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UNDERSTANDING THE CHALLENGE. TRACKING THE THREAT.

DISPERSED BUT NOT DEGRADED:

IRANIAN UNIVERSITIES AND THE REGIME'S NUCLEAR WEAPONIZATION ACTIVITIES

WARREN MARSHALL

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Executive Summary

Iran has mastered the technology necessary to produce weapons-grade uranium and currently has enough centrifuges operating to produce fuel for several weapons each year, if its leaders choose to do so. The U.S. is currently negotiating with Iran in hopes of reducing its stockpiles of enriched uranium and centrifuge capability, but the Obama administration has already conceded that Iran will retain some indigenous enrichment capacity. It has also apparently conceded that Iran will not have to come clean about the history or even current state of its efforts to perfect a workable nuclear warhead. Iran's progress toward weaponization as opposed to enrichment has thus largely dropped from policy discussions. The trouble is that careful review of Iranian published scientific papers and advertised industrial capabilities indicates that Iran may be much closer to being able to build a nuclear weapon than many people think. In the worst case, Iran may already have the technical capability to complete every part of the weaponization process, including testing a nuclear device.

Too much of the policy discussion in Washington has focused on Iran's intentions, although very little serious evidence has been brought to bear even on that question. The U.S. and its European partners must be clear-eyed about Iran's actual capabilities as we head into what may be the final stages of the negotiations. Iranian nuclear proliferation is a threat if Tehran is able to build and test a warhead and retains the ability to produce weapons-grade uranium, regardless of the current statements of its leaders. The West seems to be underestimating that capability, unfortunately, by ignoring the work being done in Iran's leading universities rather than in its military centers.

An examination of Iranian scientific literature demonstrates that Iran has conducted studies relevant to four of the five components of a basic nuclear implosion device (electrical firing set, detonators, high explosive lenses, and tamper/reflector) and may already have firing equipment and detonators suitable for a bomb. Several of the researchers involved in these experiments can be tied to Malek Ashtar University or the Organization of Defense Innovation and Research (SPND), both of which have been placed at the heart of Tehran's potential nuclear weapons research by the International Atomic Energy Agency (IAEA). The close ties between the Iranian academy and the regime evident in this research show that Iran's university system must be included within the verification protocols of any final nuclear deal with Tehran.

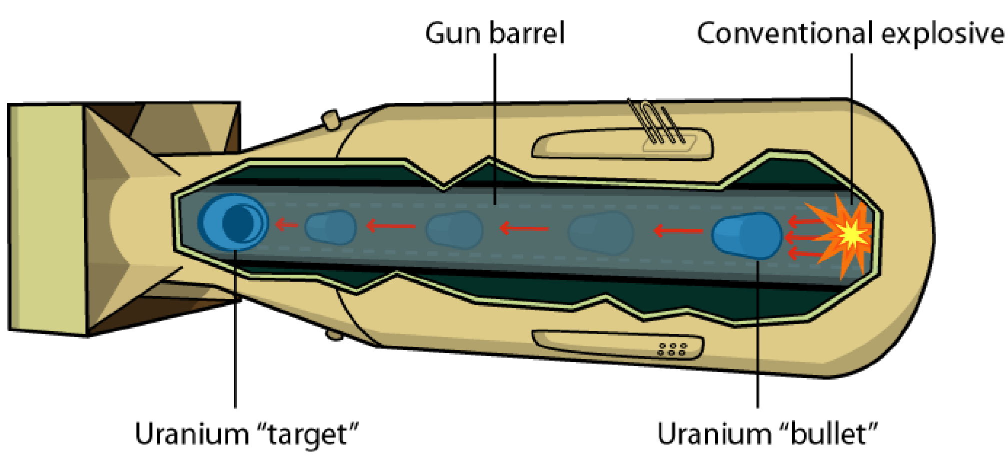
Introduction

Iran has always maintained that its nuclear program is for strictly peaceful purposes, but the International Atomic Energy Agency has repeatedly sought answers from Tehran regarding the possible military dimensions (PMD) of its nuclear work. These concerns, laid out in detail in the annex to the Agency's November 2011 report, include nuclear-related research and development involving military organizations, high explosives testing, and the reengineering of the Shahab-3 missile reentry vehicle in order to accommodate a nuclear payload. The IAEA has also indicated that some of this possible weaponization work may be ongoing despite a "halt order" issued in 2003 by senior Iranian officials.[1]

