CORONA SATELLITE IMAGERY INDICATORS OF SOVIET NUCLEAR-WEAPONS PRODUCTION ACTIVITIES

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INTRODUCTION

During the period of its existence from 1960 to 1972, the Corona satellite program provided the U.S. government with a wealth of information on the Soviet nuclear weapons infrastructure and operations. The extraction of this information from satellite photographs, however, would not be possible without photo-interpreters from the National Photographic Interpretation Center developing signatures (indicators) of particular activities or facilities. These indicators were developed and refined over many years on the basis of a collation of intelligence information from covert and overt sources, an analysis of analogous U.S. practices and facilities, and careful observation of target facilities by specially-assigned teams of photo interpreters. Indicators of nuclear energy and military activities remain classified.

This report discusses some of more obvious signatures of the Soviet closed nuclear cities and associated nuclear weapon production facilities that are observable on Corona photographs. To a significant extent, photograph analysis was performed while working on a report New Perspectives on Russia's Ten Secret Cities (co-authored with T. Cochran and R.S. Norris; forthcoming). The analysis relies on open information. Most satellite photographs used in this report are from latest-generation Corona satellites (KH-4B) flown in the late 1960s - early 1970s (Table 1). A single, typically summer-time photograph of each location is used. When possible, the satellite imagery is complemented by aerial photographs of Russian nuclear facilities. To illustrate generic features of nuclear facilities as well as similarities and differences in national approaches the report also contains photographs of functionally similar U.S. facilities.
US CORONA SATELLITE PROGRAM

The Corona satellite program was created in the fall of 1957 to conduct strategic reconnaissance of the Soviet Union, China, and other "denied territories". Corona's first successful mission (Mission 9009/Discoverer 14) was launched on August 18, 1960 and yielded more imagery of the Soviet Union than all 24 U-2 missions combined. (Among "major items of intelligence significance" covered by the mission was the "Sarova Nuclear Weapons Research and Development Center.\(^1\)) A hundred more Corona missions were flown before the program was terminated in May 1972.

Major improvements were made in photographic camera and spacecraft technologies during program's 12 years.\(^2\) A typical mission profile of first-generation KH-1 satellites included 17 orbits, eight of which were over the "denied territory" of the Soviet Union. KH-1 cameras provided a continuous coverage of the Soviet territory along the satellite track.\(^3\) A capsule of film was ejected for recovery approximately a day after the satellite launch. Such a short flight duration was due to relatively small amounts of film (20 lb), limited capacity of satellite batteries, and orbit degradation. In contrast, latest generation Corona KH-4B satellites stayed on the orbit for over two weeks, had two loads (baskets) of film (160 lb), which were returned separately, and were able to shoot selected target areas.\(^4\)

Reductions in vibrations, improvements in optical systems, and better orbit control allowed a considerable improvement in ground resolution as well. Early KH-1 missions provided for a resolution of approximately 40 feet, which was sufficient only for detection and general identification of major targets such as airfields and urban and industrial areas. In contrast, KH-4B systems had a ground resolution of approximately 5 ft. This resolution makes possible detection and identification of roads and railroads, isolated area security

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\(^1\) CORONA: America's First Satellite Program, CSI CIA, Washington, DC 1995, p. 120.
\(^2\) A useful overview of the Corona program is provided in Curtis Peebles The CORONA Project: America's First Spy Satellites, Naval Institute Press, Annapolis, MD, 1997, 351 p.
\(^3\) The camera would turn on and off automatically at the beginning and the end of each pass. When on, the camera would swing in the -35° to +35° arc photographing everything below. Adjacent frames were designed to overlap by approximately 10 percent.
perimeters, pipelines, cars, and major details of individual buildings. Shadows from various objects are also visible and help to analyze the imagery. Starting from KH-4 systems (Mural cameras), two cameras looking at an angle were used to provide for stereoscopic images.

