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A Summary of Indicators of Nth Country Weapon Development Programs

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A SUMMARY OF INDICATORS OF Nth COUNTRY WEAPON DEVELOPMENT PROGRAMS

by

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ABSTRACT

This report is a discussion of indicators that various phases of weapon development programs are being carried out. It is an attempt to answer the question "what observations can one make that would help in deciding whether country X is developing nuclear explosive devices?" The indicators themselves are accompanied by some general discussions of what is likely to be going on in the areas of nuclear materials "manufacture", nuclear materials chemistry, development and testing, scientific personnel, delivery systems, and evasion of safeguards.

INTRODUCTION

The detailed nature of a nuclear explosive development program in another country is, of course, impossible to predict. Among other factors, the program will depend upon the planned source of nuclear materials, some details of the design itself, the amount of money that can be spent, and the country's motivation. At the same time, in a less detailed sense, technological goals must be fulfilled which do not differ greatly from one approach to another. Work done to fulfill these goals will be accompanied by technological observables that may be broadly classifiable into a limited number of categories. The categories might be, for example, "Procurement of Nuclear Materials," "High-Explosive Development," "Laboratory Experiments," and so on. Within the broad categories, the detailed differences among the observables for different kinds of programs may then be noted. In previous work a variety of hypothetical Nth country nuclear weapon development programs were discussed and detailed observables, or indicators, were drawn from those programs and grouped into six broad categories. The list of detailed indicators has been expanded somewhat and is presented here in a format that includes explanatory comments to help the readers understand what the indicators indicate. The material is in outline form for convenience and brevity.

I. MANUFACTURE OF NUCLEAR MATERIALS

It is assumed that for the next five to ten years plutonium and enriched uranium will be the only nuclear materials of importance to nuclear proliferation. Although uranium-233 made in the thorium fuel cycle is fissile and can be used for nuclear explosives, its use is still rather limited to breeder research and development activities. Produced this way, it has an isotopic impurity that makes it an undesirable choice for use in explosive manufacture. Almost all nuclear reactors, research or power, begin operation by fissioning the nuclei of uranium-235. In some reactors a significant part of the fissions later take place in the plutonium formed as the reactor runs. Plutonium must be made in a reactor by the absorption of neutrons in the uranium-238 that is in the reactor. Since reactors used for electrical power have a great deal of uranium-238 in them and run for long periods of time with a high neutron flux, they are the ones that manufacture the most plutonium. Some research reactors, however, may make enough plutonium to be significant in proliferation matters. If the reactor fuel is "changed out" often enough, the used fuel contains almost isotopically pure plutonium-239, mixed of course with unburned uranium and fission fragments. If the fuel in a light water power reactor is changed at a rate most economical for power production, it will contain a mixture of plutonium isotopes, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, etc. Although this "reactor grade" Pu is somewhat more radioactive than the more isotopically pure material, it is still useful for nuclear explosive manufacture.

Enriched uranium for nuclear explosives must be produced by an enrichment plant. Gaseous diffusion plants exist in several places in the world, and other enrichment processes may be productive soon. These processes increase the fraction of uranium-235 in uranium from the natural value of 0.7% to various higher percentages. The 3% enriched power reactor fuel is not usable in nuclear explosives.

Nuclear explosive devices based on the implosion principle can be made with either plutonium or highly enriched uranium. The "gun-assembled" device must use highly enriched uranium only.

The following observations may be made with respect to sources of nuclear materials for possible explosive or weapon development programs in Nth countries.

A. Plutonium

1. Nuclear power plants that are in operation, under construction,or planned indicate a potential source of nuclear material.

2. Some research reactors make a significant amount of plutonium: e.g., NRX or BGR (high flux and a significant amount of U-238 in the fuel elements).

3. A country developing an indigenous uranium mining industry might be planning to build natural uranium reactors such as Candu (heavy-water moderated) or graphite-moderated types.

4. The use of reactors with on-line refueling systems (e.g.,Candu) in a country's power program makes plutonium diversion more difficult to detect.