The most recent IAEA report on Iran issued in November 2014 reiterates that Tehran has not addressed the concerns described in the 2011 report and has, in fact, taken additional actions the IAEA regards as troubling.[2] This paper, therefore, uses the 2011 IAEA report, supplemented by the Department of Defense Militarily Critical Technologies List (MCTL) and Nuclear Suppliers Group (NSG) guidelines, to assess the proliferation significance of Iran's technical achievements.[3]

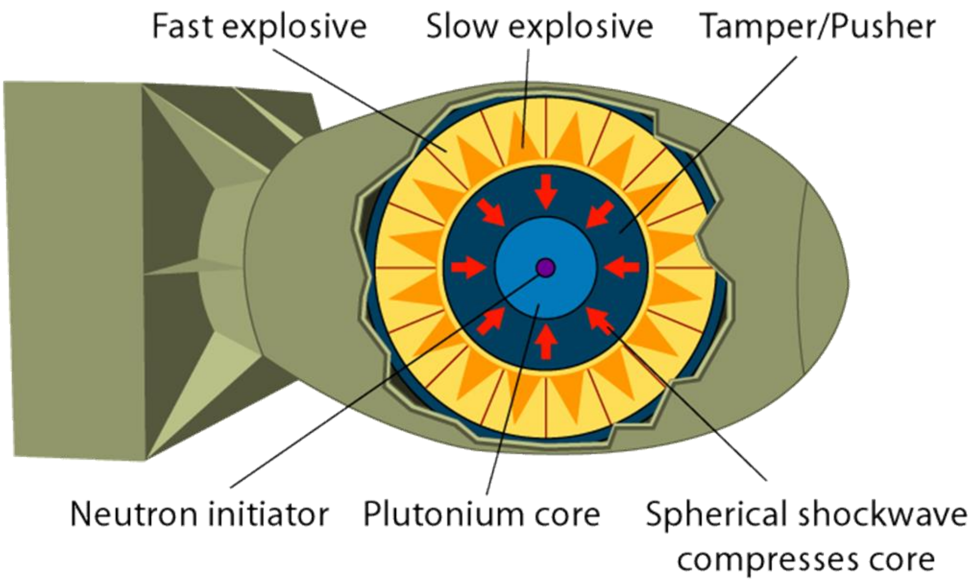
The IAEA has reported that it believes Tehran's potential nuclear weapons research is concentrated on developing components for an implosion design (as opposed to a cruder "gun-type" weapon; see Figure 1 for an illustration of a gun-type design).[4] The Pakistani scientist A.Q. Khan delivered a design document for this type of nuclear weapon to the Iranians in the 1980s.[5] Besides the fissile core of nuclear material, a basic implosion nuclear weapon consists of an electrical firing set, detonators, high explosive lenses, a tamper/reflector, and a neutron initiator (see Figure 2, which omits the firing set and detonators).[6] The data presented in this paper indicate that Tehran has conducted research relevant to the first four of these components and may already have developed firing equipment and detonators suitable for a nuclear weapon.