Table 1: Corona satellites

<table>
<thead>
<tr>
<th></th>
<th>CAMERA</th>
<th>GROUND RESOLUTION</th>
<th>TIME PERIOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>KH-1</td>
<td>C' (C Prime)</td>
<td>30 ft</td>
<td>1960-61</td>
</tr>
<tr>
<td>KH-3</td>
<td>C'' (C Triple Prime)</td>
<td>12 ft</td>
<td>1961-62</td>
</tr>
<tr>
<td>KH-4</td>
<td>M (Mural)</td>
<td>10 ft</td>
<td>1962-63</td>
</tr>
<tr>
<td>KH-4A</td>
<td>J (J-1)</td>
<td>9 ft</td>
<td>1964-69</td>
</tr>
<tr>
<td>KH-4B</td>
<td>J-3</td>
<td>6 ft</td>
<td>1967-72</td>
</tr>
</tbody>
</table>

CLOSED NUCLEAR CITIES

The USSR's nuclear weapons production complex (categorized at that time by the U.S. intelligence as "Nuclear Energy" facilities) was on the list of highest priority targets for the Corona reconnaissance program. The core elements of the Soviet nuclear weapons production infrastructure were situated in ten closed nuclear cities that were built for this purpose in the late 1940s - 1960s (Table 2). Five cities (Chelyabinsk-65, Tomsk-7, Krasnoyarsk-26, Sverdlovsk-44, and Krasnoyarsk-45) were involved in the production and processing of plutonium and highly-enriched uranium (HEU) for the Soviet nuclear weapons program. (Another uranium enrichment complex was built in Angarsk, which is an open city.) The other five (Arzamas-16, Chelyabinsk-70, Sverdlovsk-45, Penza-19, and Zlatoust-36) were established to design and mass-produce nuclear weapons.

The cities remained officially secret until 1992. At present they have a status of "closed territorial-administrative units" and are controlled by the federal government. Approximately 750,000 people

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4 All KH-4B missions had a designation 11XY-2, where XY was the number of the mission, and Z (1 or 2) was the number of the film basket.
5 Most of the table data are from CORONA: America's First Satellite Program, CSICIA, Washington, DC 1995, 360 p. Resolution data are from Curtis Peshles The CORONA
currently live in the closed cities. An estimated 130,000 work at nuclear facilities, half of them in defense programs.

Table 2: Russia’s closed nuclear cities

<table>
<thead>
<tr>
<th>Traditional name</th>
<th>New name</th>
<th>Nuclear weapons activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arzamas-16</td>
<td>Sarov</td>
<td>nuclear weapons R&amp;D serial production of nuclear weapons</td>
</tr>
<tr>
<td>Chelyabinsk-70</td>
<td>Sverkhinsk</td>
<td>nuclear weapons R&amp;D</td>
</tr>
<tr>
<td>Sverdlovsk-45</td>
<td>Lesnoy</td>
<td>serial production of nuclear weapons</td>
</tr>
<tr>
<td>Penza-19</td>
<td>Zarechny</td>
<td>serial production of nuclear weapons</td>
</tr>
<tr>
<td>Zlatoust-36</td>
<td>Trekhgorny</td>
<td>serial production of nuclear weapons</td>
</tr>
<tr>
<td>Chelyabinsk-65</td>
<td>Ozersk</td>
<td>plutonium production production of HEU, plutonium, and tritium components of nuclear warheads</td>
</tr>
<tr>
<td>Tomsk-7</td>
<td>Saversk</td>
<td>plutonium production production of HEU and plutonium components of nuclear warheads</td>
</tr>
<tr>
<td>Krasnoyarsk-26</td>
<td>Zheleznogorsk</td>
<td>plutonium production</td>
</tr>
<tr>
<td>Krasnoyarsk-45</td>
<td>Zalenogorsk</td>
<td>HEU production</td>
</tr>
<tr>
<td>Sverdlovsk-44</td>
<td>Novouralsk</td>
<td>HEU production</td>
</tr>
</tbody>
</table>

The organization and layout of closed cities reflect a set of comprehensive, layered security measures, which were implemented to prevent attacks by foreign special forces and to protect secrecy of nuclear installations. Each city occupies a restricted area that is surrounded by double fences and is guarded by troops of the Ministry of Foreign Affairs (MVD). Inside the restricted area is a town for the facility workforce and several technical areas. Technical areas are also surrounded by double- or triple fences and patrolled by MVD forces. Access to the cities is limited and is controlled by the Federal Security Service. As of 1999, no foreigners have visited the serial warhead production sites of Zlatoust-36 and Sverdlovsk-45.