5. Frequent shutdown of light-water power reactors may indicate weapon-grade plutonium manufacture. Production of low-irradiation plutonium requires abnormally high fuel throughput.

6. Any placement of unnecessary U-238 in or around a reactor core will produce some plutonium, though the amount might be small if care is not exercised in the location.

7. Some "critical assemblies" for breeder reactor research contain large quantities of plutonium and uranium, interleaved or possibly alloyed.

B. Enriched Uranium

1. Some research reactors use highly enriched uranium in their cores. The uranium could be diverted from several unused cores for a nuclear device development program.

2. Some "critical assemblies" (Godiva) used for research purposes contain substantial amounts of highly enriched uranium. These devices could be used either in nuclear weapon development or as the source of nuclear material for a live nuclear test program.

3. Any uranium enrichment (isotope separation) program carried out,with or without foreign assistance and with or without safeguards commitments, indicates possible nuclear weapon plans.

II. PROCESSES FOR EXTRACTION, CONVERSION, AND FABRICATION

A. Plutonium

1. Plutonium may be obtained from spent reactor fuel elements by chopping up and dissolving the elements, subjecting the solution to solvent extraction and ion exchange processes, and chemical conversion of resulting liquids to desired forms, Pu metal, PuO_2, etc. The following indicate these operations.

a. So-called "laboratory facilities" or "pilot plant facilities" are more than likely large enough to process plutonium in significant quantities in the context of early nuclear device development work.

b. Effluents from such plants or facilities as described will contain radioactive fission products, including xenon and krypton. They will also contain uranium, plutonium, and the chemicals characteristic of the processes themselves.

(1) Leaching: Nitric acid, uranium, plutonium, and fission products in solution.

(2) Solvent Extraction: Nitric acid, TBP, ferrous sulfamate, hydroxylamine, ascorbic acid, sodium nitrite, kerosene, carbon tetrachloride, normal dodecane, plutonium, and uranium.

(3) Chemical Conversions: Hydrogen peroxide, oxalic acid, carbon dioxide, hydrofluoric acid, calcium, iodine, magnesium oxide, potassium hydroxide, magnesium fluoride, hydrogen, and plutonium.

c. A laboratory-scale operation would need 500 to 1000 gallons of TBP solvents (kerosene, carbon tetrachloride, or normal dodecane) to start up, then 50 to 100 gallons per six months of operation.

d. Although plutonium compounds, such as PuO_2 and PuC, are materials that may be used to produce an explosion, it is more likely that the metallic form (Pu) would be used. The chemicals listed in Sec. II.A.1.b.(3) are those required for conversion from plutonium in nitric acid solution to plutonium metal. The metal "buttons" must then be cast into raw shapes and machined. If casting and machining are taking place in a facility, some or all of the following materials would probably be found in effluents.

(1) Casting: Tantalum, magnesium oxide, aluminum, graphite calcium fluoride, plutonium, and plutonium oxide

(2) Machining: Plutonium and plutonium oxide

e. Analysis of the plutonium from some of the above operations will show the irradiation level of the reactor fuel. Low irradiation would be a strong indicator of weapon activities.

2. As noted above, some critical assemblies for mixed-oxide breeder fuel research contain large amounts (measured in metric tons) of plutonium and uranium in metallic form. These assemblies are usually purchased from a nuclear weapon state. The separation of the plutonium from the uranium, if alloyed, could be done by dissolving the alloy in nitric acid and then using either solvent extraction, as before, or oxalic acid precipitation. The latter may have to be done twice to get plutonium with less than 1% uranium in it. Indicators for this recovery from critical assemblies would have much in common with those for spent fuel element processing except that there would be no fission products present. The following chemicals and materials would characterize this operation.

