CHAPTER THREE

The NRDC Nuclear War Simulation Model

The NRDC Nuclear Program has developed software and databases that provide new capabilities to analyze the scale and consequences of nuclear violence. During the Cold War, a number of individuals and institutions published studies and reports about nuclear conflict, creating a reference set of calculations and formulas in the process. We have revisited some of these earlier efforts with vastly improved technological and computing resources and with greater access to once secret information. NRDC's nuclear war simulation model can now provide a glimpse of the war planning process.

The NRDC Nuclear War Simulation Model relies on a collection of nuclear weapon effects formulas and several sets of input data, including:

- Characteristics of the attacking nuclear weapons or forces
- Parameters of the attacked targets, including coordinates, and vulnerability
- Geographic and demographic data for the attacked country
- Meteorological data, particularly wind data for fallout calculations

These nuclear weapons effects formulas and input data are integrated into a Geographic Information System (GIS) called ArcView. This commercial software package allows the user to display any data that have associated spatial coordinates, such as latitude and longitude. The user can integrate into ArcView other computer models, e.g., the nuclear weapon effects, to perform additional calculations. ArcView is then able to further analyze and display the results of the calculations. NRDC has customized ArcView to facilitate management of the input and output data, to perform the nuclear weapon effects calculations, and to reduce the time required for the calculations.

Below we review the components of NRDC's nuclear conflict software and database suite.

CHARACTERISTICS OF THE ATTACKING NUCLEAR FORCES

Our model describes the nuclear arsenal of the attacking nation—in this case the United States—in terms of:

▸ The type and number of nuclear warheads and their nuclear weapon delivery systems
▸ The various levels of alert at which the nuclear force operates
▸ The yield or yield options of the warhead, and the fraction of the yield produced by fission, for the different design types (e.g., gun-type fission, boosted-fission implosion, high-yield thermonuclear)
▸ The performance features of the several kinds of delivery systems (e.g., MX ICBMs, Trident D-5 SLBMs, B52H bombers) measured by range, flight time, accuracy, and reliability

To gain a clear picture of what a U.S. nuclear attack on Russia would look like, NRDC started by analyzing the characteristics of the U.S. arsenal. There are currently seven kinds of delivery vehicles and nine warhead types in the U.S. arsenal.[1] The 1,054 U.S. strategic delivery vehicles (ICBMs, SLBMs and strategic bombers) and approximately 7,200 operational strategic nuclear warheads are deployed at four alert levels: "Launch Ready," "Generated I," "Generated II," and "Total Forces." The four alert levels are distinguished by how many delivery vehicles are fully deployed, and how quickly they are able to fire their weapons (see Table 3.1). Launch Ready refers to the day-to-day alert level of U.S. nuclear forces that includes most (95 percent) of the ICBMs and four SSBNs at sea within range of their targets. The second level, Generated I, would add five SSBNs. Generated II would indicate a serious crisis where six more SSBNs and 64 bombers would be placed on alert. At this point, approximately 90 percent of the total forces would be on alert. It would take considerable effort to generate the last ten percent—the entire force including all 550 ICBMs, 18 SSBNs, 16 B2s, and 56 B52Hs—to full alert status, though theoretically it could be done. The basic characteristics of the nine types of nuclear warheads in the current U.S. arsenal are presented in Table 3.2. The 550 U.S. ICBM silos, two strategic submarine bases, and three strategic bomber bases are depicted in Figure 3.1.

In addition to listing the various nuclear warheads, we also analyzed each weapon's fission fraction. Assumptions about fission fraction play an important role in calculating the initial radiation produced in a nuclear explosion and the amount of fallout. Here we assume the fission fraction of all thermonuclear weapons at full yield is between 50 and 80 percent. For low-yield options of the bomber-delivered weapons, we assume the fission fraction is 100 percent. The fission fraction may be

TABLE 3.1
Summary Data for the Four Alert Levels of the Current U.S. Strategic Arsenal

Alert Level	% ICBMs on Alert	% SLBMs on Alert	% Bombers on Alert	Total # Delivery Vehicles	Total # Warheads
Launch Ready	95	22	0	618	2,668
Generated I	95	50	0	738	3,628
Generated II	99	78	90	944	6,238
Total Forces	100	100	100	1,054	7,206

TABLE 3.2
Characteristics of Delivery Vehicles and Nuclear Warhead Types in the U.S. Arsenal

Warhead	Total Number	Delivery Vehicle Type	Delivery Vehicle	Accuracy (CEP, m)	Yield(s) (kt)	Fission Fraction(s) (%)
W62	600	ICBM	MM III/Mk-12	183	170	50
W78	900	ICBM	MM III/Mk-12A	183	335	50
W87-0	500	ICBM	MX/Peacekeeper/Mk-21	91	300	50
W76	3,072	SLBM SLBM	Trident I C-4/Mk-4; Trident II D-5/Mk-5	229-500; 130-183	100	50
W88	384	SLBM	Trident II D-5/Mk-5	130-183	450-475	50
B61-7	300	Bomber Bomber	B2 and B52 Bombers	0	0.3, 5, 10, 80, 350	100, 100, 100, 50, 50
B61-11	50	Bomber	B2 Bomber	0	0.3, 5, 10, 80, 350	100, 100, 100, 50, 50
W80-1	800	Bomber	B52 Bomber/Air Launched Cruise Missile	0	0.3, 5, 10, 80, 150	100, 100, 100, 50, 50
B83	600	Bomber	B2 and B52 Bombers	0	1000	50

varied in the NRDC model. Accuracy is expressed in circular error probable (CEP), which is defined as the radius of a circle centered on the desired target within which on average half the warheads will fall. The government has classified its estimates of the CEP of various delivery systems. We drew our estimates from ones generally used in unclassified studies. We have used them to compute the probability of damaging or destroying specific target types. We currently plan in a later phase of this project to address the complex choreography of thousands of nuclear weapons

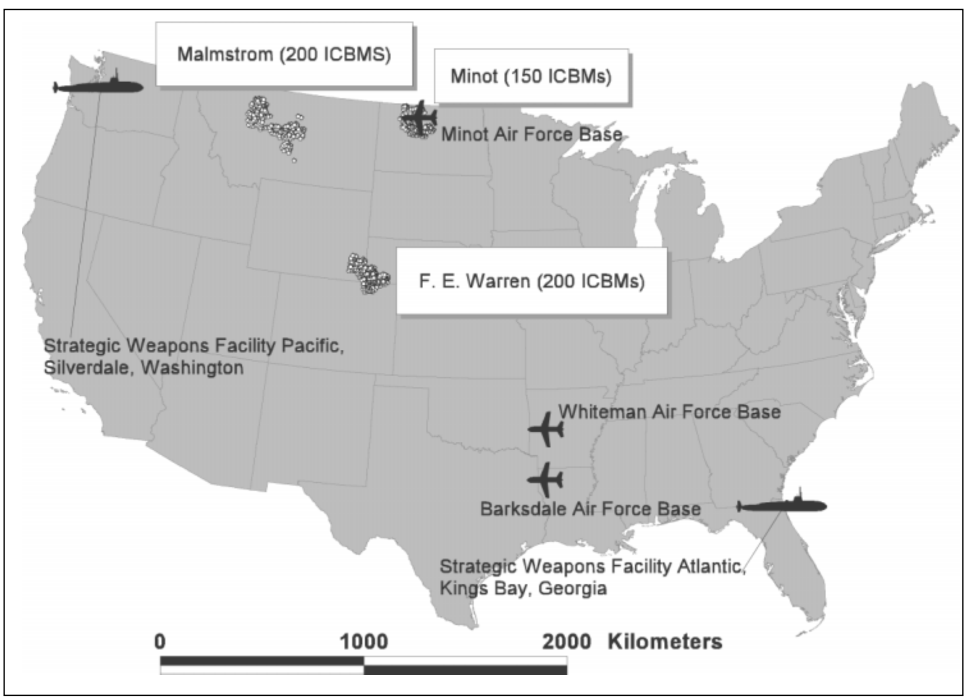

FIGURE 3.1
Locations of U.S. Nuclear Forces
This map shows: the 550 U.S. ICBM missile silos deployed at F.E.Warren (150 Minuteman III and 50 MX missiles distributed over approximately 22,000 square kilometers (km^2) at the intersection of Colorado, Wyoming, and Nebraska); Minot (150 Minuteman III missiles distributed over approximately 16,000 km^2 in North Dakota); and Malmstrom (200 Minuteman III missiles distributed over approximately 30,000 km^2 in Montana); three U.S. air force bases where strategic bombers are deployed; and the two U.S. naval strategic-weapons facilities.

launched at their targets, including calculations of warhead trajectories and flight times, footprint size, and fratricide based on the location and timing of the launches (as well as bomber flight paths and refueling points).

In the NRDC nuclear war simulation model, the user may assign attacking warheads to targets with respect to a constraint on the number of available warheads of each type. For example, the user may opt to construct an attack based on current U.S. launch-ready forces only, or with START II, START III, 1,000-warhead and 500-warhead forces at any of the four alert levels. We included the constraint option in our model to see what the capabilities are and the extent of damage that results for various sized forces.

TARGET DATA

As discussed in Chapter Two, USSTRATCOM has selected a set of potential nuclear weapon targets, known as the National Target Base (NTB), from a larger target list called the Modified Integrated Database (MIDB). We believe that the number of targets in the NTB is currently around 2,500, with about 2,000 of them in Russia, 300 to 400 in China, and 100 to 200 elsewhere.[2]

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USSTRATCOM also maintains the Joint Resources Assessment Database System (JRADS), a comprehensive database used to facilitate strategic war planning. JRADS contains worldwide population data, industrial worth, and information about U.S. and non-U.S. installations. It is the U.S. government's central repository of accurate population data and facility information and is widely used throughout their departments and agencies.[3]

NRDC is in the process of assembling from public sources its own series of target databases to serve the NRDC nuclear war simulation model. Instead of compiling a single global database, we have six databases covering six geographic regions:

- Russian targets
- U.S. targets
- European, North African and Middle Eastern targets
- Chinese targets
- East Asian targets (excluding China)
- South Asian targets (India and Pakistan)

Of the six, our Russian database is the most fully developed: it contains almost 7,000 sites in Russia. We have sought to include the types most likely to be in the National Target Base. It should be emphasized that our databases do not purport to be a replication of the NTB. Our suite of databases might be thought of as a hybrid, containing some targets not in the NTB, but far fewer than those in the MIDB. For instance, our database contains almost twice as many targets as the NTB. Some of the differences in the numbers can be readily explained. For example, for historical purposes we have included many closed facilities, including dismantled missile silos. For completeness, we have sought to include all airfields, even small civilian ones, since we are not always confident whether a specific airfield is civilian, military, or dual purpose. We have included all known power plants with a capacity greater than about one megawatt-electric (MWe). Also included are all of the military sites identified in the data exchanges related to the START and Conventional Forces in Europe (CFE) treaties. We lack knowledge in certain areas, such as the locations of important leadership sites, communication nodes, and industrial facilities.