FIGURE 1
GUN-TYPE NUCLEAR WEAPON



Source: Wikimedia Commons

FIGURE 2
IMPLOSION-TYPE NUCLEAR WEAPON



Source: Wikimedia Commons

Exploding Bridgewire Detonator

An exploding bridgewire detonator (EBW) is a short, small-diameter wire welded between two ends that can be used to detonate a nuclear device (see Figure 3 for an example).[7] EBWs were originally developed as part of the Manhattan Project for use in "Fat Man," the first implosion weapon.[8] Although EBWs have some civil applications, such as in oilfield perforation, mining, and explosive welding, they are of nonproliferation concern because they are precise enough in their firing time to provide the simultaneous detonation needed in a nuclear implosion design.[9]

FIGURE 3
EXPLODING BRIDGEWIRE (EBW) DETONATOR

Source: "Implosion Systems Development Equipment," in Handbook for Notification of Exports to Iraq: Annex 3, prepared by the U.S. Department of Energy Nuclear Transfer and Supplier Policy Division, April 1998

The annex to the November 2011 IAEA report describes a 2005 paper on EBW development that was presented at an international conference by two Iranian researchers affiliated with Malek Ashtar University and the Air Defense Industries Group of Tehran.[10] This article is almost certainly identical to a study titled “Evaluation & Analysis of Performance of Exploding Bridgewire” that was submitted to the 2005 International Autumn Seminar on Propellants, Explosives, and Pyrotechnics in Beijing, China.[11] The authors, Farshid Mahdavi and Majid Etminanbakhsh, list Malek Ashtar University as their correspondence address in the article’s byline. Malek Ashtar is located across the street from a facility that has been identified as the administrative center for Iran’s nuclear weaponization work (known as the “Organization of Defense Innovation and Research,” or SPND).[12] According to the IAEA, Malek Ashtar University itself once served as the headquarters for an earlier iteration of SPND.[13]

The 2005 study involved a series of about 200 trials carried out over six months investigating the effects of PETN (pentaerythritol tetranitrate) explosive particle size, cable impedance, and initiation surface area on EBW detonation. PETN explosives are cited in the Nuclear Suppliers Group (NSG) guidelines on export control as the type of explosive material used with exploding bridgewire detonators.[14] The Iranian researchers were able to obtain high-order (i.e., complete) detonation on a number of trials using low-impedance firing circuitry, high-voltage capacitors, and coaxial cables, all of which are also needed for nuclear weapons detonation.[15]

It is important to note that EBWs can also be used for stage separation in ballistic missiles.[16] The 2005 Malek Ashtar report’s abstract alludes to this purpose by noting exploding bridgewires’ applications in the “missile and space vehicle fields.” The article does not, however, mention any particular use in the oil and gas industries, which has been Iran’s stated justification to the IAEA for its work with these detonators.[17] Malek Ashtar University, where the research was conducted, also does not have a dedicated college of petroleum engineering, which casts further doubt on Iran’s explanation.[18] Finally, the article’s second author, Majid Etminanbakhsh, wrote a thesis on warhead design in the mid-1990s, raising questions about whether his EBW research was truly for civilian purposes.[19] Taken together with Iran’s admission that it has been able to simultaneously fire multiple EBWs in about one microsecond,[20] the Malek Ashtar study indicates that Tehran may already possess a detonator suitable for use in a nuclear implosion weapon.

Firing Equipment: Capacitors, Switches, and Pulse Generators

Among the "possible military dimensions" of Iran's nuclear program mentioned by the IAEA in its November 2011 report is Iran's procurement of high-speed electronic switches and spark gaps that can be used for triggering and firing detonators.[21] In an implosion nuclear weapon, a switch transfers the stored electrical energy from a capacitor into the firing circuits, which in turn initiate the multiple detonators that create the symmetrical implosion wave.[22]

An Iranian company known as Pulse Niru sells spark gap, rail gap, and multi-gap switches, trigger circuits, and pulse capacitors.[23] At least several models of these switches and capacitors appear to exceed NSG and MCTL guidelines for use in a nuclear firing set.[24] Figures 4 and 5 show examples of a spark gap switch and pulse capacitors listed on the company's website. Pulse Niru also displays a "picosecond pulse generator" that could be used to calibrate cables for hydrodynamic testing with a simulated nuclear core (see Figure 6).[25] The firm's CEO, Mohammad Mahdi Attaran, received a master's degree in electrical engineering from Malek Ashtar University, which as previously mentioned has been heavily linked to Iran's possible nuclear weapons research.[26]

