robert S. Norris and Thomas B. Cochran, United States Nuclear Tests: July 1945 to 31 December 1992. NRDC Working Paper, February 1997, pp. 29-31.

12 *Russia's Arms and Technologies: The XXI Century Encyclopedia, Vol. 1, Strategic Nuclear Forces* (Moscow, 2000).

13 *Soviet Military Power: An Assessment of the Threat*, U.S. DOD, 1998. p. 47.

14 *Russia's Arms and Technologies*, p. 100.

15 Steven Zaloga, "Strategic Forces of the SNG," *Jane's Intelligence Review*, February 1, 1992, p. 79.

16 "Military Denies Possible Reinforcement with Russian Tactical Missiles," BBC Summary of World Broadcasts, November 17, 1998 (source: Belapan News Agency, Minsk).

17 On March 10, 1994, a Russian soldier killed his commander and two fellow soldiers with a sub-machine gun at the Barnaul base. Guards reportedly did not return fire immediately because they were prohibited from shooting in the direction of an SS-25, even in the event of a terrorist attack. "Silo Shooting a Cause for Concern," *Jane's Defense Weekly*, April 9, 1994, p. 15.

18 Coordinates from the START I MOU are given to the nearest minute, an uncertainty of about 900 meters in the north-south direction and at this latitude an uncertainty of about 500 meters in

the east-west direction. We assume the garrison and base locations are indicated by the nearby small circles on the JOG, which indicate populated places on the map.

19 It is possible that in the intervening years the hardness of the transporter-erector-launcher (TEL) vehicles was improved. The 1989 *NATO Target Data Inventory Handbook* assigns a VN number for severe damage to wheeled vehicles, armored cars and tanks of 18Q9, 20Q9 and 24Q9, respectively.

20 "If the weapon yield is greater than several hundred tons . . . the predominant type of damage to targets in the open results from the drag force caused by dynamic pressures. These drag forces may be large enough to move properly oriented, unshielded targets great distances. They may slide, roll, or bounce along the ground surface and may be damaged seriously by the violent motions. There have been instances in which heavy equipment has been picked up and thrown dozens of feet, and then has hit the ground with sufficient force to be dismembered." From Philip Dolan, editor, *Capabilities of Nuclear Weapons: Defense Nuclear Agency Effects Manual Number 1*. Headquarters, Defense Nuclear Agency, Washington, D.C. 20305. p. 14-1.

21 *CIA's Analysis of the Soviet Union: 1947-1991*, documents released at the conference sponsored by the Center of International Studies at Princeton University and CIA's Center for the Study of Intelligence, 2001.

22 In the *NATO Target Data Inventory Handbook* (NTDI), one target category "includes all surface-to-surface missile sites," including "a facility from which a launch of mobile missile(s) could be effected." NTDI Handbook, p. 670. Within this target category a code number is assigned to the SS-25 missile. Unfortunately there is no undeleted mention of specific structure types associated with the SS-25 in the NTDI Handbook, but "Additional Data" provided for these targets in the NTDI Handbook does include the "Center of the smallest rectangle that will enclose. . . . All single-bay sliding roof garages." NTDI Handbook, p. 682.

23 In the NTDI Handbook, under the heading "Component Damage—Missile-ready

Structure," descriptions of severe and moderate damage are given along with vulnerability numbers for severe and moderate damage to two structure types which will serve as bounding values in this analysis: "The VN for severe damage to the missile-ready structure predicts failure of one or more structural elements (roof, wall, or closure) enclosing protected spaces which house missiles, equipment, and/or personnel and causing damage to contents by crushing, translation impact due to overpressure, or impact by collapse of a structural element and associated damage generally as follows: physical damage to associated equipment located at the launch site to such extent that the items are rendered inoperative and require major repair. The VN for moderate damage to the missile-ready structure predicts structural damage to the building sufficient to cause roof spall, jamming of closure(s), or movement or collision of contents such that medical treatment of personnel and/or inspection, checkout, and minor repairs of missile equipment are required and associated damage generally as follows: damage to associated equipment and facilities located at the launch site to such extent that performance is degraded, curtailed, or interrupted. NTDI Handbook, p. 679.

24 In addition, the K factor for this vulnerability number (the fourth character) is 7, meaning that these structures are very sensitive to the duration of the positive phase of the blast wave.