The closed nuclear cities, as seen on the Corona imagery, exhibit a number of distinct signatures (Fig. 1A):

Restricted area
A closed city restricted area is typically wooded to prevent ground observation and could be very large (for example, 200 km² for Chelyabinsk-65). Its perimeter consists of two or more layers of barbed wire fences (Fig. 1B). The isolation zone between the fences contains a plowed strip. There is a foot patrol path. In some cases, there is a vehicle patrol road. In populated areas, the outer fence is often replaced with a solid concrete or brick wall.

Perimeter isolation zones and roads are often clearly seen on Corona photograph. Unlike other visible lines (roads, high-voltage transmission line, etc.), the perimeter line encircles the restricted area or ends at a river bank or lake shore. To accommodate electronic intrusion detection systems, the perimeter line often consists of straight segments that are connected with each other at an angle. In some cases, security checkpoints are also visible.

Residential area
Most nuclear cities were built simultaneously with primary facilities according to a comprehensive construction plan. As a result, residential areas appear modern, compact and well planned. Often, they are situated in a picturesque location by a lake or a river. Most houses are multi-story apartment buildings. Streets are wide and straight. There are parks and athletic complexes (Fig. 1C).

Technical areas
Each closed nuclear city has several isolated technical areas that house primary research and production facilities, testing areas, and a support infrastructure. A primary facility technical area typically is surrounded by a high-security perimeter consisting of two or three barbed wire fences, some of which could be electrified. Solid walls are also used widely and are visible on Corona photographs because of their shadows.

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CLOSED NUCLEAR CITIES: INDICATORS
- Large restricted area
- Compact, modern residential area
- Isolated technical areas
- Rail-lines

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6 Most facilities and cities were designed by the Institute of Energy Technologies in St. Petersburg and its branches in Moscow and other locations.
Rail-lines
Each closed city has a railroad link with spurs to technical areas and loading/unloading stations. (Some cities also have airfield or heliport facilities.) Compared to other roads, rail-lines typically appear wider and darker (presumably because of a wide cleared area around the tracks) and have wide-radius curvatures.

NUCLEAR MATERIAL PRODUCTION COMPLEX

Fissile material production centers (with the exception of Krasnoyarsk-26, where the production facilities are located underground) are readily identifiable by their primary production facilities: enrichment plants, production reactors, and reprocessing buildings. A variety of support facilities, including electric switchyards, cooling-water supply systems, and waste-management facilities, are also visible and can be identified.

Enrichment facilities
There were four enrichment complexes (eight plants) built in the Soviet Union. Initially, enrichment plants featured U-shaped buildings. Enrichment facilities, which were built in the 1950s and 1960s, typically consist of several long (sometimes over 1 km long) interconnected buildings for enrichment cascades with support equipment located in side corridors and premises (Fig. 2A). The latest enrichment plant in Sverdlovsk-44 is a single long building.

The roofs of most buildings have ventilation shafts that are clearly visible on Corona photographs (and are also present at U.S. facilities, see Fig. 2B). Smaller buildings between cascade halls presumably are
Fig. 2:
A - Two enrichment cascade buildings in Sverdlovsk-44
B - Portsmouth Gaseous Diffusion Plant, Piketon, Ohio
C - Depleted uranium tails at the Paducah Plant, Kentucky.
D - Presumed solid waste trenches at the Tomsk-7 enrichment plant
E - Holding ponds and liquid waste discharge area at the Angarsk enrichment complex
control centers and/or UF6 sublimation/desublimation units. Enrichment buildings are connected by a network of pipes, which are used to move UF6 gas between enrichment stages and to supply dry air and cooling water. Most buildings are rail-serviced. There is often a nearby fossil fuel power plant to supply the enrichment complex with hot water and electricity.

The gaseous-diffusion equipment, which continued to be used extensively during the Corona period, is power intensive. Electric power is typically transmitted via high-voltage power lines, which are visible on Corona photographs. Large electric switchyards (substations) are also an important element of the power supply system and can be identified on the imagery.

Gaseous diffusion plants need large amounts of cooling water. All Soviet facilities were built near rivers or lakes. Water is supplied to a water intake facility (and heat is subsequently rejected) through a system of specially built canals.