FIGURE 4
HIGH-VOLTAGE SPARK GAP SWITCH

FIGURE 5
LOW-INDUCTANCE PULSE CAPACITORS

Source: Pulse Niru website

FIGURE 6
HIGH-VOLTAGE PICOSECOND PULSE GENERATOR

Source: Pulse Niru website

Iranian researchers have also published computational and experimental studies on compact, high-speed, and high-voltage electrical generators that are similar to those used in nuclear weapons.[27] Several of these studies, including one by Pulse Niru's CEO, involve vaporization of metal wires under high current in a process comparable to EBW detonation.[28] The résumé of another scientist involved in this type of research, Jouya Jadidian, indicates that he was exempted from compulsory military service as a member of Iran's Armed Forces National Elite Foundation in 2009.[29] Under this plan, Iranian university students can be excused from mandatory conscription and compensated in exchange for conducting research of use to the armed forces, including for classified projects.[30] SPND is listed as among the centers eligible for student assignment under this arrangement.[31]

PETN Explosive Lens

In a nuclear implosion weapon, an explosive lens can be used to take the detonation wave originating from a single detonator and shape it to arrive simultaneously over an extended output surface (see Figure 7 for two examples). This "wave-shaping" focuses the explosion in order to create the necessary compression for nuclear detonation.[32] A 2004 Iranian-Japanese study on aluminum/silicon carbide particle composites manufactured by explosive compaction involved the use of a planar (two-dimensional) explosive lens composed mostly of PETN.[33] As previously mentioned, PETN is typically used in detonators in nuclear weapons.[34] Although a spherical implosion nuclear weapon requires three-dimensional explosive lenses (as opposed to the two-dimensional lens used in the 2004 study), the manufacturing processes involved in casting a planar lens are still relevant to the early stages of a weapon design program.[35] Notably, one of the report's authors, Saeed Borji, has also published on detonation synthesis of nanodiamonds.[36] The explosion physics involved in this process would be of interest to anyone trying to achieve the rapid compression required to detonate a nuclear weapon.[37]

FIGURE 7
HIGH EXPLOSIVE LENSES

Source: "Implosion Systems Development Equipment," in Handbook for Notification of Exports to Iraq: Annex 3, prepared by the U.S. Department of Energy Nuclear Transfer and Supplier Policy Division, April 1998

Iranian scientists have also conducted a number of studies on the various high explosives controlled under NSG guidelines, such as HMX (cyclotetramethylenetetranitramine), HNS (hexanitrostilbene), RDX (cyclotrimethylenetrinitramine), and TATB (triaminotrinitrobenzene).[38] This work is complemented by published research on detonation, hydrodynamics, shaped charges, and shock waves that is cited by the IAEA in its November 2011 report as relevant to nuclear weapons.[39] In one 2007 study conducted at Malek Ashtar University, for example, the authors calculated the pressure required to initiate explosives pressed to 90%, 95%, and 98% of their theoretical maximum density.[40] Such highly-pressed explosives are a key component of a nuclear implosion weapon.[41]

Microbarograph

A microbarograph (or microbarometer) is a very sensitive instrument that measures changes in atmospheric pressure. It is used in nuclear weapons testing as well as nuclear explosion detection for verification and nonproliferation purposes (such as for the Comprehensive Nuclear Test Ban Treaty), but can also be used for detecting natural phenomena like volcano eruptions and avalanches.[42]