The availability of a data set larger than the NTB permits us not only to identify likely targets, but to have a better understanding of which sites are not included under various attack options and which are included in the collateral damage resulting from the selection of nearby higher priority targets.

USSTRATCOM, in the JRADS database, uses a hierarchical functional classification code structure to categorize facilities and targets.[4] It appears that the same classification coding system is used in the MIDB and in the NTB.[5] While we still do not know all of the facility types and classification code numbers used in the U.S. government databases, many of these are known and are reproduced in Appendix A.

The NRDC target database uses a more simplified classification scheme. All targets are first grouped under four broad "Target Classes:"

- Nuclear forces (NF)
- Leadership-including command, control and communication (L-C^3)
- Other military targets (conventional military forces) (OMT)
- War support industry ("urban/industrial") (WSI)

We break these four down even further into "target categories" and "target types." The classification scheme used in the NRDC target databases is provided in Appendix C.

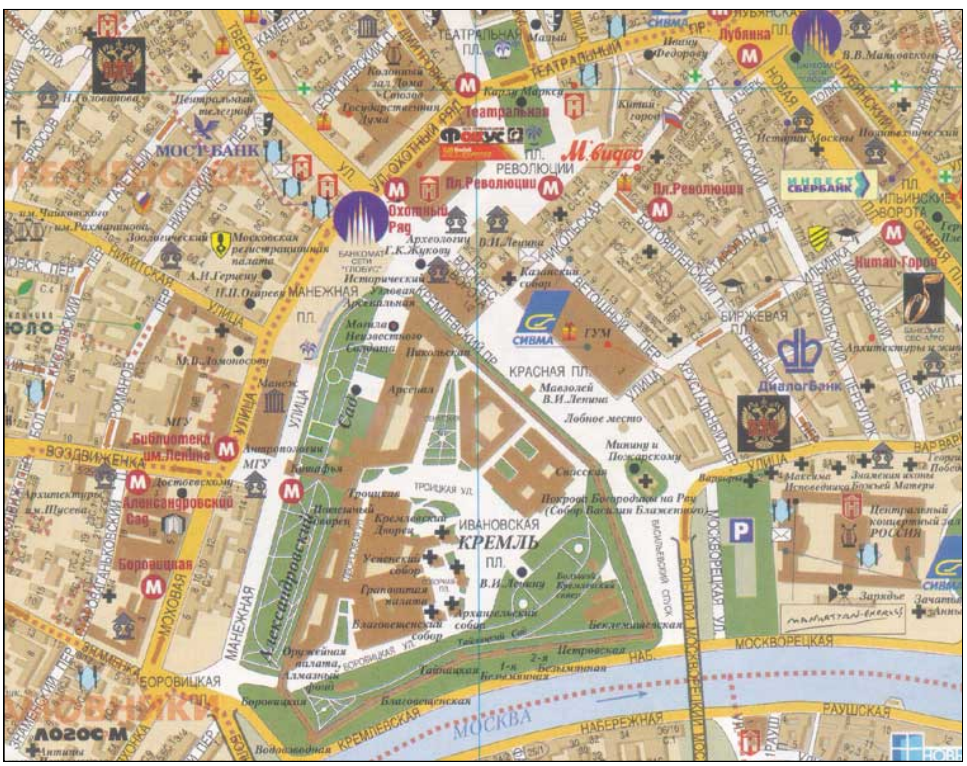


FIGURE 3.2
A Geo-referenced Moscow Street Atlas
This geo-referenced portion shows the Kremlin and the Duma (Russian lower house of parliament). This street atlas was geo-referenced by aligning it with a larger-scale street grid that in turn was aligned to the corresponding U.S. military JOG based on features such as the intersection of roads, railroads, rivers, and streams. Source: Atlas-Moskva, April 1998.

We have located the coordinates of the vast majority of targets we have identified. Target locations are recorded to the nearest second of latitude and longitude where the data is available. In some cases, we know the coordinates to the nearest minute, in others only by the name of the city or town where a facility is located. The coordinates of cities and towns are easily obtained from the National Imagery and Mapping Agency's (NIMA) publicly available database or from U.S. government maps.[6] We found three series of government maps particularly useful: Operational Navigation Chart (ONC) 1:1,000,000 scale; Aeronautical Charts 1:500,000 scale; and Joint Operations Graphic (JOG) 1:250,000 scale. For large cities, unless a precise address or street map is available, the uncertainty in location can be 15 minutes or more. Moscow and St. Petersburg street maps have been geo-referenced as part of this project and thus if we know the street address we can locate the coordinates to within about 100 meters. Figure 3.2 shows a portion of our geo-referenced Moscow street atlas in the vicinity of the Kremlin. Table 3.3 converts minutes and seconds to meters as a function of latitude in order to put into perspective the precision of the NRDC database coordinates.[7]

Satellite imagery provides a valuable tool for locating and understanding the layout of such major targets in Russia as the closed nuclear cities, naval bases, nuclear-weapon storage facilities, and airfields. Public availability of high-resolution satellite imagery creates a fundamentally new opportunity for non-governmental organizations to research arms control information. Increasingly, these organizations, such as the Federation of American Scientists, are using historical satellite imagery or commercially available imagery of military facilities in their work.[8] The two main sources of satellite imagery used in the NRDC project are the U.S. government's images from the Corona program (which are available for purchase from the National Archives in College Park, Maryland) and contemporary film footage taken by the Ikonos satellite (licensed commercially through the Space Imaging Corporation).

The Corona satellite photography program began in August 1960 and continued until May 1972, and involved over 100 missions.[9] The program provided extensive (but not continuous) coverage of nuclear and other military sites in Russia.[10] The first Corona camera had a resolution of about 40 feet.[11] By 1963 improved cameras for the KH-2 and KH-3, achieved a resolution of 10 feet.[12] By 1967, the J-3 camera of the KH-4B was able to photograph with a resolution of five feet,[13] continuing until 1972.[14] Figure 3.3 shows a Corona image of the Nenoksa SLBM test facility west of the Russian city of Arkhangelsk.

Archived, one-meter resolution images taken by the Ikonos satellite may be browsed in a 16-meter resolution format at the Space Imaging Corporation's Internet site (www.spaceimaging.com). At the base price for archived or new Ikonos imagery, the Space Imaging Corporation will geo-reference its images to within an accuracy of ± 50 meters. For a significantly higher price the geo-referencing accuracy can be increased to ± 12 meters. Figure 3.4 is an Ikonos image of the Russian Rybachiy nuclear submarine base near the city of Petropavlovsk-Kamchatskiy in the Russian Far East. Though the image is in the 16-meter resolution format, features such as piers and buildings are clearly visible.

We derived the information for the NRDC Russian target database from a wide variety of sources. Data on strategic nuclear forces derives primarily from the "START Treaty Memorandum of Understanding Data" exchanges. The coordinates of missile silos, launch-control centers and bases, SSBN bases, strategic-bomber bases, missile-storage facilities, and missile- and bomber-production and elimination facilities to the nearest minute of latitude and longitude are found in Annex 1 of the START Treaty data exchange. Thus, the locations are known to within ± 0.5 minutes (± 927 meters, or less). Some of these sites can be identified on more recent JOGs. On these 1:250,000 scale maps, coordinates can be recorded with a precision of about ± 15 seconds (± 460 meters, or less). The "START Treaty Memorandum of Understanding Data" is updated biannually (31 January and 1 July), and is publicly available within 90 days. The MOU includes the number of deployed and non-deployed ICBMs, ICBM launchers, SSBNs, SLBMs, strategic bombers, and production, storage, and elimination facilities.

The principal source of information about conventional military force deployments west of the Ural Mountains (for the Moscow, Northern, Volga, and North Caucasus Military Districts) is provided in the Conventional Forces in Europe Treaty (CFE) data exchange. There is little publicly available information about Russian conventional force deployments in the Ural, Siberian, Transbaikal, and Far East Military Districts. The CFE Treaty data exchange provides coordinates of military units (e.g., regiments and divisions) to the nearest 10 seconds (i.e., ± 5 seconds or about ± 150 meters or less) and data on the numbers of military personnel, combat aircraft, helicopters, tanks, armored vehicles, and artillery in the units.

The NRDC target database has drawn upon numerous additional sources including:

- The six editions of the U.S. Department of Defense's *Soviet Military Power* (1981–1987), and *Military Forces in Transition* (1991), which provide useful data on the deployment of conventional and strategic Russian forces.
- The Digital Chart of the World (a commercial product of ESRI Corporation), the NIMA public database, the ONC and JOG maps, Aeroflot commercial flight timetables, various DOD Flight Information Publications, and the maps in *Soviet Military Power* have been used to determine locations and characteristics of Russian airfields.
- NRDC publications about the Soviet nuclear-weapons production complex.[15] A recent NRDC report by Oleg A. Bukharin of Princeton University analyzes Corona images of the Russian, closed nuclear cities.[16]

TABLE 3.3
Conversion of Minutes and Seconds to Meters as a Function of Latitude

At Latitude	45°	55°	65°	75°
1 min latitude ≈	1,852 m	1,850 m	1,848 m	1,846 m
1 sec latitude ≈	31 m	31 m	31 m	31 m
1 min longitude ≈	1,312 m	1,064 m	784 m	480 m
1 sec longitude ≈	22 m	18 m	13 m	8 m

FIGURE 3.3
Corona Satellite Image of the Nenoksa SLBM Test-Launch Facility
Near Arkhangelsk in northern Russia, acquired during mission 1115-2 on September 18, 1971. Source: Joshua Handler, Princeton University.