Some enrichment sites have waste management and disposal facilities including liquid waste discharge areas, holding ponds, and solid waste burial trenches (Fig. 2C and 2D).

Certain facilities, the presence of which could be expected at a uranium enrichment complex but which have not been identified on Corona photographs in this analysis, include: water-preparation, dry-air, and nitrogen plants, depleted uranium storage areas (Fig. 2E), steam plants, and cooling towers.

**Production reactors**

Seventeen reactors (fourteen during the late 1960s) of different designs and of several generations were used in the USSR to produce plutonium, tritium, and other isotopes for the nuclear weapons program. Three plutonium production reactors in Krasnoyarsk-26 are located underground and thus cannot be observed on Corona photographs. (Corona imagery of the Krasnoyarsk-26 complex, however, reveals cooling water reservoirs by the river and ventilation shafts. An absence of ice on
Fig. 3

A - L-Reactor, Savannah River Site, South Carolina

B - EI-2 and ADE-3 plutonium production reactors in Tomsk-7

C - Photograph of EI-2 and ADE-3 reactors in Tomsk-7
the river would indicate the cooling water discharge point on winter-
time photographs.)

Single-purpose (once-through), uranium graphite plutonium-production
reactors of the first and second generations are difficult to identify
on Corona imagery. The reactor buildings themselves are fairly
nondescript and are difficult to find among many other industrial
buildings in the target area. Their observable indicators would include
cooling water pipelines from a water-treatment plant and rejected heat
pipelines to a water reservoir, and high stacks to provide for
dispersion of gaseous radioactive effluents to safe concentration at
ground level (see, for example, Fig. 3A). This analysis, however, has
not been able to detect these signatures at some known reactor areas in
Chelyabinsk-65 and Tomsk-7.

Uranium-graphite reactors of the third generation were dual-use
reactors and were designed to both produce plutonium and generate heat
and electricity. Two pairs of such reactors were built in Tomsk-7 and
are easily seen on Corona photographs (Fig. 3B and 3C). Their reactor
buildings are similar to RBMK-plant reactor buildings. High stacks are
evident. Each pair has a 330-m long building for auxiliary equipment
and turbine units and an electrical switchyard. Each reactor is also
equipped with highly visible cooling towers: six for the 1,200 MW EI-2
reactor and seven-eight each for 1,900 MW ADE-type reactors.

Plutonium separation plants
The Soviet Union had four reprocessing plants during the Corona period:
Plant 0-15 in Tomsk-7, Plant B and Plant BB in Chelyabinsk-65, and an
underground facility in Krasnoyarsk-26. All of them (except the
Krasnoyarsk-26 facility) feature long, rail-served processing
buildings-canyons with high stacks for gaseous radioactive discharges
(see Fig. 4A and 4B). For example, the plant 0-15 in Tomsk-7 is 850 m
long. (For a general layout and functional areas of a reprocessing
facility see Fig. 4C and 4D, which presents the reprocessing plant in
Richland, WA.)
Each plutonium production site has an extensive infrastructure to manage liquid radioactive waste. Distinctly visible on Corona are waste and sludge holding ponds and reservoirs. In Krasnoyarsk-26 and Tomsk-7 radioactive waste also was disposed of by underground well injection. The injection well areas are easily identifiable on Corona photographs.

NUCLEAR WEAPONS R&D AND PRODUCTION

Nuclear warhead design and production activities take place at five closed nuclear cities. The principal Russian warhead R&D institutes are located in Chelyabinsk-70 and Arzamas-16. Corona photographs of both locations reveal technical areas that are presumably associated environmental (robustness) testing of nuclear warheads and high explosive firing experiments.

Warhead assembly, disassembly and maintenance are conducted at four serial production facilities in Arzamas-16, Sverdlovsk-45, Penza-19, and Zlatoust-36. The R&D institutes in Arzamas-16 and Chelyabinsk-70 also have pilot production facilities that are capable of assembling perhaps tens of nuclear warheads per year.