An Iranian scientist named Bashir Behjat Khajeh lists a project for the "reverse engineering and conceptual design" of a microbarograph on his résumé. Khajeh also includes a project on "analysis of a missile structure under explosive loads."[43] The microbarograph study was undertaken for the "Center for Innovative Defense Technologies," which is very similar in name to the "Center for Readiness and Innovative Defense Technologies" that is listed as one of SPND's subdivisions in the November 2011 IAEA report.[44] Khajeh's work could have been commissioned either to help defeat the Comprehensive Test Ban Treaty Organization's nuclear detection infrastructure—which Iran has refused to provide with data from the monitoring stations on its soil—or to prepare measuring equipment for a future Iranian nuclear test.[45]

Explosive Compaction of Tungsten

The November 2011 IAEA report cites "information provided by Member States" indicating that Iran had manufactured simulated nuclear explosive components using high-density materials such as tungsten as part of experiments to test the design of an implosion device.[46] Such testing would not leave radioactive traces, unlike depleted uranium. A 1996 Los Alamos National Laboratory study, for example, describes an experiment involving an underground explosion with tungsten as a plutonium analog.[47] The high density of tungsten and its alloys also makes it a candidate for use as a tamper and/or reflector in a fission nuclear weapon.[48] A "tamper" serves to reduce the velocity of the expanding core during nuclear detonation and thereby allows for a greater yield, while a "reflector" backscatters neutrons into the core in order to increase the efficiency of the reaction.[49]

A 2006/2007 study by a team of Iranian researchers presented an underwater explosive compaction method for tungsten that increased the hardness of tungsten powder by 40% compared to regular explosive compaction.[50] In a similar study presented at a conference in Italy in 2006, the researchers reported achieving 96% of tungsten's theoretical maximum density using this method.[51] The authors also calculated an equation of state for the tungsten powder under the experimental conditions.[52] An "equation of state" is a thermodynamic equation describing the state of matter under a given set of physical conditions (such as temperature, pressure, volume, or internal energy).[53] According to an IAEA document, the calculation of equations of state for materials such as tungsten is one possible indicator of a nuclear weapons program.[54]

There is other evidence that Iran's scientific work with tungsten may be tied to its nuclear weapons research. Ali Mehdipour Omrani, the author of several tungsten compaction papers, has been cited by *Intelligence Online* as the head of the production department for Iran's "Research Center for Explosion and Impact," or METFAZ.[55] The November 2011 IAEA report describes METFAZ as involved in shaped charge studies that have conventional military applications but can also be used to develop computer codes for modeling nuclear explosives.[56] Omrani himself has also published on ballistics and been associated with Malek Ashtar University.[57] Additionally, an "S.

Borgi" of Malek Ashtar University—likely the aforementioned Saeed Borji who has also written on detonation synthesis of nanodiamonds and explosive lenses—appears as the second author of another 2012 article on sintering of tungsten-copper composites.[58] Finally, two of the four authors of a 2006/2007 Iranian study on the preparation of tungsten-copper composite powder list affiliations with the "Center for Research and Technology of Advanced Materials," which was identified as an SPND subdivision in the IAEA's November 2011 report.[59]

Interestingly, at the end of one article on tungsten explosive compaction Omrani and colleagues note "the significant advantages of explosive powder forming despite limitations…like the need for a location outside of residential areas."[60] Given that all of the authors are affiliated with universities in downtown Tehran, it is likely that the study's explosive tests were performed outdoors at a military or government defense industry site, possibly including the nearby Parchin facility.

Conclusion

Successfully weaponizing a nuclear device is only one step toward developing an effective nuclear deterrent, as proliferant states often struggle with the systems engineering needed to integrate individual components into a viable delivery vehicle. Iran's potential progress toward the miniaturization and "ruggedization" of components necessary to mount a nuclear device onto a ballistic missile is difficult to assess using open sources. This does not mean, however, that Iran has not already begun tackling the technical steps required for an operational delivery system. SPND's plans to open a space radiation reference laboratory and its participation in a January 2013 conference on hardening electronics against space radiation, for example, suggest an interest in technologies relevant to ensuring the electronic integrity of a nuclear warhead after launch.[61] A program for the following year's conference also lists a "Parviz Kattani," head of SPND's radiation protection center, as a chair for the first session on space radiation measurement and detection.[62]