- Exchanges and research programs funded under the DOD's Cooperative Threat Reduction (Nunn-Lugar) programs, various Department of Energy (DOE) initiatives in Russia, and the International Science and Technology Center's research programs.
- Russian power plant data from three sources. First a set of four maps commercially available from East View Cartographic, Minneapolis, Minnesota shows the name, type, size, and approximate location of all power plants larger than about one megawatt-electric. Second, a power plant database (without locations), from McGraw-Hill Publications. And third, the JOG and ONC maps, which indicate vertical obstructions, smokestacks, and power lines.
- Two CD-ROMs published by the International Telecommunications Union (Union Internationale des Télécommmunications), Geneva, which provide information about Russian radio transmitters, and satellite earth station. Since the coordinates are not always accurate, we have attempted to improve the accuracy by using the ONC and JOG maps.
- Bellona Foundation reports (www.bellona.no), which provide information on the Russian Northern Fleet.[17]
- Joshua Handler's research on Russian naval bases and nuclear-weapon storage sites.[18]
- The growing volume of data that identifies the names and addresses of Russian commercial firms marketing military technology, thus providing information about the War Support Industry targets.

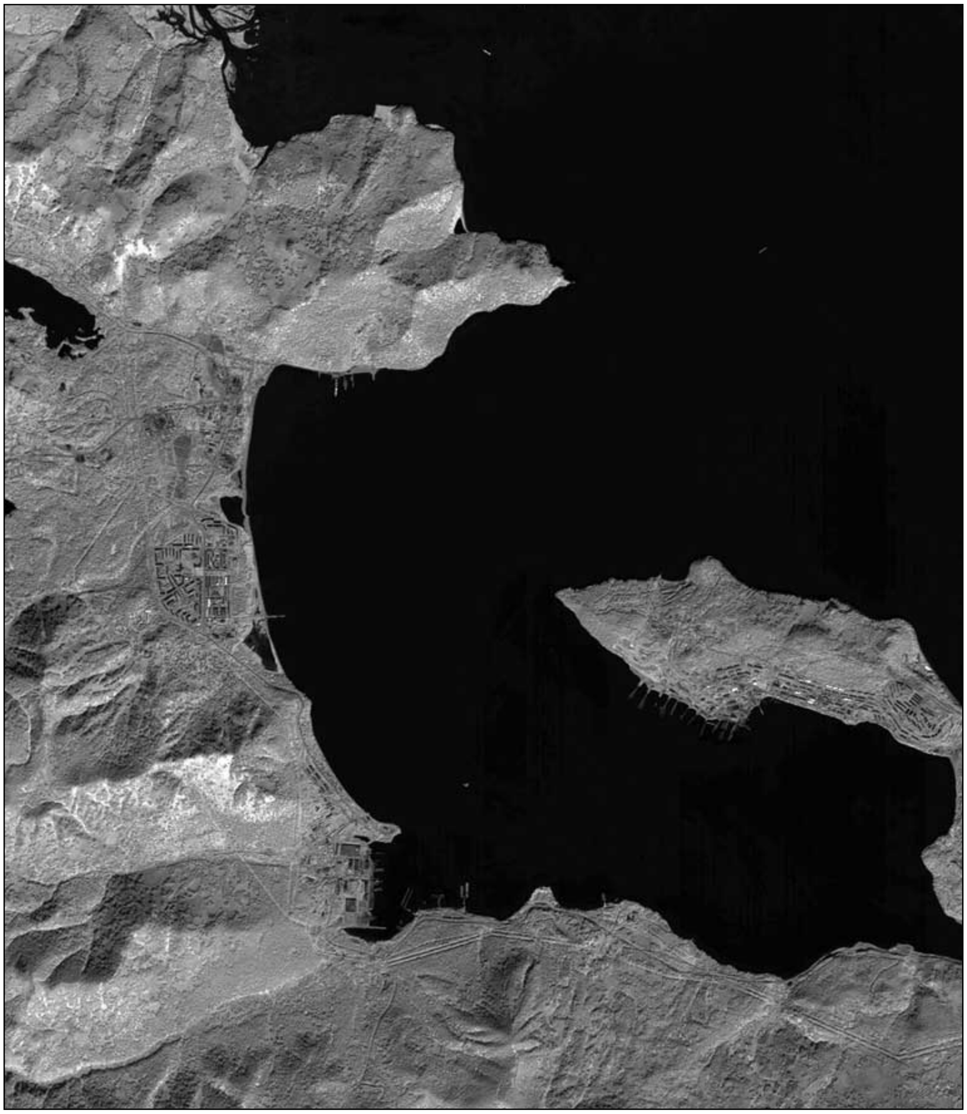


FIGURE 3.4
Ikonos Satellite Image of the Russian Rybachiy Nuclear Submarine Base
This image shows the base near the city of Petropavlovsk-Kamchatskiy in the Russian Far East. Acquired on September 6, 2000. Source: spaceimaging.com.

A unique identification number and name identify each target in NRDC's six databases. Each target record also includes the coordinates, a description of the target, and additional fields of data. The Russian database has more than 90 data fields (see Appendix B).

THE EFFECTS OF NUCLEAR EXPLOSIONS

In order to fully analyze nuclear war plans, we have sought to understand the complex effects of nuclear explosions. With this initial version of the NRDC nuclear war simulation model, we have been able to quickly and accurately calculate the principal effects of a nuclear explosion for a sub-surface burst, a surface burst, and an air burst using a personal computer. We then used these calculations to determine the probability of damaging specific target types, and to compute civilian casualties and the radioactive contamination of the environment.

TABLE 3.4
Nuclear Weapon Types and Their Associated Yield Ranges

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	not given

Glasstone and Dolan describe the general effects of nuclear explosions in the standard reference work, *The Effects of Nuclear Weapons*.[19] We found useful supplementary information in: the declassified 1972 Defense Nuclear Agency *Effects Manual Number 1*,[20] the Defense Nuclear Agency computer codes BLAST[21] and WE,[22] and the Lawrence Livermore National Laboratory computer code KDFOC3.[23] We provide in Appendix D an NRDC compilation of formulas based on these sources for the nuclear explosion blast wave parameters, crater dimensions, thermal radiation (heat) flux, and initial radiation dose.

The following four sections on nuclear weapons effects record our journey and highlight some of the interesting things that we have learned. The first section provides an overview of the thirteen basic types of nuclear weapons noting how they differ in their effects. In the next section, we draw from the historical record of Hiroshima and Nagasaki to discuss the deaths and injuries that could result from the use of high-yield nuclear weapons. In the third section, we examine the nuclear fallout models based upon a Lawrence Livermore computer code, and we compare and contrast it with data from U.S. atmospheric tests conducted in Nevada and the Pacific. The fourth section introduces the U.S. physical vulnerability system whereby damage expectancies or kill probabilities are calculated for specific classes of targets.

Thirteen Nuclear Weapon Types

Scientific and engineering knowledge of nuclear explosives has evolved for more than a half century and continues to develop in the United States through the Science-Based Stockpile Stewardship Program. The first two nuclear weapon types were plutonium-implosion and uranium gun-type fission designs—the "Fat Man" and "Little Boy" bombs dropped on Japan in 1945. Subsequent advances increased the efficient use of fissile material, reduced the weight of a nuclear weapon for a given explosive yield, incorporated fusion reactions in the explosion, provided for multiple-yield options in a single weapon, and enhanced the initial radiation output of the bomb with respect to blast. In a 1984 report, the U.S. Defense Nuclear Agency listed 13 nuclear weapon designs and their yield-range (see Table 3.4). It is unclear what the differences are among "old design," "contemporary design," and "modern design" for types 2–5.

The nuclear weapons effect of initial radiation refers to the radiation released up to one minute after the explosion.[24] It has three components: the prompt neutrons (emitted in the course of the fission and/or fusion reactions), the gamma rays from the decay of fission products, and the secondary gamma rays produced when the prompt neutrons interact with atoms of the air or ground. The initial radiation produced in a nuclear explosion will vary according to the type of nuclear weapon. For example, the fusion reactions occurring in the explosion of a thermonuclear weapon produce high-energy neutrons (in the range 10–15 MeV) that are not produced in the explosion of a fission weapon. To give another example, neutrons are absorbed and scattered when they pass through a nuclear weapon's absorbing materials, e.g. the tamper, chemical high explosive and casing. A weapon type with relatively thin absorbing materials, for example the "Little Boy" gun-assembly fission design (type 1 in Table 3.4), will produce a higher dose of radiation to human tissue at a given distance from the explosion than a weapon type of the same yield but with relatively thick absorbing materials, like the "Fat Man" fission implosion weapon (type 2 in Table 3.4).[25]

To show how the effects of initial radiation depend on design, Figure 3.5 compares the prompt neutron output at one-kiloton explosive yield for four types of nuclear weapons. The lowest initial-radiation dose occurs in the old fission implosion design. The dose from a gun-assembly or a thermonuclear explosion is two to three times higher, and for an enhanced-radiation weapon (or neutron bomb)

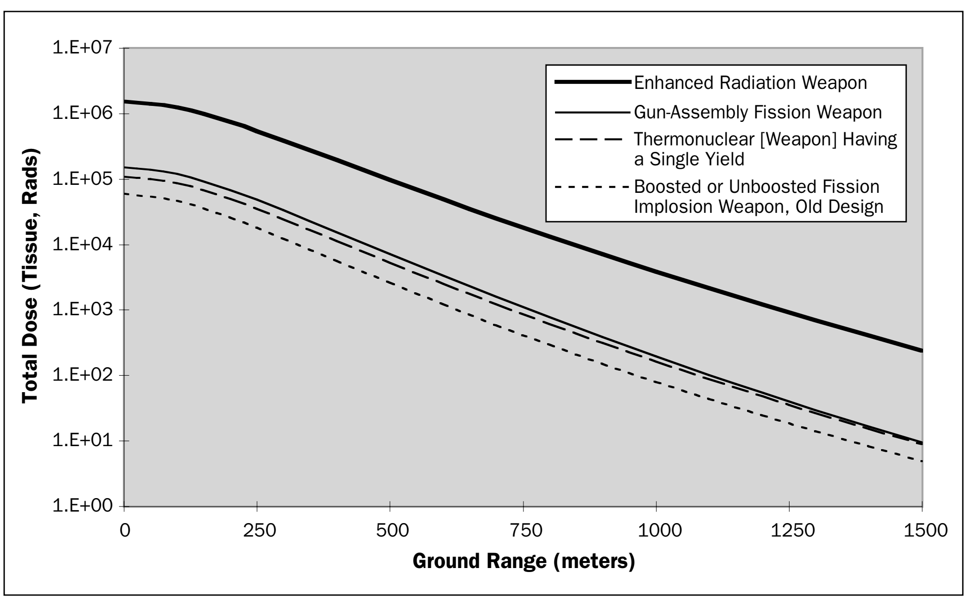


FIGURE 3.5
Initial Radiation Output of Four Nuclear Weapon Designs
In these calculations, we used yields of one kiloton, heights of burst of 238 meters, and mean sea-level air density. For the thermonuclear weapon, a fission fraction of 50 percent was used and for the enhanced radiation weapon, a fission fraction of 75 percent was used.