25 For example, a peak blast overpressure of 111 psi is calculated to produce a 50 percent probability of severe damage for a vulnerability number of 26P3, given an attacking warhead yield of 100 kt.

26 The threshold height of burst for production of local fallout from a 100 kt warhead is calculated to be 350 meters.

27 While we do not know how hardened the communications structures are at the bases, two 100 kt ground bursts should be illustrative of the risk to Russian civilians in the vicinity of these military sites.

28 As for the ICBM silo discussion above, we performed calculations for 12 months, 3 wind conditions—the center of most probable sector

direction and  $\pm 15$  degrees off center, two warhead fission fractions—0.5 and 0.8 and four sheltering factors—1, 4, 7 and 40.

29 *Soviet Military Power: An Assessment of the Threat* (1988), p. 11.

30 *Russia's Arms and Technologies*, pp. 103–04.

31 Coordinates from the START I MOU are given to the nearest minute, an uncertainty of about 900 meters in the north-south direction and at this latitude an uncertainty of about 500 meters in the east-west direction.

32 Vladimir Kuroedov, Commander-in-Chief of the Russian Navy, "Interests in the World's Oceans," *Krasnaya Zvezda*, May 24, 2000, pp. 1–2.

33 The Montreux Convention of 1936 restricts submarine passage between the Black Sea and the Mediterranean.

34 *Soviet Military Power: Prospects for Change 1989*, U.S. Department of Defense, p. 113.

35 *Russia's Arms and Technologies*, p. 178.

36 "So-called secure military zones began to be created in the Barents, White, Kara, Norwegian, Okhotsk, and Japanese seas and in ice-covered regions of the Arctic in the beginning of the 1970s. The zones were protected by minefields and were patrolled by multipurpose nuclear-powered submarines, and also by combatant surface ships and aircraft whenever possible. Safe and reliable communications with strategic missile-armed submarines were also possible in the secure zones." *Ibid.*, p. 178. Soviet (and American) SSBNs patrolled under the Arctic ice as well.

37 *Soviet Military Power 1987*, U.S. DOD, Washington, D.C., pp. 128–129. During the Cold War, the U.S. Navy had a major geographic advantage: "The Soviets could not easily reach open sea. Geography had shaped the Russian empire since before Peter the Great, and it was to stymie it again. Whether in the Arctic, the Far East or by the Black Sea to the Bosphorus, the Soviets could not enter deep water without passing through choke points which made it far easier to spot and track their submarines. One choke point is the channel formed by Greenland, Iceland and the United Kingdom. It was here that the United States

and allies such as Great Britain and Norway first concentrated their underwater listening devices, air surveillance and submarines.

But the United States also planted listening devices near the northern tip of Japan, in the Mediterranean and at dozens of other locations.

... The plan was to have an attack sub pick up the Soviet nuclear-missile subs and follow them on their patrols in the Atlantic and Pacific. ... For the sub crews on this anti-submarine warfare team, the aim was to learn the Soviet boats' operational patterns and be able to identify the U.S. cities and military installations within range of the 16 missiles each carried. But the U.S. sub crews also wanted to keep the Soviet boats in their torpedo sights in case war broke out, hoping to destroy them before they could launch.

"Soviets Improve Subs, Tactics," Christopher Drew; Michael L. Millenson, *Chicago Tribune*; Robert Becker: *Newport News Daily Press*, *The Orange County Register*, February 24, 1991, p. A29.

38 John Downing, "Navy's Needs: Hard to Justify," *Jane's Defense Weekly*, August 2, 2000, Vol. 34; No. 5.

39 "Russian Servicemen Steal Radioactive Submarine Fuel," Associated Press, February 1, 2000.

40 "Damage to Russian Naval Vessel Worse than First Admitted," ITAR-TASS News Agency, Moscow, April 11, 2000.

41 "5 Metal Collectors Die of Suffocation in Sub," ITAR-TASS News Agency, March 21, 2000.

42 Patrick E. Tyler, "Thieves Looting Russia of Its Power Lines," *New York Times*, April 18, 2000, p. A1.

43 "Admiral Sentenced to Eight Years in Prison for Embezzlement," NTV International, Moscow, April 28, 2000.

44 "Toxic Fuel Leak Reported in Russian Far East," United Press International, June 16, 2000.

45 "Russian Authorities Warn of Toxic Fuel Leaking from Tanks," AP Worldstream, July 25, 2000.