The fact that most of the above-cited research was conducted by professors working within Iran's university system bears significant consequences for the IAEA's ability to detect Iranian weaponization under any final nuclear deal. Besides its own state-run military institutions such as Malek Ashtar and Imam Hossein Universities, the Iranian government continues to mobilize the expertise and facilities available in academia for use in the nuclear program via research contracts and sponsorship of student research.[63] These overlapping efforts can be seen, in part, as an attempt to create redundancy and decentralize weaponization-related work in case Tehran later decides to go nuclear. According to public comments by former senior American and Israeli officials, Supreme Leader Ali Khamenei fears that any decision to build a bomb would be detected by Western intelligence services before a device could become operational.[64] Khamenei's concerns aside, the low signatures associated with weaponization facilities and the intelligence community's mixed record in detecting clandestine nuclear programs necessitate a robust verification regime in a comprehensive accord. This arrangement should include access to both university personnel and facilities that have undertaken weaponization-related work for Tehran.

Iran must fully disclose and explain the so-called "possible military dimensions" of its nuclear program if the international community is to remain confident that the regime will not build nuclear weapons. The involvement of SPND—a military organization reporting to the Minister of Defense—in research relevant to nuclear weapons design is particularly concerning.[65] There is evidence that even senior officials in the Iranian government, including current President Hassan Rouhani during his tenure as chief nuclear negotiator, have not always been fully informed of SPND's activities.[66] A complete accounting of weaponization-related research is necessary to ensure the world that Iran will not undertake these activities again at a time when it has also made further advances in its missile and uranium enrichment capabilities.

Glossary of Nuclear Weapon Terms

Coaxial cable: An electrical cable consisting of two conducting wires separated by an insulation layer and surrounded by an outer protective sheath. These cables can be used to link a mock implosion-type nuclear weapon to electronic data recording instruments during hydrodynamic testing.

Equation of state: An equation describing the relationship among the thermodynamic properties of a material, such as pressure, density, or temperature. Equation of state information is vital in modeling the performance of nuclear explosive devices.

Exploding bridgewire (EBW) detonator: A small electrical conductor (the bridgewire) that vaporizes when a surge of electrical current passes through it, leading to the initiation of a high explosive charge. EBW detonators were developed as part of the Manhattan Project for use in "Fat Man," the first implosion nuclear weapon.

Explosive lens: A specially-shaped high explosive charge that squeezes the fissile core in an implosion-type nuclear weapon in order to set-off a fission chain reaction. The result is a nuclear explosion.

Firing set: The system of components (e.g., capacitors and switches) in an implosion-type nuclear weapon that provide the electrical pulse needed to simultaneously initiate the detonators at the proper time.

Fissile core: A sphere of radioactive material (either highly-enriched uranium or plutonium) in an implosion-type nuclear weapon that, when compressed, sets-off the fission chain reaction resulting in a nuclear explosion.

Gun-type nuclear weapon: A nuclear weapon design in which a fission chain reaction is produced by propelling one piece of radioactive material into another at very high speed. Gun-type nuclear weapons are easier to build than implosion designs but have a much lower yield.

HMX: A high explosive that can be used in explosive lenses in an implosion-type nuclear weapon. Its chemical name is cyclotetramethylenetetranitramine.

HNS: A high explosive that can be used in detonators in an implosion-type nuclear weapon. Its chemical name is hexanitrostilbene.

Hydrodynamic testing: Testing of a mock implosion-type nuclear weapon in which a simulated fissile core is imploded to determine its behavior under high pressure and assess the function of the high explosives. The IAEA has indicated that Iran may have conducted such testing at its Parchin military facility.

Implosion-type nuclear weapon: A nuclear weapon design in which a fission chain reaction is produced by compressing radioactive material using high explosives. Implosion-type nuclear weapons are harder to build than gun designs but have a much higher yield.