The interpretation of the Corona imagery of the Soviet nuclear warhead production facilities has been a difficult task. Compared to the fissile material production complex, there is very little public information regarding functions, operations and history of individual weapons facilities or Soviet warhead management operations in general. Unlike fissile material production centers, nuclear weapons facilities lack prominent and unambiguous signatures. Some of their observable signatures could be attributable to conventional munitions manufacturing facilities. There are also significant variations between the five warhead production locations. Some of these probably reflect differences in their specialties. Other differences could be due to changes in design and construction approaches over time. (The Avangard plant in Arzamas-16, USSR's first serial production facility, was built

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7 It has been suggested, for example, that "physics packages" are assembled only in Arzamas-16 and Sverdlovsk-45; Penza-19 produces primarily non-nuclear components and subassemblies; and Zlatoust-36 integrates physics packages with reentry vehicles of ballistic missiles.
in the early 1950s. Other serial production facilities were constructed in the late 1950s and early 1960s.) Finally, Corona resolution is not sufficient for observing more direct warhead-activity indicators such as lightning arrestors (lightning rods).

The existing information about Soviet nuclear weapons practices, general considerations regarding nuclear weapons technologies and operations, and analysis of the Corona imagery of the Soviet facilities suggest that three signatures are observable on satellite photographs and could be indicative of nuclear weapons activities. These include high-explosive processing and storage buildings, warhead assembly cells, and warhead storage bunkers. In addition, each warhead production facility has general-purpose industrial areas for non-nuclear assembly operations.

High-explosives processing and storage
High-explosives (HE) are used in nuclear warhead primaries and a variety of explosives-actuated warhead components (for example, in neutron generators of certain designs). All warhead-manufacturing facilities therefore could be expected to have an extensive infrastructure to process (compact, melt, cast, machine and test-fire) and store high explosives.8

According to the Russian nuclear weapons safety principles, the "operations of HE processing, and manufacturing of HE components and systems are assigned to a separate danger category and are carried out in special buildings that are located away from other operations."9 Corona photographs of the Russian weapons facilities reveal numerous bermed buildings that are grouped in isolated technical areas situated away from other industrial operations and residential areas (see Fig. 5A). A soil and/or gravel berm around a building is designed to prevent sympathetic explosions in nearby buildings (should an initial

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8 It is believed that the bulk of high-explosives is not produced at warhead production facilities (as is the case for Pantex in the United States) but is supplied by a different facility.
A - Presumed non-nuclear assembly buildings and HE component area and bermed buildings in Penza-19

B - Warhead assembly building in the Tech Area II, Sandia National Laboratories, 1949
detonation occur\(^1\) by reflecting the blast wave upwards. Large size of buildings (up to 100 m long) and relatively large buffer zones between them indicate the presence of large amounts (possibly tens or more tons) of explosives.\(^1\)

In the United States, above-ground bermed buildings were built for HE lens assembly in the Area II of the Sandia National Laboratories and were U.S. first warhead assembly buildings (Fig. 5B).\(^1\) Design approaches for other U.S. facilities handling large amounts of high explosives, however, were different and relied on buildings essentially buried by their concrete and earth blast revetments. Russian sites, for example, the Avangard plant in Arzamas-16, also use earth-covered structures.

HE waste and scrap management and disposition activities could be expected to provide another indicators of large-scale HE processing activities. These, for example, could include HE waste catch basins and burning pads. These features, however, were not observed consistently at Corona photographs of the Russian facilities. (The Avangard plant does have a large square pond that might be used to retain HE waste.) It is possible that some Russian facilities use filter-based systems to treat effluents and that HE materials are returned for disposition to their original manufacturer.

Nuclear weapons assembly and disassembly

Nuclear warhead physics package assembly and disassembly operations involve much smaller amounts of explosives (perhaps, tens of kilograms). However, because HE components are handled in close

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\(^1\) Safety measures to prevent a detonation include: special safety procedures (e.g., prohibition of detonators in HE buildings), use of smooth surfaces to prevent an accumulation of HE dust, use of specialized low-voltage electric circuitry, use of non-sparking materials, and measures to prevent electrostatic discharges.

\(^1\) According to the accident prevention regulations in Germany, for example, a safety distance between two HE buildings is determined as \(L = \frac{f}{d}\) (amount of explosives in kg)\(^1\), where \(f = 1.5\) for two bermed HE storage buildings. (J.Kohler and R.Mayer Explosives, 4\(^{th}\) Edition, Weinheim: VCH, Germany, 1993, p. 83.)