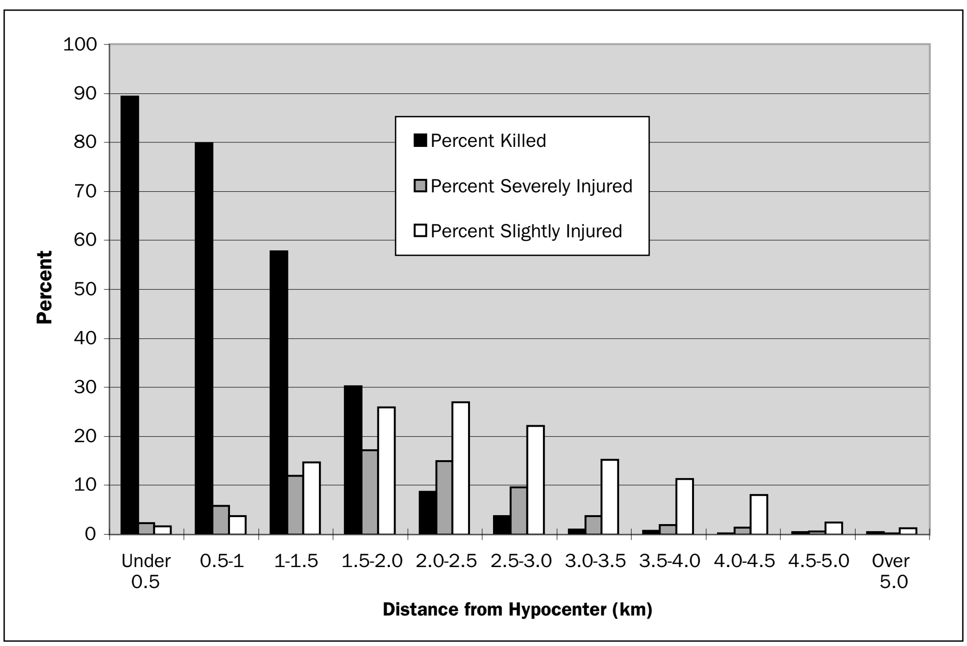
ten times higher. Clearly, to accurately calculate nuclear conflict, nuclear weapon design details become important variables.

Estimating Deaths and Injuries from Nuclear Explosions

In 1945, two nuclear weapons—primitive by today's standards—killed over 210,000 people in the Japanese cities of Hiroshima and Nagasaki.[26] The uranium gun-type nuclear weapon used in the Hiroshima attack had an estimated yield of 15 kt,[27] and was detonated at 580 meters above the surface.[28] The deaths and injuries are plotted in Figure 3.6 for concentric 500-meter zones around ground zero. In the innermost zone (out to one-half a kilometer), close to 90 percent of the people were killed. The incidences of severe injury peaked from 1.5 to 2.0 kilometers from ground zero, with incidences of slight injury from 2.0 to 2.5 kilometers. In what follows, we focus on the details of the Hiroshima bombing to help understand the effects of nuclear explosives.

Three weapons effects of the Hiroshima nuclear detonation killed and injured people: blast, thermal radiation, and initial radiation. Because the bomb was detonated in the air at a high height of burst, almost no local fallout occurred. Many of the fatalities were immediate; additional deaths occurred days, weeks, or even years later. The cause of death for the victims varied depending upon whether they were outdoors or inside. Injuries to those people outdoors from thermal burns and initial radiation extended further from ground zero than injuries caused by blast. But for those inside wooden houses, injuries from blast occurred further from ground zero than for thermal burns or initial radiation. In comparison, people inside concrete structures were significantly shielded from all three effects. At the time of the bombing, 8:15 a.m., the air was clear with visibility of up to 20 kilometers, and many people were outdoors in light clothing.

FIGURE 3.6
Hiroshima Casualties
This graph shows the percentages of persons killed, severely injured, or slightly injured as a function of distance from the Hiroshima hypocenter (i.e., ground zero).[29]



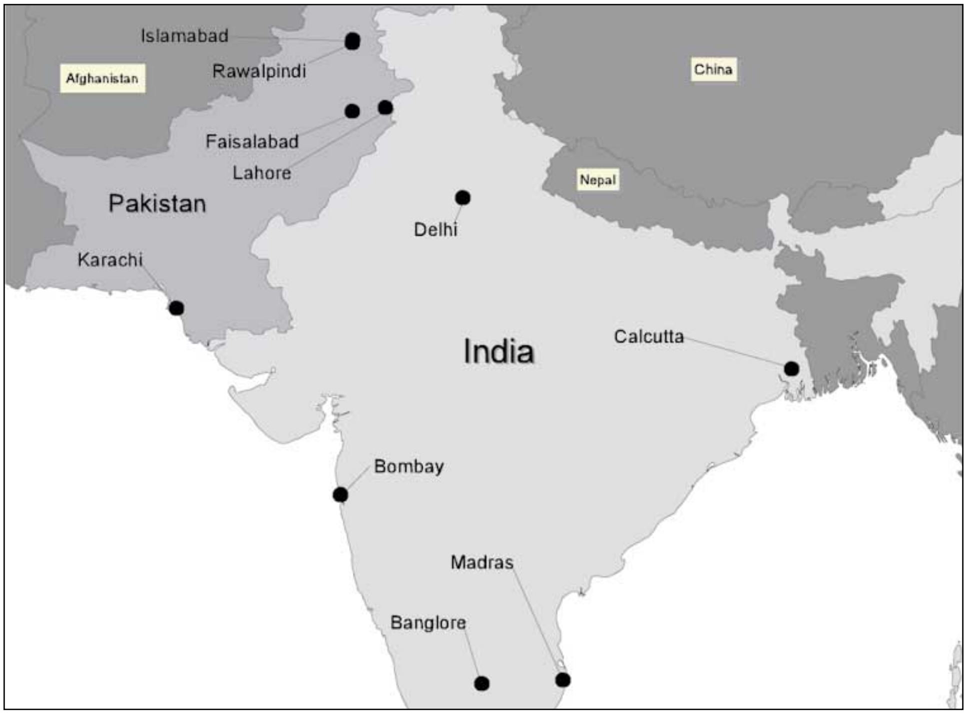


FIGURE 3.7
Ten Indian and Pakistani Cities for Which Hiroshima-Like Casualties Were Calculated

As a first step towards estimating the consequences of nuclear conflict today, the Hiroshima death and injury rates can be superimposed on the population patterns of major urban areas. The same conditions will not apply, such as the number and types of structures and houses, the weather, and the topography, but Hiroshima can provide a point of reference. To illustrate, we have superimposed the Hiroshima rates on the ten major Indian and Pakistani cities mapped in Figure 3.7. Due to much higher population densities, the casualties in the ten South Asian cities are two- to three-times higher than Hiroshima (see Table 3.5).

Clearly, higher-yield weapons can cause many more casualties than the bomb at Hiroshima. To calculate these casualties during the Cold War, the death and injury rates observed at Hiroshima were extrapolated to death and injury rates caused by weapons of other explosive yields. Typically this has been done with emphasis on peak blast overpressure, as seen in an Office of Technology Assessment report, *The Effects of Nuclear War.* Figure 3.8, based on data in that report, shows the percentages of the affected population killed or injured as a function of peak blast overpressure. While the historical record at Hiroshima showed that the distribution of all types of injuries could be roughly correlated with blast effects, this may not be a reasonable assumption for weapons of very different yields. This is because blast effects scale differently with yield compared to other nuclear weapons effects.

For example, in the innermost zone at Hiroshima, less than one-half kilometer from ground zero, 89 percent of the people were killed. From that 15-kiloton bomb at 0.5 kilometers from ground zero the peak blast overpressure was 15.8 pounds per square inch (psi) and the thermal flux was 67.1 cal/cm^2. For a 300-kiloton weapon, detonated at the equivalent altitude of 1,575 meters, an overpressure of 15.8 psi

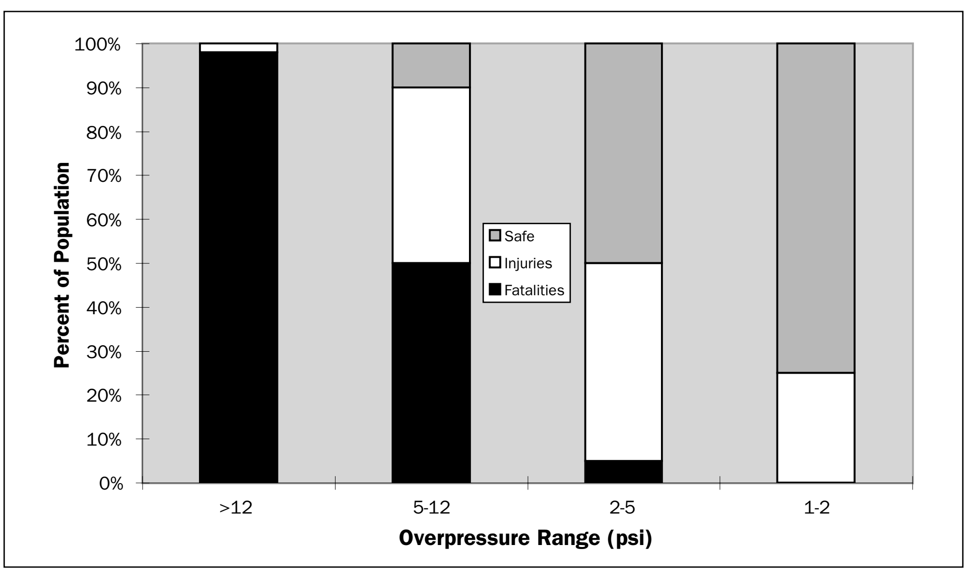
TABLE 3.5
Casualty Calculations for Ten Indian and Pakistani Cities
These calculations use the historical record of Hiroshima casualties as a function of distance from ground zero. Population densities are from the Oak Ridge National Laboratory's "LandScan" data (see below). Ground zeroes were chosen to lie approximately at the centers of these cities.