Microbarograph: A device that records minute changes in atmospheric pressure. An array of microbarographs can be used to measure the location and yield of nuclear explosions.

Nanodiamond: A diamond produced by compressing graphite using high explosives. The physics and experimental procedures involved in this process are relevant to a nuclear weapons research and development program.

Neutron initiator: A nuclear weapon component that produces the burst of neutrons necessary to set-off the fission chain reaction resulting in a nuclear explosion.

PETN: A high explosive that can be used in detonators in an implosion-type nuclear weapon, such as exploding bridgewire detonators. Its chemical name is pentaerythritol tetranitrate.

Pulse capacitor: The component in an implosion-type nuclear weapon that stores the electrical energy needed to simultaneously initiate the detonators at the proper time.

Pulse generator: A device that creates electrical pulses with varying characteristics in order to test the performance of electronic equipment. A pulse generator capable of producing pulses on a picosecond-scale can be used to calibrate electrical cables deployed during the hydrodynamic testing of a simulated implosion-type nuclear weapon.

RDX: A high explosive that can be used in explosive lenses in an implosion-type nuclear weapon. Its chemical name is cyclotrimethylenetrinitramine.

Reentry vehicle: A space vehicle designed to protect its payload from the heat and stress encountered upon re-entering the Earth's atmosphere. The November 2011 IAEA report cites evidence indicating that Iran had pursued the re-engineering of its Shahab-3 missile reentry vehicle in order to accommodate a nuclear warhead.

Reflector: A nuclear weapon component that bounces some of the escaping neutrons back into the fissile core as the fission chain reaction progresses in order to increase the yield of the resulting nuclear explosion. Use of a reflector reduces the amount of radioactive material required to achieve nuclear detonation.

Ruggedization: The process of designing equipment capable of withstanding harsh environmental conditions such as shock, vibration, and high temperature.

Shaped charge: An explosive charge designed to focus its energy in a particular direction. These charges have conventional military applications, such as in armor-piercing projectiles, but are also relevant to nuclear weapons modeling and design.

Spark gap switch: A gap in an otherwise closed electric circuit across which a discharge occurs when a specific voltage of electricity is applied, completing the circuit and allowing current to flow. These switches can be used in an implosion-type nuclear weapon.

Stage separation: The jettisoning of an element of a missile propulsion system once it has exhausted its fuel. Exploding bridgewire (EBW) detonators can be used in this process.

Tamper: A nuclear weapon component that helps contain the rapidly-expanding fissile core upon detonation in order to allow more time for the fission chain reaction, thereby producing a greater yield. Use of a tamper reduces the amount of radioactive material required to achieve nuclear detonation.

TATB: A high explosive that can be used in explosive lenses in an implosion-type nuclear weapon. Its chemical name is triaminotrinitrobenzene.

Yield: The energy released in a nuclear explosion, usually expressed as the number of tons of TNT that would produce the same amount of energy.

Notes

[1] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," GOV/2011/65, November 8, 2011, 8, 10; Annex, 6, http://www.iaea.org/sites/default/files/gov2011-65.pdf.

[2] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council Resolutions in the Islamic Republic of Iran," GOV/2014/58, November 7, 2014, 3, 11-14, http://www.iaea.org/sites/default/files/gov2014-58.pdf.

[3] See J. Arenas Carrasco, "Indicators of Nuclear Programmes," IAEA-CN-184/289, 2, http://www.iaea.org/safeguards/symposium/2010/Documents/PapersRepository/289.pdf, and Richard Wallace and Arvid Lundy, "Using Open Sources for Proliferation Analysis," in *Nuclear Safeguards, Security and Nonproliferation: Achieving Security with Technology and Policy*, ed. James E. Doyle (Burlington, Massachusetts: Butterworth-Heinemann, 2008), 212-13.

[4] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," GOV/2011/65, November 8, 2011, Annex, 4, http://www.iaea.org/sites/default/files/gov2011-65.pdf.