46 "Unpaid Utility's Power Cuts Put Control of Russian Pacific Fleet at Risk," Agence France Presse, July 26, 2000.

47 "Russia Solves Mystery of Huge Floating Object," *The Commercial Appeal* (Memphis, TN), August 8, 2000, p. A8.

48 "Entire Russian Navy Crew Abandon Ship, Complain of Beatings," *Segodnya*, Moscow, July 19, 2000.

49 "Russian Pacific Fleet Cancels Navy Day Parade Due to Lack of Fuel," NTV, Moscow, July 30, 2000.

50 "Russian Ship Accidentally Fires Sea-to-Shore Missile," Agence France Presse, September 15, 2000.

51 "Russian Pacific Fleet Nuclear Submarine Unit Disbanded on Cost Grounds," *Segodnya*, Moscow, October 13, 2000.

52 The Northern Fleet operates out of Russia's only year-round ice-free ports—in winter the waters of Russia's Arctic coast are icebound except for a 100-kilometer segment of the Kola Peninsula.

53 One aimpoint is centered on the piers across the Kola Inlet from Polyarnyy Naval Base.

54 "Russia Downsizes Strategic Aviation, Closes Air Bases," *Aerospace Daily*, April 16, 1998, p. 92.

55 Nuclear weapons that had been in storage at Mozdok air base at the start of the 1994 war in Chechnya were reportedly moved deeper inside Russia.

56 Nikolai Novichkov, "Russia's Air Force in Crisis Situation," *Jane's Defense Weekly*, October 11, 2000. In addition, Morozov claimed that 54 percent of frontal aviation and 62 percent of the transport fleet were serviceable.

57 The NATO Target Data Inventory Handbook (p. 540) defined one category of targets as: "Permanent airfields which are or can be used as bomber or fighter bases. Also includes reserve airfields, seaplane stations, heliports, highway airstrips, and new installations under construction which can positively be identified as supporting aircraft operations and when potential development equals the minimum NTDI criteria."

The minimum NTDI criteria have been deleted from the declassified document, but under "Selection Criteria," it is noted, "Military aircraft in less than squadron strength are not considered for basic categorization." (p. 545) The NTDI Handbook notes that the objective for attack will vary according to the strategic or tactical situation, but offers the following list of objectives: runways; administration buildings,

barracks, shops or storage buildings; hangars; aircraft in the open; aircraft in bunkers (including underground bunkers); POL storage; and conventional ammunition storage

58 "NRDC Nuclear Notebook: Russian Nuclear Forces, 2000," Robert S. Norris and William M. Arkin, *Bulletin of the Atomic Scientists*, July / August 2000, pp. 70-71.

59 See also, Joshua Handler, "Lifting the Lid on Russia's Nuclear Weapon Storage," *Jane's Intelligence Review*, August 1, 1999.

60 Anatoly Yurkin, "Safety of Nuke Arms Handling Enhanced," TASS, December 29, 2000.

61 "USA Installing Automated Nuclear Weapons Monitoring System in Russia," ITAR-TASS News Agency, Moscow, December 5, 2000 (BBC Summary of World Broadcasts, December 7, 2000).

62 General Accounting Office, "Security of Russia's Nuclear Material Improving; Further Enhancements Needed," GAO-01-312, February 2001, p. 32.

63 The United States FY 2002 budget indicates some of the Navy sites are for temporary storage, e.g. storage near the piers where the SSBNs are docked (DEFENSE NUCLEAR NONPROLIFERATION, pg. 51).

64 The Nizhny Tagil Sites 1 and 2 and the Yuryuzan Sites are near warhead or warhead component assembly and disassembly plants, but it is our understanding that it is appropriate to characterize them as National Level nuclear warhead storage sites.

65 "Nuclear Decay—Specialists Claim It Would Take Only 26 Men to Commandeer a Nuclear Warhead," Kirill Belyaninov, *Noviye Izvestia* staff. *Noviye Izvestia*, February 19, 2000, pp. 1-4 (Current Digest of the Post-Soviet Press, March 22, 2000, Vol. 52, No. 8; Pg. 6). This article goes on to discuss the closing of the national-level facility at Tula and U.S. General Habiger's inspection of the Krasnoarmeyskoye national-level storage site in 1998: "State-of-the-art 'Potemkin villages' were built specifically for the official delegations, where a single facility would be equipped to perfection. . . . The first installation used as a showpiece was near Tula, but it became the site of a 'revolt of

officers' wives' in 1996: These women had had it with salary arrears and blocked the access road to the installation. After that the installation was taken off line, the nuclear weapons were removed, and the officers were transferred to other units. . . . Meanwhile, all the state-of-the-art sensors and security systems were reinstalled at another showpiece facility, this one in the Volga region. It was inspected in the summer of 1998 by Gen. Eugene Habiger, commander in chief of the U.S. Strategic Command."