City Name	Total Population within 5 kilometers of Ground Zero (thousands)	Killed (thousands)	Severely Injured (thousands)	Slightly Injured (thousands)
		India		
Bangalore	3,078	315	175	411
Bombay	3,143	478	229	477
Calcutta	3,520	357	198	466
Madras	3,253	364	196	449
New Delhi	1,639	177	94	218
		Pakistan		
Faisalabad	2,376	336	174	374
Islamabad	799	154	67	130
Karachi	1,962	240	127	283
Lahore	2,682	258	150	354
Rawalpindi	1,590	184	97	221

extends three-times further out to 1.4 kilometers. But at this distance from ground zero, the thermal flux from the 300-kiloton explosion is 166 cal/cm^2. As general rule, the thermal flux increases at a given distance more rapidly than the peak blast overpressure as the explosive yield increases. Therefore the deaths and injuries from a high-yield nuclear explosion are probably underestimated in Figure 3.8. The thermal flux accompanying the blast would cause retinal burns, skin burns, and fires.

MIT physicist, Theodore Postol, calculated that "superfires," produced by much higher-yield weapons than those detonated at Nagasaki or Hiroshima, would create

FIGURE 3.8
Pecentages of the Population Killed, Injured, and Safe
As a function of peak blast overpressure. Source: The 1979 OTA report *The Effects of Nuclear War.*



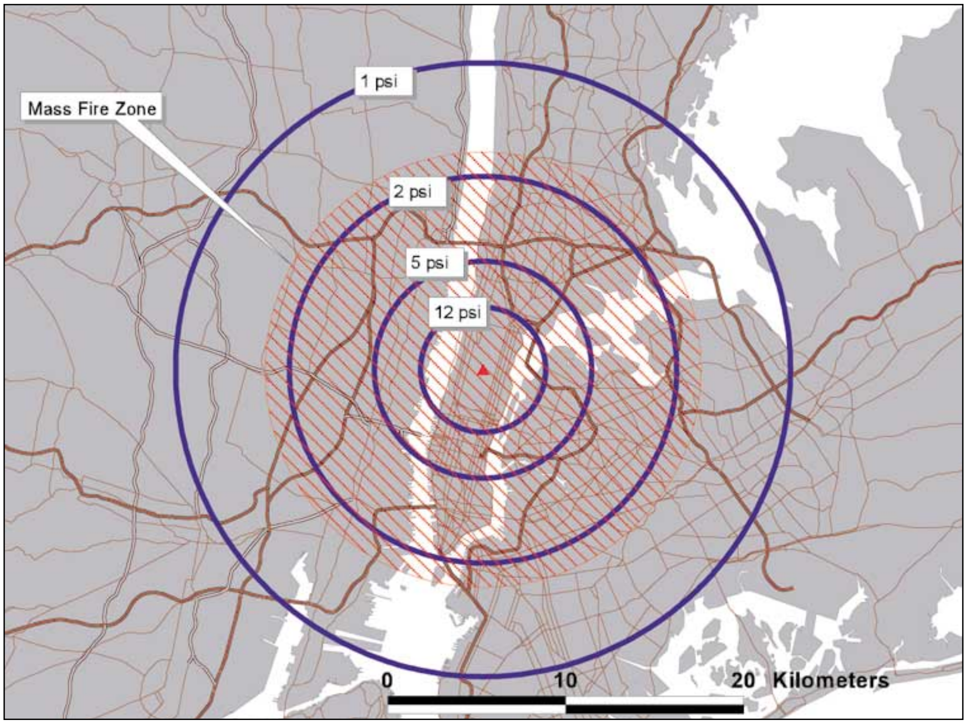


FIGURE 3.9
A One-Megaton Air Burst over New York City
At a height of burst of 2000 meters. Shown in red crosshatch is the zone of "superfires" predicted by Postol's model. The blue rings delineate the casualty zones from the OTA model based on blast effects alone.

high temperatures, noxious smoke fumes and gases, and hurricane-force winds. These superfires would cause mortality to approach 100 percent in urban areas. Postal estimated that the minimum thermal flux required to cause such mass fires was 10 cal/cm^2.[30] The assumption of 100 percent mortality for thermal fluxes greater than 10 cal/cm^2 produces a significant increase in the number of calculated fatalities over the blast model. For example, Figure 3.9 shows a 1 Mt weapon detonated over Central Park in New York City. We calculated 1.25 million deaths and 2.65 million injuries using the blast model of Figure 3.8, while Postol's firestorm model predicts 4.39 million persons would be killed—three-and-a-half-times as many fatalities.

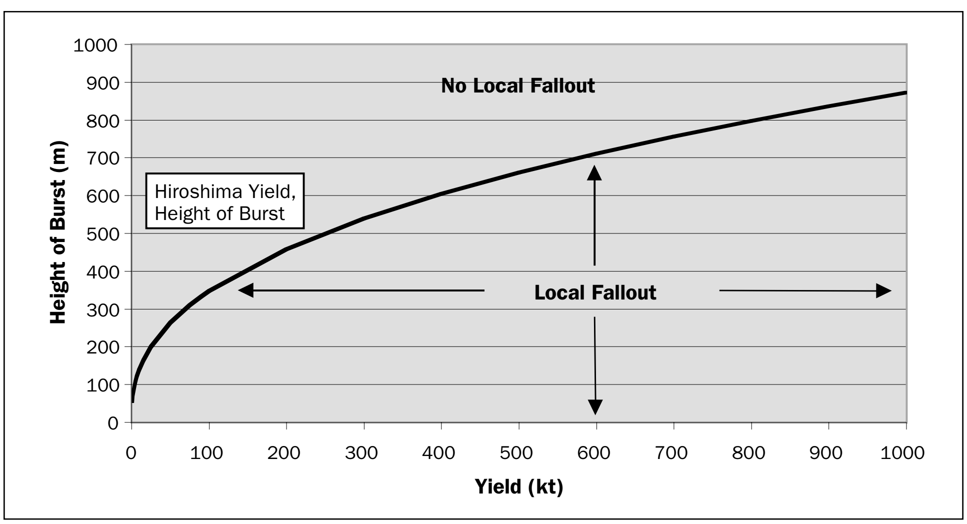


FIGURE 3.10
Threshold Height of Burst for the Occurrence of Local Fallout

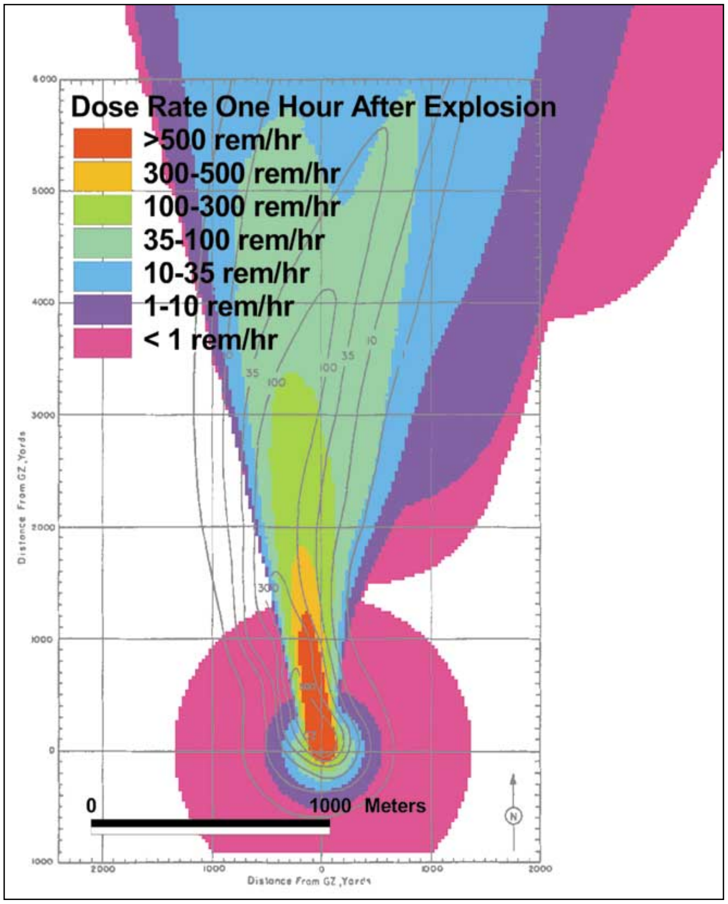


FIGURE 3.11
Fallout Data and Calculations for the U.S. Test "Sugar"

The models we used to calculate deaths and injuries are restricted to the immediate effects of a nuclear detonation. Clearly other effects on the society and the environment will unfold over months, years, or generations. These longer-term effects are beyond the scope of this study, but should be kept in mind. Two key studies focus on these effects: *Life After Nuclear War*[31] by Arthur M. Katz, and a Lawrence Livermore National Laboratory report, "Internal Dose Following A Large-Scale Nuclear War," which examines the long-term impact of fallout on the food supply.[32]

Calculating Fallout from Nuclear Explosions

The residual nuclear radiation produced in a nuclear explosion is defined as the radiation emitted more than one minute after the detonation. Two sources generate residual radiation: neutron activation of the local environment and fallout. Fallout is further divided into early (also called local) fallout and delayed fallout. Early fallout reaches the ground within a day after the explosion, producing lethal radioactive doses to living organisms over potentially large areas. The NRDC Nuclear War Simulation Model incorporates U.S. government software to calculate both neutron activation and local fallout.