a. Dissolution: Nitric acid, plutonium, and uranium

b. Solvent Extraction: Nitric acid, TBP, ferrous sulfamate, hydroxylamine, ascorbic acid, sodium nitrite, kerosene, carbon tetrachloride, normal dodecane, uranium, and plutonium

c. Precipitation: Oxalic acid, plutonium oxalate, and carbon dioxide

d. Conversion to Metal: Plutonium, plutonium oxide, hydrofluoric acid, calcium, iodine, magnesium oxide, potassium or sodium hydroxide, magnesium fluoride, calcium fluoride, and hydrogen

e. Casting and Machining: Plutonium, plutonium oxide, tantalum, magnesium oxide, aluminum, graphite, and calcium fluoride

3. The dissolution of metals or oxides in nitric acid is accompanied by considerable quantities of brown fumes. These fumes may be sent via a stack to the atmosphere. There would also be present in the stacked gas some small but detectable amount of the materials being dissolved, unless extreme measures were used to remove them.

B. Enriched Uranium

1. To reclaim enriched uranium from research reactor cores, the most straightforward method would be dissolution in nitric acid and solvent extraction as described earlier for spent fuel processing. The same process would probably be used whether or not the research reactor core elements had been used in a reactor, because the chemistry of solvent extraction is relatively well understood. Chemicals and materials characteristic of such an operation would be as follows.

a. Dissolution: Nitric acid, uranium, and aluminum (plus fission products and a small fraction of plutonium if fuel has been exposed)

b. Solvent Extraction: Nitric acid, TBP, ferrous sulfamate, hydroxylamine, ascorbic acid, sodium nitrite, kerosene, carbon tetrachloride, normal dodecane, uranium (and possibly a small fraction of plutonium)

c. Precipitation: Hydrogen peroxide and uranium

d. Conversion to Metal: Uranium, uranium oxide, hydrofluoric acid, calcium, iodine, magnesium oxide, potassium or sodium hydroxide, magnesium fluoride, calcium fluoride and hydrogen

e. Casting and Machining: Uranium, uranium oxide, graphite, zirconium silicate and magnesium silicate

2. The casting and machining of natural uranium and enriched uranium are done in exactly the same way except that there is a limit on the amount of enriched uranium that can be melted and poured into a mold because of nuclear criticality. Casting and machining uranium can be done in any modern foundry and machine shop. No part of these operations is beyond the capabilities of equipment and tools normally used in such a facility. Since melting and pouring are done in graphite crucibles and molds coated with a zirconium silicate and magnesium silicate mix, there will be stocks of these materials in or around the shop. A mold coating commercially available in the U.S. is "Mold Wash A" from Titanium Corporation of America. Foundry sand is not likely to be used for uranium fabrication. The scrap from molds and crucibles will be contaminated with uranium. A great deal of casting and machining of natural uranium will probably be done as part of the device development program.

3. If the country has obtained enriched uranium in the form of uranium tetrafluoride (a green powder), the reduction of this material to the metallic form would involve the following chemicals and materials.

Reduction to Metal: Calcium, iodine, magnesium oxide, calcium fluoride and uranium

The crucible containing the reactants is a magnesium oxide ceramic cylinder. The reactants are uranium tetrafluoride, calcium, and iodine. The products are uranium and calcium fluoride, the iodine going into the calcium fluoride slag.

III. DEVELOPMENT AND TEST PROGRAM

A. Implosion Program

1. An extensive program using high explosives is necessary. Some of the kinds of tests done are on the explosive itself, and others involve driving metal shapes with explosive. Almost all of the tests need electronic or optical instrumentation to observe what is going on. The following indicators would characterize such a program.

a. Expansion of facilities and/or personnel at or near an existing ordnance plant.

b. Purchase or production of energetic HE, i.e., something better than pure TNT. More likely materials are RDX, HMX, or PETN--any of which may be mixed with TNT.

c. Equipment for melting and casting HE. This operation could be done in a high-explosive loading plant that produces standard ammunition and bombs. Some minor modification of equipment might be needed.

d. As an alternative to casting, facilities for pressing explosives into shapes could be used. Such facilities are not normally needed in conventional HE loading plants, however, production of shaped charges for anti-tank ammunition may be done this way. Presses are large, weigh many tons, and are probably remotely operated.

e. Facilities for precise machining of high explosives. Tools for machining spherical contours would be especially noteworthy.

f. The waste and scrap from the operations listed above. Evidence might include the following.