66 NTDI, p. 369. In the *NATO Target Data Inventory Handbook*, the storage sites are identified according to the "type of command(s) supported by the overall storage site: Air Forces, Rocket Forces, Ground Forces, Naval Forces, Air Defense Forces, Strategic Bombs, Tactical Bombs, ASM (i.e., Air-to-Surface Missile) Warheads, AAM (i.e., Air-to-Air Missile) Warheads, ICBM Warheads, IRBM Warheads, MRBM Warheads, Artillery Projectiles, Atomic Demolition Munitions (ADM), SLBM Warheads, Torpedoes/Mines, SAM (i.e., Surface-to-Air Missile) Warheads, Tactical Missile Warheads and Unknown." NTDI, p. 371.

67 Ruffner, Kevin C., ed., *Corona: America's First Satellite Program*, CIA Cold War Records, (Washington, DC: History Staff, Center for the Study of Intelligence, Central Intelligence Agency, 1995), pp. 169-173.

68 Thomas B. Cochran, Robert S. Norris, Oleg A. Bukharin, *Making the Russian Bomb: From Stalin to Yeltsin* (Boulder, CO: Westview Press, 1995).

69 Oleg Bukharin, Thomas B. Cochran, Robert S. Norris, *New Perspectives on Russia's Ten Secret Cities* (Washington, DC: NRDC, October 1999); Oleg Bukharin, et al., *Helping Russia Downsize its Nuclear Complex: A Focus on the Closed Nuclear Cities* (Princeton University: Center of International Studies and Center for Energy and Environmental Studies, June 2000).

70 *Ibid.*

71 *Ibid.*

72 Viewgraphs presented by Lev Ryabev, First Deputy Minister of Atomic Energy, Russian Federation, "The Role of the NCI in

Meeting Russia's Nuclear Complex Challenges," Washington, DC. January 11, 1999.

73 *Ibid.*

74 Lev Ryabev, First Deputy Minister of Atomic Energy, Russian Federation, "The Role of the NCI in Meeting Russia's Nuclear Complex Challenges," January 11, 1999, Washington, DC.

75 But some records are present for historical reasons and would clearly not be targeted under MAO-NF, for example the Skruna large phased-array early warning radar, which ceased operations on August 31, 1998.

76 Russia had 61 operational communications spacecraft in 1997 "Russian Space Activity," *Air Force Magazine*, August, 1998, p. 33.

In operation since 1985, the low-orbiting *Strela-3* military communications satellites (twenty currently operational) use near polar circular orbits, and are launched in sextets into two mutually perpendicular orbital planes which provide worldwide communications relays. *Strela-3* provides military store-dump (frame relay communications) for the Main Intelligence Directorate (GRU) of the General Staff of the Defense Ministry. They are referred to as "space mailboxes for Russian spies" ("Commission to Investigate Why Military Satellites Ended up in Wrong Orbit," *BBC Summary of World Broadcasts*, June 23, 1998; "Russia Orbits Six Military Communications Satellites," *Aerospace Daily*, June 18, 1998, p. 446.). The same technology was used for the civil version of the system, called *Gonets-D1* (6). In 1996 and 1997 *Strela-3* and *Gonets-D1* satellites shared two launches to combine initial deployment of the civil system with maintenance of the military version. Problems with the 1997 launch, however, placed these six satellites into probably useless orbits.

The *Raduga* (7) (*Raduga* means rainbow in Russian) satellites comprise the main Russian secure military/government telecommunications system. Russia states it plans to replace the original *Raduga* satellites with a more capable *Raduga-1* series, of which one is currently operational (Phillip Clark, "Russia's Satellite Launches on the Wane," *Jane's Intelligence Review*, November 1, 1996, p. 485). The control station

for the *Raduga* satellites is the Main Center for the Testing and Control of Spacecraft, which is just outside Moscow in the city of Golitsino (55° 37' N 036° 59'E).