Throughout the Cold War, several computer programs were developed to calculate the local fallout from nuclear explosions such as DELFIC,[33] SEER3,[34] or WSEG10.[35] We have chosen to use a Lawrence Livermore National Laboratory (LLNL) fallout computer model known as KDFOC3 (K-Division Defense Nuclear Agency Fallout Code, version 3). KDFOC3 was developed to provide predictive capability for "dirty" and "clean" weapons,[36] for militarily significant radiation levels, and for surface, shallow, and deep burials over a range of yields from one ton to 10 Mt.[37] The algorithms in KDFOC3 use both physics models and empirical data from extensive test film footage and records and fallout measurements from tests conducted at the Nevada Test Site.[38]

Whether early fallout occurs after an explosion depends on the height of burst. If the height of burst is high enough that the nuclear fireball does not touch the ground, then the tiny radioactive particles loft into the upper atmosphere, circulate, and descend to earth over a period of weeks, producing delayed fallout. Delayed fallout spreads over a larger area later in time than local fallout, and therefore the radiation is much less concentrated and has decayed substantially from its initial strength and poses less of an immediate health threat than local fallout. If the nuclear fireball touches the ground, soil particles are drawn into it, mix with the radioactive debris, and produce larger-sized particles—ranging from microns to several millimeters in diameter—which quickly descend to the ground as local fallout. The code KDFOC3 specifies a minimum height of burst for the production of local fallout as a function of weapon yield (see Figure 3.10). Note that for the Hiroshima height of burst—580 meters—no early fallout is predicted for yields less than about 300 kilotons.

NRDC received the KDFOC3 source code from LLNL under a beta-testing agreement. We subsequently modified the source code to run it on a personal computer and to incorporate it into the overall simulation model. In order to understand the predictive capability of KDFOC3, we made comparisons between unclassified fallout data and our own calculations. Observed fallout patterns and other relevant data such as the ambient winds have been compiled in a two-volume report by the General Electric Company under contract to the Defense Nuclear Agency.[39] While KDFOC3 is considered one of the best fallout codes, it does have some limitation best seen when compared to fallout measurements.

We ran comparisons for two low-yield U.S. tests conducted at the Nevada Test Site and one high-yield U.S. test conducted in the Pacific. The agreement between the computer calculation and data is good for the 1.2 kiloton test "Sugar" for H+1 dose rates[40] greater than 10 roentgens per hour (see Figure 3.11). The calculation for test "Ess" is in disagreement with the measured fallout contours because the effects of local topography are not included in KDFOC3 and the cloud ran into the nearby Banded Mountain at the Nevada Test Site (see Figure 3.12). In the analysis of nuclear attacks presented later in this report, we calculated fallout patterns for weapon

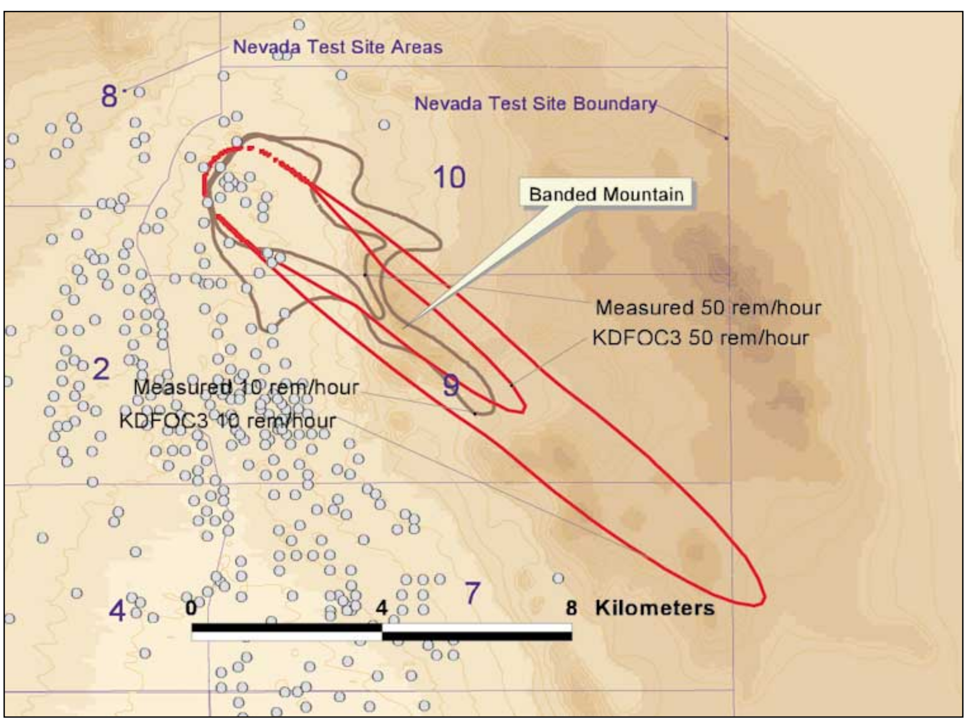
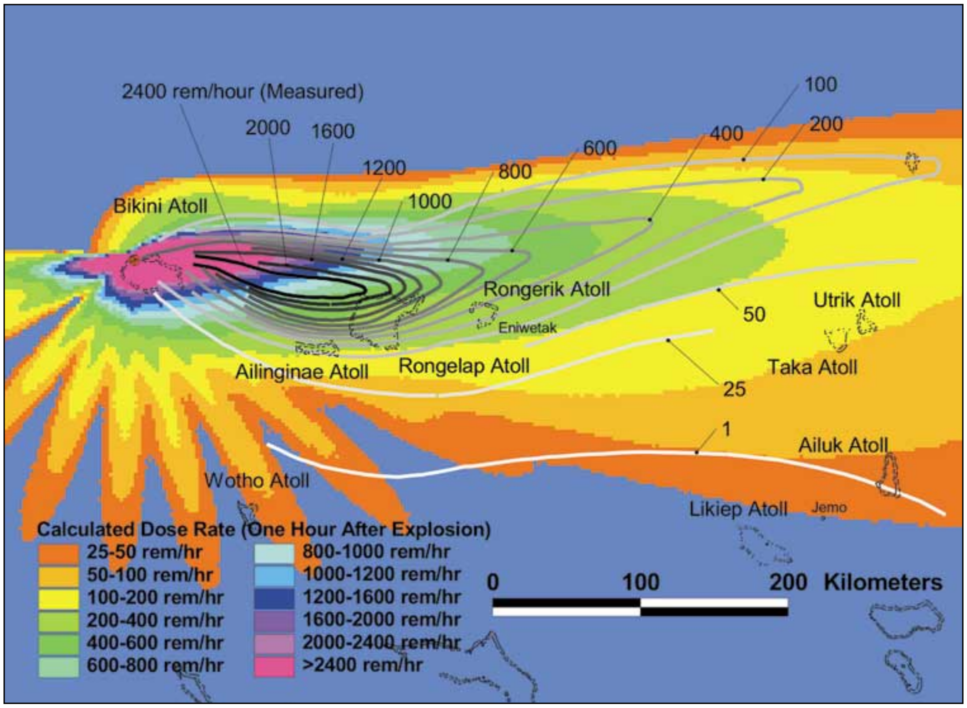


FIGURE 3.12
Fallout Data and Calculations for the U.S. Test "Ess"

**FIGURE 3.13
Fallout Data and Calculations for the U.S. Test "Bravo"**



yields in the range of hundreds of kilotons. Therefore to illustrate a fallout pattern for a large-yield weapon, we examined data and calculations for "Bravo," which is "one of those used as the basis for fallout prediction for megaton-yield weapons," (see Figure 3.13).[41] For "Bravo," fallout did not begin over much of the contaminated region until many hours after the explosion because of the vast size of the mushroom cloud. Therefore the fallout pattern would be sensitive to any changes in wind speed and direction during that time. KDFOC3 uses a static set of wind parameters that can vary with altitude but are not permitted to vary horizontally.

The initial radiation produced in a nuclear explosion is absorbed by human tissue over a brief time interval. The dose from radioactive fallout, by contrast, will accumulate over days or weeks after a nuclear explosion. While many atomic nuclei are present in the fallout, on average the radiation will decay with time (t) as $t^{-1.2}$. Two days after fallout begins, the dose rate will have fallen to one percent of its original value. During that time, people may seek shielding from the radiation, for example above ground in houses or below ground in basements or fallout shelters. The degree of shielding from the radioactive fallout is quantified in KDFOC3 by a sheltering factor, a number greater than one that is divided into the dose rate. In the calculations performed in Chapters Four and Five, we integrate the fallout dose to humans over the first 48 hours with respect to four sheltering factors: 1 (no sheltering); 4 (above-ground, residential structures); 7 (above-ground, multi-story structures) and 40 (basement environments). In terms of health effects, we assume that a dose of 4.5 Sieverts (Si) will cause death 50 percent of the time, and we use a standard probability distribution for death and severe radiation sickness for other values of the 48-hour integrated dose.

The U.S. Physical Vulnerability System

In Chapter Four, we calculate not only the human casualties and radioactive contamination from nuclear attacks on Russia, but also the probability of damaging or destroying components of Russia's nuclear arsenal. In order to calculate the damage probabilities, we employ the U.S Physical Vulnerability (PV) methodology, a mathematical approach to calculating the probability of achieving a specific level of damage based on the target's ability to withstand the blast effects of a nuclear explosion. In the PV methodology a four-character vulnerability number (VN) is assigned to each target. The vulnerability number, the yield of the nuclear weapon, the distance between the aimpoint and the target, and the CEP provide input data for a set of equations that predict the probability of achieving the specified level of damage.

NRDC obtained an unclassified version of the1989 NATO Target Data Inventory (NTDI) Handbook through the Freedom of Information Act. The 900-page volume identifies 124 categories of Soviet and Warsaw Pact targets for conventional and nuclear weapons. Vulnerability numbers and corresponding levels of damage are given for these target categories and objects associated with them. For example, the document assigns a vulnerability number/damage level assignment of 12P0 for a "Bison (M-4) Long-range Bomber, Nose-on orientation." This rating constitutes a level of damage specified as "Moderate damage to aircraft which requires extensive field level repair consisting of structural failure of control surfaces, fuselage components, and other than main landing gear such as nose, outriggers, or tail."

TABLE 3.6
U.S. DOD Vulnerability Assessments for Nuclear Weapons Blast Effects

Source: *NATO Target Data Inventory Handbook*, 1989.