\(^1\) Warhead assembly operations at Sandia (minus fissile core) took place in specially designed Buildings 904 and 907 in the Area II. Both are rectangular, one-story buildings with flat roofs. Each building has an external and three internal blast walls (concrete boxes filled with rubble) separating four internal assembly bays. The fifth bay is located at the end of the building and was used for packaging and shipping of weapon assemblies. Each building has a concrete retaining wall with 17 feet-high dirt blast berm 25 feet from its north and south ends (in the direction of the other assembly building). The east and west walls and the roof are frangible. (Rebecca Ullrich "Tech Area II: A History," SAND98-1617, July 1998, SNL, pp. 24-31.)
proximity to special nuclear materials, assembly and disassembly operations are classified in Russia as "especially dangerous." Physics package assembly and disassembly are conducted in "containment (localization) cells" that are designed to contain a HE explosion and to prevent plutonium and other nuclear materials from escaping into the environment. No more than one explosive device is allowed in a cell to prevent a sympathetic explosion of HE components.\textsuperscript{13}

Yuri Zavalishin, the Director of the Avangard plan, describes a warhead dismantlement cell (such cells are also called "towers") as follows:\textsuperscript{14} "This is a reinforced concrete cell the internal diameter and the height of which are approximately 10 m. Adjacent to the tower are airlock rooms, corridors to transport 'objects', ventilation filter and vacuum pump rooms, and so on. The tower and airlocks have over 1.5-m thick walls. Other premises have walls that are over 0.5 m thick. The premises are separated by 150-mm thick armored doors. To provide for a hermetic isolation of the tower, there is another door between the airlock and the corridor." A sketch of a hypothetical warhead dismantlement facility, which was developed by Russian nuclear weapons experts, presumably provides some indications regarding the outside features of a warhead assembly cell in Russia (see Fig. 6A). The berm and the disassembly cell, as they appear on the sketch, would probably be visible on Corona photographs.

At Pantex in the United States, physics package assembly and disassembly and HE removal are performed in special cells known as gravel gerties. Assembly bays are used for mechanical warhead assembly operations. Gravel gerties assembly cells have a thick, concrete-encased gravel roof that is designed to collapse and contain a plutonium release should a HE explosion occur. Gravel gerties are easily identifiable on aerial or satellite photographs (Fig. 6B). A typical layout for Pantex's assembly cells is presented on Fig. 6C.

\textsuperscript{14} "'Avangard' – half-century old," Atompressa, No. 8 (339) March 1999, p. 3.
Fig. 6

A - Presumed HE component and warhead assembly area at Sverdlovsk-45
B - Hypothetical Russian warhead dismantlement facility
C - Gravel Gerties warhead assembly cells at Pantex, TX
D - Layout of a typical Pantex assembly cell
E - Warhead storage magazines at Pantex
This analysis has not been able to identify conclusively warhead assembly and disassembly cells on Corona photographs of the Soviet facilities. Russia only relatively recently has begun using special reinforced, hermetically sealed cells as described above and it is possible that they were not available during the Corona period.\textsuperscript{15} It was judged in this analysis that probable assembly structures were observed photographs of Sverdlovsk-45 and Chelyabinsk-70 (see, for example, Fig. 6D). These structures feature a string of small buildings (four 10-m long and one longer buildings in Sverdlovsk-45, for example) that are separated by berms. Presumed loading areas and roads associated with these buildings are also visible.

Warhead storage facilities
The interface between the warhead production complex and the Ministry of Defense in the Soviet Union was provided by a network of military-controlled national-level stockpile storage facilities. Three such storage complexes are associated with the serial warhead assembly/disassembly facilities in Zlatoust-36 (one double-capacity storage facility) and Sverdlovsk-45 (two storage facilities). (In Sverdlovsk-45, one of the storage facilities is located within the closed city's restricted area.)

In addition to national-level storage facilities, each of the serial production plants as well as pilot production plants of the warhead design institutes at Arzamas-16 and Chelyabinsk-70 are likely to have nuclear warhead bunker areas for short-term storage. These smaller, on-site facilities are used to stage newly assembled (or prototype) warheads before they are moved to a military-controlled storage facility and warheads entering the disassembly or maintenance processes.