[5] See "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," GOV/2011/65, November 8, 2011, Annex, 7-8, http://www.iaea.org/sites/default/files/gov2011-65.pdf; David Albright, Paul Brannan, Mark Gorwitz, and Andrea Stricker, "ISIS Analysis of IAEA Iran Safeguards Report: Part II - Iran's Work and Foreign Assistance on a Multipoint Initiation System for a Nuclear Weapon," Institute for Science and International Security (ISIS) Report, November 13, 2011, http://isis-online.org/uploads/isis-reports/documents/Foreign_Assistance_Multipoint_Initiation_System_14Nov2011.pdf, 3; and David Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies* (New York: Free Press, 2010), 78-9.

[6] See John Coster-Mullen, *Atom Bombs: The Top Secret Inside Story of Little Boy and Fat Man* (2012), 186, and Carey Sublette, "Implosion Assembly," http://nuclearweaponarchive.org/Nwfaq/Nfaq4-1.html#Nfaq4.1.6.2.

[7] "Implosion Systems Development Equipment," in *Handbook for Notification of Exports to Iraq: Annex 3*, prepared by the U.S. Department of Energy Nuclear Transfer and Supplier Policy Division, April 1998, 21, http://www.iraqwatch.org/government/US/DOE/DOE-CHAPTR11.PDF.

[8] Lillian Hoddeson, Paul W. Henriksen, Roger A. Meade, and Catherine Westfall, *Critical Assembly: A Technical History of Los Alamos During the Oppenheimer Years, 1943-1945* (Cambridge: Cambridge University Press, 2004), 169-73, 301-7.

[9] See "Electric Initiation Device - RF Safe Exploding Bridgewire Detonators & Igniters," Core Laboratories Website, http://www.corelab.com/owen/cms/docs/TechCat/sfs_det_chart-eid-rfsebdi.pdf; "Selecting the Right EBW Detonator," Teledyne Risi, Inc. Website, http://www.teledynerisi.com/products/0products_1ebw_page10.asp; "Reynolds Industries Systems Incorporated Explosive Products," Teledyne Reynolds Website, http://www.teledynereynolds.com/pdf/facil-part5.pdf; and "Implosion Systems Development Equipment," in *Handbook for Notification of Exports to Iraq: Annex 3*, prepared by the U.S. Department of Energy Nuclear Transfer and Supplier Policy Division, April 1998, 23, http://www.iraqwatch.org/government/US/DOE/DOE-CHAPTR11.PDF.

[10] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," GOV/2011/65, November 8, 2011, Annex, 8, http://www.iaea.org/sites/default/files/gov2011-65.pdf.

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[13] "Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran," GOV/2011/65, November 8, 2011, Annex, 5-6, http://www.iaea.org/sites/default/files/gov2011-65.pdf.
[14] "Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software, and Related Technology," June 2013, Annex, 6-1, http://www.nuclearsuppliersgroup.org/images/Files/Updated_control_lists/Prague_2013/NSG_Part_2_Rev._9_clean.pdf.
[15] "The Militarily Critical Technologies List, Part II: Weapons of Mass Destruction Technologies," Office of the Under Secretary of Defense for Acquisition and Technology, February 1998, II-5-59, II-5-63, II-5-103, and II-5-108, https://www.hsdl.org/?view&did=443125; "Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software, and Related Technology," June 2013, Annex, 6-2 and 6-3, http://www.nuclearsuppliersgroup.org/images/Files/Updated_control_lists/Prague_2013/NSG_Part_2_Rev._9_clean.pdf.
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[17] "IAEA Director General Comments on Visit to Iran," Press Release, International Atomic Energy Agency, August 17, 2014, http://www.iaea.org/newscenter/pressreleases/iaea-director-general-comments-visit-iran.
[18] See the Malek Ashtar University of Technology Website at http://www.mut.ac.ir.
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