Object	Damage Level	VN
Single-story, light-steel-framed or reinforced-concrete-framed buildings	Severe structural damage	13Q7
Steel surface storage tanks	Rupture, resulting in loss of contents	21Q9
Exposed aboveground generator set—gas turbine or diesel (2–20 GW)	Overturning and/or severe damage to fuel systems, cooling systems, instrumentation, and power trains.	17Q6
Concrete/Masonry arched dam, 30 m or over	Breach	39P0
Locomotives	Forcefully derailed or overturned.	21Q5
National nuclear-weapon storage bunker	Severe Damage	46P8
Parabolic, solid dish antenna	Moderate Damage	10Q6
SS-11/19 (Silo type III-G MOD)	Severe Damage	55L8
Bison (M-4) Long-range Bomber, Nose-on orientation	Moderate damage to aircraft which requires extensive field level repair consisting of structural failure of control surfaces, fuselage components, and other than main landing gear such as nose, outriggers, or tail.	12P0

The first two digits of the vulnerability number relate to the peak overpressure or peak dynamic pressure corresponding to a 50 percent probability of achieving the designated level of damage. The third character (a letter) of the VN specifies whether the damage probability should be calculated using peak overpressure or peak dynamic pressure, and how rapidly the damage probability falls off with distance. The last character, known as the "K-factor," accounts for the increase in the duration of the blast wave with increasing yield. For targets assigned a non-zero K-factor, a higher-yield weapon will have a greater probability of destroying a target at a given pressure than a lower-yield weapon because the blast wave from the higher-yield weapon acts over a longer time. For further explanation of the PV methodology see Appendix D.

We have incorporated the PV system into the NRDC Nuclear War Simulation Model. We have amassed well over a thousand VN assignments—VN numbers and an associated level of damage—for a wide range of target types (see Table 3.6).[42]

METEOROLOGICAL DATA

Wind speed and direction as a function of altitude has a significant impact on fallout patterns. In order to calculate fallout patterns, we used the "Global Gridded Upper Air Statistics" (GGUAS) produced by the National Climactic Data Center.[43] For cells measuring 2.5 degrees latitude by 2.5 degrees longitude covering the globe, wind rose data are provided at 15 elevations (more specifically, pressure levels) by month, typically to about 30 kilometers above the earth's surface. The spatial resolution of a 2.5-degree cell is about 250 kilometers near the equator. These wind roses are not discrete measurements or even averages, but instead are the output of a global circulation model fitted to many measurements made in each latitude-longitude cell. For each NRDC fallout calculation, the most probable wind direction and speed as a function of altitude for the user-selected month is read as input from the GGUAS cell containing the target.

RUSSIAN DEMOGRAPHIC DATA

To make our nuclear war simulation model as accurate as possible, NRDC drew on the most current Russian population information available. We obtained population data for Russia from the 1989 Soviet Census published in electronic form by East View, and the LandScan world population dataset from Oak Ridge National Laboratory.

The Last Soviet Census

The last census of the Soviet Union was the All-Union Population Census of 1989, published in 1992, and released in electronic form by East View Publications in 1995. The census gave the population figures for four political-administrative levels. The largest were Republics of Ukraine (18 percent of the Soviet population), Uzbekistan (6.9 percent), Kazakhstan (5.8 percent) and Belarus (3.5 percent). All of the republics are now independent countries. The next level includes the *oblasts*, *krays*, and Autonomous Republics. These are further broken down into gorsovets (Soviet cities), urban *rayons*, and *rayons.* A *rayon* is somewhat analogous to a U.S. county. Fourth there is the population in smaller cities, villages, or other named settlements. Generally the rural population is assigned to *rayons.*

In 1989 Russia's total population was 147,021,869, just over half of the total Soviet population of 285,742,511. Nearly three-quarters of the Russian population was classified as "urban." The census listed a total of 3,230 urban settlements, with 1,037 classified as "cities" and 2,193 classified as "urban-type settlements." The cities had a population of 94,840,355, or 87.8 percent of the urban population. Early in this NRDC project, we geo-referenced most of the urban settlements and many of the rural settlements using latitude/longitude coordinates from ESRI's Digital Chart of the World (see below) or the NIMA Geonet Names Server. Figure 3.14 is a map of cities and other settlement types for European Russia, west of the Ural Mountains. Figure 3.15 is a map of the population centers for Siberia and parts of the Russian Far East, many of which are located along railroads.[44] *Rayons* and *gorsovets* vary in size from 1,400 square kilometers in the central economic region around Moscow, to *oblast* areas of up to one-half million square kilometers in the sparsely populated regions west of the Ural Mountains (see Figure 3.16).

To calculate casualties from nuclear attacks in or near large urban areas, we preferred to show population spread throughout the area instead of assigning an entire population to a single point at the center of a city (see Figures 3.14 and 3.15). Population densities in urban areas can be estimated using ESRI's Digital Chart of the World data. A second method for handling urban areas, used by some U.S. Department of Defense contractors, is to devise a general formula for population density. For example, *The Feasibility of Population Targeting* report (discussed in

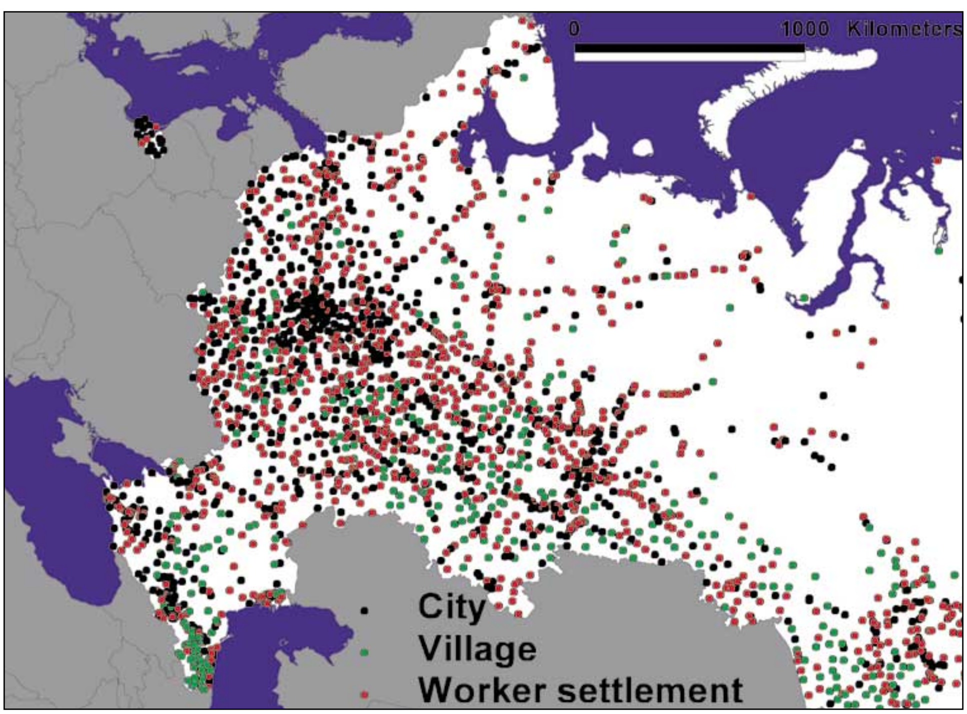
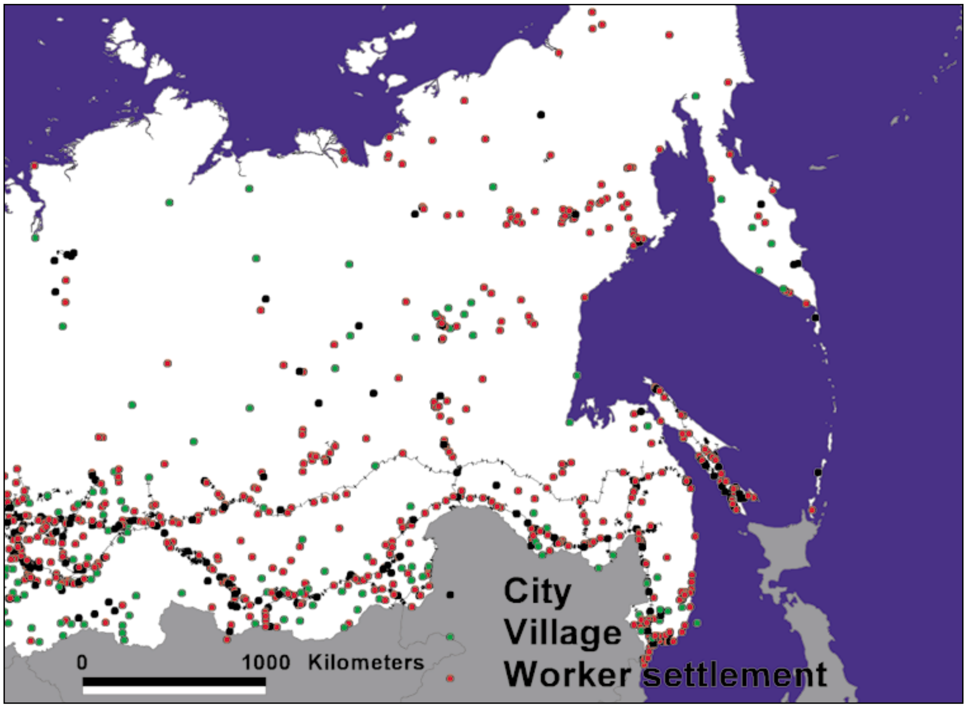


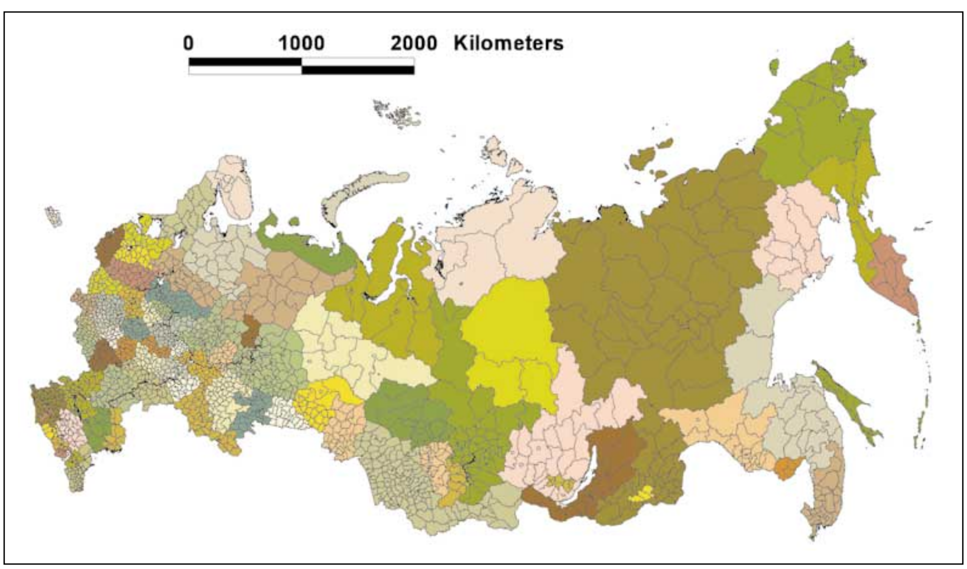
FIGURE 3.14
Geo-referenced Population Centers, European Russia
Source: 1989 Soviet Census.