(1) Effluent waste water systems involving filters or catch basins

(2) Pronounced red coloration in waste water caused by dissolved TNT

(3) Solid scrap periodically destroyed by burning or detonation

g. Purchase or development of exploding bridge wire detonators (EBW).

h. Purchase of certain types of linear detonation cord, for example, "mild detonating fuze" (MDF)

i. Construction of an instrumented firing point for testing HE and HE/metal systems. Charges up to hundreds of pounds need to be fired. Usually the charges would be set on simple wooden tables, and cables run to a control bunker or underground room to the firing system and data recording equipment. The control room might be several hundred meters away for electronic data recording, but probably would be within a few meters if optical instrumentation is used.

j. Instrumentation may be a combination of the following.

(1) High-speed oscilloscopes (a few dozen might be required)

(2) High-speed rotating mirror "streak" camera

(3) Electronic image converter camera

(4) High-speed framing camera

(5) Pulsed x-ray generator

k. Test firing of HE/metal systems containing uranium (probably natural U) is indicated by the following.

(1) Bright streamers radiating from the test shot caused by burning fragments of uranium. Streamers can be recorded by a camera and may be visible to the eye.

(2) Any sample of dust, debris, or vegetation from the vicinity of the firing point will be contaminated with uranium.

(3) There may be people associated with the firing crew who carry portable radiation monitoring equipment, especially after the shot is fired. There may also be permanently installed air sampling-type radiation monitors around the firing point.

(4) Because of fires often started by the burning uranium fragments falling nearby, one can expect a fire truck or at least fire extinguishers to be associated with a test containing uranium.

(5) Note that some advanced non-nuclear ammunition programs may involve natural or depleted uranium tests that may have indicators like those listed above.

B. Gun Weapon Development Program

1. Gun-type nuclear devices do not involve high explosives, but do require propellants like those used in artillery. The nuclear explosive material must be enriched uranium, and there would probably be a neutron-reflecting material surrounding the enriched uranium. That material would probably be any one of the following.

a. Natural uranium

b. Tungsten or a tungsten alloy

c. Beryllium (metal)

d. Beryllium oxide (ceramic)

2. A development program for a gun-type nuclear explosive would use probably thousands of pounds of natural uranium, tungsten or tungsten alloy, or hundreds of pounds of beryllium or beryllium oxide for the neutron reflector

alone. Imports of these materials in substantial quantity might indicate such work. The following additional indicators apply to a gun-type device development program.

a. Firing points used for "gun" programs would not show the effects of HE blast. The area would probably not be cleared of ground cover in a circular pattern, but possibly in one direction only.

b. A firing point for gun work is likely to have a concrete pad to mount test devices on and to eliminate dust clouds that obscure photography of the early portions of the test.

c. Photography of test devices requires only medium-speed framing cameras such as "Fastax" or possibly "Mitchell" cameras.

d. Photography of projectiles is conveniently done with a shutterless moving film camera incorporating a slit in the optical path. Such cameras can be bought or made in a modern shop.

e. Pressures in the gun breech are usually recorded by a quartz-type pressure gage working in the pressure range of 70mPa to 300mPa (10000 to 45000 psi). Gages need 10- to 100- microsecond response times. In the U.S., gages are manufactured by Kistler Instruments.

f. There are probably fewer cables needed for data recording for most gun tests as compared to implosion tests. There may be individual cases, however, in which the reverse is true.

g. Gun tests that contain natural uranium as a mockup for enriched uranium will also produce bright streamers of hot metal. The streamers will not be produced uniformly in all directions as they are from an implosion. They will be contained mostly in a conical volume coaxial with the direction of motion of the uranium projectile of the gun assembly.

h. Fire trucks or at least fire extinguishers will probably be associated with gun tests containing uranium.

i. The noise from a gun shot is easy to distinguish from an HE detonation with a little practice.

j. There is very little visible flash from a gun shot compared to an HE test.