Additional secure government/military communications for the Russian Federation is provided by the *Molniya* satellite system (*Molniya* means "flash of lightning" in Russian). *Molniya-1* (4) are used for government and military communications whereas *Molniya-3* (4) are used for TV programs. Originally, *Molniya-1* and *Molniya-3* satellites operated with one satellite of each type within each of eight orbital planes, allowing 24-hour communications coverage (a total of 16 satellites). The last space launch for the *Molniya-2* program was in 1977.

The Potok network (2), used for military-data relay, employs *Cosmos* satellites based upon a satellite bus called *Geizer*. There have been three Potok locations registered at 80 East, 168 West, and 13.5 West, although only the first and third locations have actually been used as of 1996. Recent Potok launches include *Cosmos 2172* (November 22, 1991), *Cosmos 2291* (September 21, 1994), and *Cosmos 2319* (August 31, 1995) (Phillip Clark, "Russia's Satellite Launches on the Wane," *Jane's Intelligence Review*, November 1, 1996, p. 485). There are two other data-relay networks that may or may not be used for government/military communications, but are used commercially: *SSRD-2* and *SDRN*. Both networks are divided into East, Central, and West zones. For *SSRD-2* this is denoted by *VSSRD-2*, *CSSRD-2*, and *ZSSRD-2* (Russian word for East begins with a v-sound, etc.) and for *SDRN* this is denoted by *ESDRN*, *CSDRN*, and *WSDRN*. The Russian Satellite Communications Company (RSCC) is responsible for the operations of satellites of the *Gorizont* (9) and *Express* (2) satellite types. RSCC currently owns five large teleports and smaller regional monitoring stations all over Russia. "Russia—Liberalization of the Telecommunications Industry: An Overview," *International Market Insight Reports*, July 24, 1998.

77 In 1997, Russia had 30 operational spacecraft with a navigation mission ("Russian Space Activity," *Air Force Magazine*, August, 1998, p. 33.). The Russian analog to the Global Positioning System

(GPS/NAVSTAR) is the GLONASS system (20), planned to occupy three orbital planes 120 degrees apart with eight slots/plane. Phillip Clark, "Russia's Satellite Launches on the Wane," *Jane's Intelligence Review*, November 1, 1996. The Russians do not degrade accuracy of the satellite signal as does the US, and GLONASS does not encrypt the most accurate signal that it broadcasts. In 1994, it was reported that a Western businessman visited the Glonass command center at a high-security compound outside Moscow: "Once you get past the gate, it's like a whole city inside a fence. There are markets, apartments, schools . . . the closely guarded satellite-control center is dominated by enormous data screens and banks of computer terminals (Elliot Blair Smith, "Russia Positions System Against U.S. Satellite Program," *The Orange County Register*, July 17, 1994, p. K04)." Air Force Magazine lists two other navigation satellite systems: Kosmos-military (6) and Kosmos-civil (4).

78 In 1997 Russia had four operational meteorological spacecraft: three Meteor and one Elektro (GOMS).

79 In 1997 Russia had eight operational early warning spacecraft: six in the first-generation *Oko* system and two in the second-generation Prognoz system.

The *Oko* system is Russia's first generation early warning system: orbits are reminiscent of the *Molniya*. When fully operating, the system comprises nine satellites with their orbital planes spaced 40 degrees apart in eccentric earth orbits. The Prognoz system (also described as a Russian scientific program designed to study the sun's activity and its influence on earth's magnetosphere) is Russia's second-generation early-warning system. The goal is to have three or four operational satellites in geosynchronous orbit, however technical problems are causing deployment to be delayed. Phillip Clark, "Russia's Satellite Launches on the Wane," *Jane's Intelligence Review*, November 1, 1996.

#### Chapter Five

1 Jeffrey Richelson, "Population Targeting and U.S. Strategic Nuclear Doctrine," in Desmond Ball and Jeffrey Richelson, eds.,

*Strategic Nuclear Targeting* (Ithaca: Cornell University Press), 1986, p. 237.