Some of the assumed indicators of a nuclear warhead storage area are as follows. Nuclear warheads are likely stored in underground or earth-covered bunkers with loading docks. A storage bunker is served by a rail spur or service road. Russian safety requirements call for two independent entries into a storage bunker to facilitate access to

warheads if one entry becomes blocked as a result of an accident. A double door bunker is likely to have a ring road around it. There are nearby environmental control facilities to maintain inside temperature and humidity and multiple lightning arrestors in the storage area.

This study has not been able to identify conclusively plant-level warhead staging areas at the Soviet facilities. Corona's resolution is not sufficient to detect such signatures as lightning arrestors or bunker's ventilation shaft. Because of heavy security of the warhead production areas themselves, staging bunkers probably do not have additional large security buffer zones that would be visible on Corona photographs. At different facilities, bunkers of different types might be utilized. (Nuclear warhead storage bunkers of at least thirteen types were in use in the Soviet Union.)

A double-entry bunker with a loading pad and a circular road might be the most visible indicator of a warhead storage area. Several possible warhead storage areas, for example, can be identified in Sverdlovsk-45's technical area (Fig. 6D), which is presumed to be associated with warhead assembly operations. Double-entry bunkers also could often be observed on Corona photographs of the Soviet national-level stockpile storage facilities.

At Pantex assembled warheads are stored in Zone 4, in magazines that were originally (in 1944) built for conventional munitions storage. Most obvious observable features of these warhead storage magazines are ventilation shafts, lightning arrestors, and earth overburden (Fig. 6E).

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16 Ibid., p. 122.
17 The types of the bunkers are as follows: national, director support, Type I, Type II (Guitar), Type III (Cruciform), Type IV, Type V, Type VI, Type VII (Aris Mod), Type VIII, Type IX, Vault, and Type VIII (Single Bay). (Joshua Handler “Russian Nuclear Warhead Dismantlement Rate and Storage Site Capacity: Implications for the Implementation of START II and De-arming Initiatives” CRSS Report No., February 1999, p. 78. A detailed description of the Type III (Cruciform) storage facility near Berdichev is provided in CORONA: America's First Satellite Program, CSF CIA, Washington, DC 1995, pp. 170-173. A description of warhead storage bunkers to support MBSS is provided in D. Brugioni Eyeball to Eyeball, Random House: New York, 1991, pp. 538-540.
18 Warheads are stored in Modified-Richmond and Steel Arch Construct magazines. Similar magazines have also been used for nuclear munitions storage at some other military bases.
General-purpose industrial areas

Each of the five Soviet weapons research and production sites contains industrial areas that are associated with the production and assembly of non-nuclear warhead components and subassemblies, auxiliary equipment (e.g., warhead dollies and transportation containers), and related manufacturing equipment. As observed on Corona photographs, common to this type of areas are rectangular-shaped industrial buildings, typically measuring 120x70 m, with high-bays (Fig. 5A). High bays presumably are designed to accommodate overhead monorail cranes that move heavy subassemblies and components along production assembly lines.
SOURCES OF FIGURES

Fig. 1
B - Photo from Frank von Hippel.

Fig. 2
A - Declassified U.S. Corona Satellite imagery; Corona Mission 1111-1 July 23, 1970.
D - Declassified U.S. Corona Satellite imagery; Corona Mission 1115-1 September 15, 1971.
E - Declassified U.S. Corona Satellite imagery; Corona Mission 1111-1 July 24, 1970.

Fig. 3
B - Declassified U.S. Corona Satellite imagery; Corona Mission 1115-1 September 15, 1971.
C - Soveshennno Otkrytto, 1994.

Fig. 4
A - Declassified U.S. Corona Satellite imagery; Corona Mission 1115-1 September 15, 1971 (Photo from Charles Vick, Federation of American Scientists).

Fig. 5
A - Declassified U.S. Corona Satellite imagery; Corona Mission 1051-1 May 4, 1969.

Fig. 6
A - Declassified U.S. Corona Satellite imagery; Corona Mission 1111-1 July 24, 1970 (Photo from Joshua Handler, Princeton University).
D - U.S. DOE, May 1997