C. Nuclear Laboratory Experiments

1. Criticality Tests

a. It is probable that some kind of nuclear criticality tests will be performed as part of a weapon program. Such experiments give the scientists confidence in their calculations and may avoid criticality accidents in final assembly operations with live nuclear materials. The following indicators might be associated with this kind of operation.

(1) The experiment is remotely operated. It probably would be in a separate building perhaps a quarter of a mile from a control room.

(2) The experiment may be conducted in a large room underground, but the U.S. does not do it that way.

(3) Live nuclear material (Pu or enriched U) is required, and pieces are brought into proximity slowly by hydraulic cylinders. Neutron counters are needed to measure the state of criticality of the assembly.

(4) A facility used for neutron irradiation research (agriculture or biology) might be modified rather easily to do the required experiments. For example, closed circuit television is often used to observe the experiments in such facilities.

(5) A criticality "accident" (inadvertent movement of nuclear material parts too close together) would probably be covered up, but if it is known that one occurred in a suspect facility, chances are pretty good that weapon R&D was going on.

2. Neutron Background Measurements

a. For a gun weapon development program, one has to be assured that there will be a minimum of "background" neutrons at the time of detonation. This requirement places some restrictions on the purity of the enriched uranium to be used. It is likely that some measurement of spontaneous neutron emission from nuclear materials and other possible sources of neutrons would be undertaken. In early U.S. programs, the nuclear initiator (a "modulated" neutron source) employed radioactive polonium and metallic beryllium. Even when not "turned on" these initiators produce a certain number of neutrons. A country using such initiators would have to measure how many neutrons were being emitted both before and after turning the source on. Neutron measurements of this type would be characterized by the following.

(1) Neutron counters of either the scintillation or gas-filled variety connected to electronic recording devices. The electronic devices are usually called "scalers." Gases used in counters might be $^{10}BF_3$ or ^{3}He.

(2) An experimental area with thick, ~0.3m (~1 ft.), water or polyethylene shielding, well away from any sources of radiation except that being measured.

3. Development and Testing of Nuclear Initiators

a. Nuclear Initiators may be of the alpha-N type or the particle accelerator type. Implosions or gun-type weapons may employ either type. An alpha-N initiator produces neutrons from the physical mixing of a radioactive alpha-emitter (such as polonium 210) with a light element (such as beryllium). Various nuclide materials can be used as alpha emitters (e.g., Pu-238, Po-208, Po-210, Ac-227, or Ra-226). A particle accelerator initiator utilizes a neutron generator vacuum tube that is electrically pulsed to accelerate deuterium or tritium ions from a source into a target containing deuterium or tritium to produce a pulse of neutrons. Neutron sources using the particle accelerator principle have been produced commercially for oil well logging and various laboratory uses. Imports of such sources for adaptation to use in nuclear programs may indicate weapon development activity. If a country decides to develop the radioactive type, this involves producing or importing the alpha-emitting material and doing considerable testing of various designs for proper functioning.

b. Experimental work on either type of initiator requires electronic instrumentation to detect neutrons. For the radioactive type, neutron background data must be taken as described above. In addition, experimental work with the radioactive type requires hot cell and glove box facilities resembling those for plutonium processing. A few "proof" tests of the radioactive type probably would be done in underground chambers containing a mockup of the nuclear device and many neutron counters. Such chambers need only be 15-30m (50-100 ft.) underground since no nuclear explosion is involved.

D. Publications

1. It is to be expected that the scientists working in any country on nuclear programs would be allowed to publish some of their work and would be anxious to read what others had done in the same fields. They would also probably obtain computer codes already developed by others for related kinds of calculations, notably for nuclear reactor studies and shock wave hydrodynamics. This facet of the theoretical and experimental work attendant to a weapon program probably would include some of the following specifics and possibly others.

a. Papers published in country X on calculations of nuclear reactor "excursions," especially energy release and the reactor core "neutronics."

b. The purchase by foreign scientists of neutron calculational codes.

c. Correspondence between the code user in country X and the code originator (possibly in the U.S.) about the application of the code to higher pressure or temperature regimes.

d. The purchase of HE burning codes.

e. The publication in country X of papers on experiments with high explosives using pin or optical instrumentation techniques.

f. The purchase by country X of formerly secret weapon laboratory reports recently declassified.