FIGURE 3.15
Geo-referenced Population Centers, Siberia and Far East
Note the distribution of population centers along railroads (railroad data from ESRI's Digital Chart of the World). Source: 1989 Soviet Census.



Chapter Five), assumes population in urban areas is concentrated in the center and decreases towards the outskirts of the city in a specific manner.[45] Here the radius of a circle enclosing 95 percent of a city's population is related to the total population by the formula: radius (P-95) = $0.5125 \times \ln(1.3 + 0.2\,P)$, where the P-95 radius is in nautical miles and the population, P, is in thousands.[46] The census data does not account for variations in population densities in rural areas within *rayons.* These limitations can be overcome by using Oak Ridge National Laboratory's LandScan data.

FIGURE 3.16
The 87 Russian Political-Administrative Units
These units are shown as the following types: *kray*, *oblast*, republic, autonomous district, autonomous oblast, and city of federal significance—Moscow and St. Petersburg are shown as colored polygons. The 2,305 political-administrative sub-units (*rayon*, ethnic administrative *rayon*, and *gorsovet*) are shown in black outline. Alexander Perepechko and Dmitri Sharkov at the University of Washington compiled these spatial data.



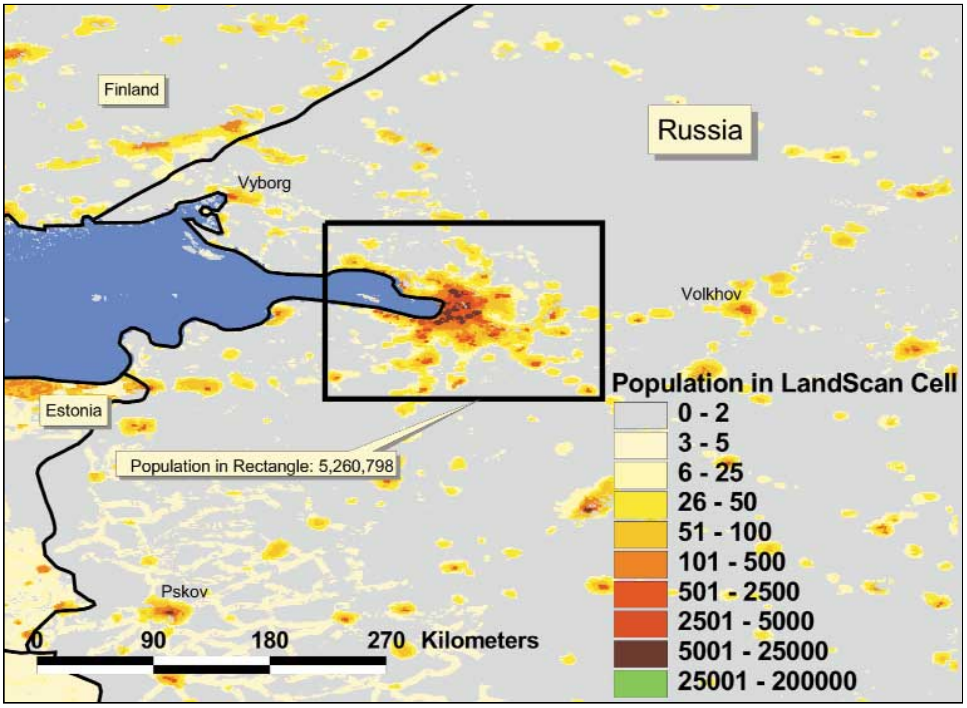


FIGURE 3.17
U.S. Government-Produced LandScan Population Distribution for the St. Petersburg Vicinity
Using the LandScan dataset, it is possible to draw an arbitrary shape (like the rectangle around St. Petersburg) and determine the enclosed population (5,175,973). This capability is necessary to sum populations subjected to nuclear effects, e.g. overpressure or fallout. USSTRATCOM uses this dataset for this purpose.

LandScan

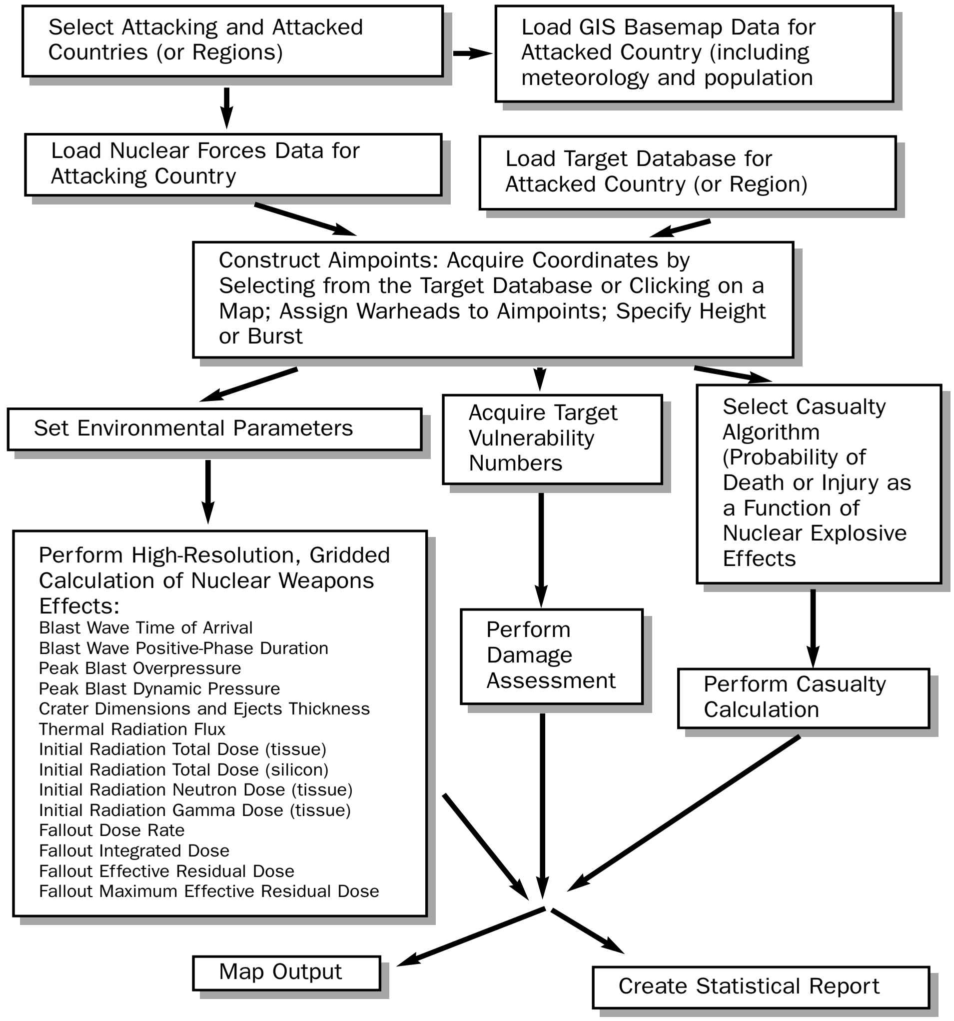
While the Russian census helped us begin compiling our population information, it did not provide clear information on population density. Fortunately, NRDC later acquired a set of unclassified view-graphs of a USSTRATCOM presentation that showcased their advanced capabilities to simulate nuclear conflicts. It became clear that the nuclear war planners had grappled with the same problem and created some interesting solutions. For instance, when U.S. planners worked on the Red Integrated Strategic Offensive Plan—the hypothetical Russian nuclear war plan envisioned by the United States—they used world census data collected and analyzed by the U.S. Census Bureau. These population distributions had been comprised of P-95 circles, as described above, and rural cells.

More recently, USSTRATCOM asked the Oak Ridge National Laboratory to generate a superior world population distribution for use in SIOP planning called "LandScan."[47] For LandScan, world census data is allocated to 30 arc-second cells (cells with areas less than 1 km^2) based on criteria such as nighttime lights as observed from satellites, proximity to roads, terrain slope, etc. We integrated the LandScan data into our simulation model. This enables us to calculate casualties based upon the same demographic data that is used by USSTRATCOM's war planners. Figure 3.17 shows the LandScan population distribution for St. Petersburg and the surrounding area.

PUTTING IT ALL TOGETHER: THE NRDC SOFTWARE AND DATABASE SUITE

The NRDC software and database suite for simulating nuclear conflict is built on the Geographic Information System (GIS) software package ArcView, a product of the

FIGURE 3.18
The NRDC Nuclear War Software and Database
A flow-chart of the basic functions of the NRDC nuclear conflict software and database suite.



ESRI Corporation. In the course of this project, NRDC and its consultants have written over 6,000 lines of computer code in both the Avenue and FORTRAN programming languages to achieve the current set of analytical capabilities. The data and formulas discussed above—those related to attacking nuclear forces, attacked nuclear targets, nuclear weapons effects, weather and demographics, as well as a host of other data relating to political boundaries and geography—are loaded into the GIS application or accessed during calculations as separate data and executable files. The data set of potential targets, in the form of Microsoft Access database files, can be queried directly by the software through an object database connection (ODBC). Effects of nuclear explosions—blast, thermal, initial radiation, and fallout—are calculated, displayed, and further analyzed to derive information such as damage assessments against specific targets and the number of casualties. Figure 3.18 is a flow-chart of the basic functions of the NRDC software and database suite.