2 Richelson, "Population Targeting," pp. 238-40.

3 As described in Chapter Three, a P-95 circle is an approximation to the actual population distribution in a given urban area. Within the P-95 circle it is assumed that 95 percent of the associated population resides. A statistical analysis of demographic data for the European continent by the RAND Corporation in the 1970s yielded the following formula for the P-95 circle radius as a function of population:  $\text{Radius (P-95, nautical miles)} = 0.5125 \times \ln(1.3 + 0.2 \times P)$ , where P is the population in thousands. One nautical mile equals 1852 meters. Thus a city of 10,000 would have a P-95 radius of 1.1 km, a city of 100,000 would have a P-95 radius of 2.9 km, a city of 500,000 would have a P-95 radius of 4.4 km and a city of 1,000,000 would have a P-95 radius of 5.0 km.

4 Robert McNamara, "Memorandum for the President; Subject: Recommended FY 1966-1970 Programs for Strategic Offensive Forces, Continental Air and Missile Defense Forces, and Civil Defense (U)," draft, December 3, 1964, p. 11.

5 Kenneth McGill, "USSTRATCOM/J53 War Plan Analysis," MSRR/MEL Users Conference, April 1999.

6 R. H. Craver, J. T. McGahan, E. Swick, M., K. Drake and J. F. Schneider, *The Feasibility of Population Targeting* (McLean, Virginia: Science Applications, 1979), Defense Nuclear Agency, Contract Number DNA 001-78-C-0061, June 30, 1979. Security Class: SECRET-RESTRICTED DATA (Released under FOIA with deletions), pp. 29-30.

7 *Ibid.*, p. 11.

8 McNamara, "Memorandum for the President," pp. 18-19.

9 *The Feasibility of Population Targeting*, p. 17.

10 *Ibid.*, p. 23.

11 *Ibid.*, p. 23.

12 *Ibid.*, p. 27.

13 The Russian population of 152 million is the number given in the 1999 LandScan data set. It is estimated that the current Russian population is probably about ten

percent less than this figure and continues to decline at a significant rate.

14 Proponents of the Trident II system have argued that in the event of nuclear conflict with the Soviet Union, U.S. leadership should have the option of precise targeting as an alternative to overwhelming destructive use of nuclear weapons.

15 John M. Donnelly, "Air Force Okayed ICBM Upgrade Despite Unproven Accuracy," *Defense Week*, February 5, 2001, p. 1.

16 "Capabilities of Nuclear Weapons [U]," revised edition, TM 23-200, prepared by Defense Atomic Support Agency, Departments of the Army, Navy, and the Air Force, Washington, DC, November 1964.

17 The 19 NATO member countries currently include Belgium, Canada, Denmark, Germany, Greece, Italy, Luxembourg, Netherlands, Norway, Portugal, Turkey, United Kingdom, United States, French Military Mission, Spain, Iceland, Czech Republic, Hungary and Poland.

#### Chapter Six

1 From the late 1960s to the early 1990s, detailed and lengthy bilateral negotiations led to the SALT and START agreements. The treaties had extensive verification procedures as well as timetables for achieving upper ceilings or lower reductions. The treaties had the virtue of providing some boundaries and rules to a difficult and dangerous competition that was often on the verge of getting out of control. The chief drawbacks were that the negotiations were time-consuming; the internal policy process on each side was overly bureaucratic with every position and word needing widespread consensus.

These limitations would probably still be operative today and thus other approaches and initiatives are recommended. Nevertheless, while it is true that the Cold War is over, and that there are far different geopolitical conditions facing the U.S. and Russia, the competition between them and the vestigial suspicions they still have of one another have not totally disappeared. It would thus seem prudent to continue to implement the measures agreed to

in the past treaties and not let the treaty regime unravel, especially the Anti-Ballistic Missile Treaty, a distinct possibility if certain choices are made.

2 George W. Bush, "New Leadership on National Security," May 23, 2000.

3 George W. Bush, "Remarks to Students and Faculty at National Defense University," Fort Lesley J. McNair, Washington, D.C. May 1, 2001.

4 "Missile Shield Argument Laughable, Russian Says," *Baltimore Sun*, May 15, 2001.

5 Erik Eckholm, "China Unconvinced as Missile Talks End," *New York Times*, May 16, 2001, p. A6.

6 Paul Mann, "Bush Team Rethinks Strategic Doctrine," *Aviation Week & Space Technology*, January 22, 2001, pp. 26-27.

7 Union of Concerned Scientists and MIT Security Studies Program, *Countermeasures, A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defense System*, April 2000.

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