E. Nuclear Testing

1. Preparation of a site for a live nuclear test probably would be characterized by the following kinds of activities.

a. Drilling rigs, mining operations, road construction, or other signs of activity in a "new" location, isolated or otherwise suitable for an underground test.

b. Sections of large diameter (up to about 1.2m, or about 4 ft.) pipe to be used for casing, laid out near drilling rig.

c. Contacts by country X (possibly through their embassy in the U.S.) with large drilling companies in the U.S. who know "large hole" drilling technology by virtue of experience with the U.S. testing program.

2. If we assume that some kind of diagnostic information is to be recorded during the live nuclear test, then cabling and electronic recording stations would be needed. The extent and sophistication of such an effort on the part of country X is difficult to predict, but the electronic skills needed for good diagnostics are believed to be widespread in the world. Good equipment can be bought from several countries, and some data acquisition schemes used by the U.S. have been published in the open literature. Some indicators relating to instrumentation of a live nuclear test follow.

a. Import or development of computer codes by country X for "unfolding" data to remove system response effects from the recorded signals.

b. A few to a dozen cable reels 1.8-2.4m (6-8 ft.) in diameter and 1.2-1.5m (4-5 ft.) wide. Reels are used to transport air dielectric or foam dielectric coaxial cables from 7/8-in. diam to 1-5/8-in. diam for recording fast signals.

c. Paragraphs a. and b. above coupled with the purchase of plastic scintillators, photo diodes, photomultipliers, and 10-50-MHz bandwidth oscilloscopes (such as Tektronix) with cameras.

IV. PERSONNEL

It is to be expected that a group of good people will be formed to organize and help conduct the nuclear weapon program. One might judge whether this has taken place by the following types of indicators.

1. Movement of top scientists from former positions into undisclosed or inaccessible locations
2. Sudden decline or cessation of published papers by top scientists
3. Extensive technological training programs in advanced countries
4. Recall of trained scientists from other countries
5. Close association of several top scientists of diversified backgrounds (e.g., hydrodynamicists associated with physicists).

V. DELIVERY SYSTEMS

A country engaged in development of a nuclear device will probably have a parallel development of some delivery system going on. The parallel program doesn't need to be extensive and costly, but may only comprise modifications to some existing aircraft. There could be a spectrum of activities, typified by the following.

1. Expansion of electronics development work for possible applications in rocket delivery system program
2. Activity in ordnance development program for rockets
3. Import or development of large size (~100-cm-diam warhead compartment) rocket systems
4. Modification and test of aircraft to carry large diameter (~100 cm), possibly external, stores
5. Evolution of aircraft or missile flight profiles uniquely suited to nuclear warheads (e.g., large safe-escape margin).

VI. PLAYING GAMES WITH IAEA TO EVADE SAFEGUARDS

A. Some possible indications of diversion of nuclear materials to undisclosed uses might turn up. Since IAEA can only come into a country on an "invited" basis, there are a number of "foot dragging" techniques that might be employed. Among them might be these. They essentially involve politics and bookkeeping.

1. Stalling tactics against IAEA inspections, such as repeated objection to agency-designated inspector.

2. IAEA inspectors refused access to certain portions of plants for a variety of reasons, e.g., an accidental spill

3. Refusal to admit IAEA inspectors to verify oralloy inventory

4. "Pilot" fuel fabrication facility not declared for safeguards

5. Substantial MUF (material unaccounted for) at processing plant

6. Bookkeeping tricks to hide MUF

B. Finally, of course, a country may achieve nuclear independence and withdraw from all safeguards agreements.

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