

## CHAPTER 2

### IRAN'S "LEGAL" PATHS TO THE BOMB

Victor Gilinsky

#### **Introduction and Summary.**

Recent events have reinforced the persistent suspicion that Iran seeks nuclear weapons. That suspicion is fed by Iran's drive to obtain all aspects of nuclear power technology, whether economically justified or not. Iran's strong emphasis on those technologies that would permit production of nuclear explosives—plutonium and highly enriched uranium—is especially worrisome. So is Iran's resistance to accepting more effective international inspections and, even more so, its likely violation of its current reporting obligations.

Iran's rationale for pursuing these technologies is that they would support the operation of its nuclear power reactors for generating electricity. So far, Iran has only one Russian-supplied unit, Bushehr 1, under construction. But it looks more and more as if the country—that is to say, the directorate of the nuclear program—has more in mind than generating electricity. Consider, for example, the issue of plutonium. The Bushehr reactor, like any uranium-fueled power reactor, would produce militarily-significant amounts of plutonium in its fuel during operation. Under U.S. pressure to make sure the plutonium from Bushehr did not end up in bombs, the Russians have agreed to take back the reactor's radioactive spent fuel, 1 percent of which would produce plutonium during the reactor's operation. Most power reactor operators are delighted to get rid of their spent fuel. The contained plutonium has no economic value. Iran, however, has made it clear that it intends to pursue reprocessing technology to separate the plutonium from spent fuel, which raises questions about the future of that Bushehr product.

As was revealed in August 2002 by an opposition group, Iran is also building a heavy water plant at Arak.<sup>1</sup> Iran has since informed

the IAEA it intends to build a heavy water reactor, which would be even more suited to producing plutonium.

Iran is also opening the door to producing the other nuclear explosive of interest—highly enriched uranium.<sup>2</sup> Bushehr, like all water-cooled power reactors, would use low enriched uranium as fuel that Russia would normally supply. Yet in August 2002 it was brought to light by the same Iranian dissidents that Iran was building uranium centrifuge enrichment plants.<sup>3</sup> These cannot remotely be justified economically on the basis of Iran's nuclear power program. They would, however, be of major importance for producing nuclear weapons. The secretiveness about these plants during their early development is unsettling. Even more unsettling is the likelihood that Iran violated its safeguards agreement with the International Atomic Energy Agency (IAEA) in testing its pilot enrichment plant.

### **Likely IAEA Reporting Violations.**

Iran, as a consequence of its adherence to the Nonproliferation Treaty, was obligated to inform the IAEA if it tested its centrifuges with uranium hexafluoride gas. It did not so inform the IAEA. It now asserts it used other gases for testing. It is, however, very difficult to believe Iran's assertion that it built its pilot centrifuge cascade and launched a huge centrifuge complex construction project without testing its unit design with the real stuff, so to speak. Such an omission would have violated all normal engineering practice. Moreover, Iran has resisted IAEA efforts to take environmental samples at the facility to check on Iran's claim.<sup>4</sup> Iran insists that it is not obligated to permit such sampling since it has not signed the Additional Protocol requested by the Agency of all its members.

There are a number of other IAEA reporting failures and activities that have raised concern:<sup>5</sup>

- In 1991, Iran imported 1.8 tons of natural uranium and failed to report it to the IAEA. Iran said it was not legally required to report it. The IAEA said Iran must declare all such imports "as soon as possible."

- Iran informed the IAEA in May that it intended to build a heavy-water research reactor at Arak, the existence of which the IAEA learned about in 2002 from media reports. This plant would yield weapons-grade plutonium.
- Iran has converted natural uranium into uranium metal. The IAEA says “the role of uranium metal . . . needs to be fully understood, since neither (Iran’s) light water reactors nor its planned heavy water reactors require uranium metal.”

### **Resisting the IAEA Additional Protocol.<sup>6</sup>**

Adding to long-term suspicions is that Iran has been also unwilling to accept advanced IAEA safeguards—the so-called Additional Protocol that most countries have signed—that would permit more extensive inspection by the Agency.

The Additional Protocol (based on INFCIRC/540 [corr.]) is, according to the IAEA, the key to its strengthened safeguards system. Signers agree to provide the IAEA with broader information covering all aspects of its nuclear fuel cycle-related activities, including research and development and uranium mining. They must also grant the Agency broader access rights, including short notice inspections of all buildings at nuclear sites. They must also allow the IAEA to use advanced verification technologies, including environmental sampling.

The new Protocol would also allow the Agency to obtain more and earlier design information. The current requirement is that the IAEA is to obtain such information “as early as possible” without specifying a definite time.<sup>7</sup>

Iran recently said it would accept such a protocol if the United States and other countries would relax current restrictions on nuclear technology exports to Iran.<sup>8</sup> The United States would not agree for obvious and sensible reasons.

### **Is the Civilian Program Only a “Cover”?**

There is still a tendency, even among those convinced Iran is intent on getting nuclear weapons, to see the country’s nuclear power

program as a *cover* for a separate clandestine weapons program rather than part of a weapon program and to fail to appreciate the nuclear explosive production capacity of the “civilian” program itself, especially that of the Russian-supplied Bushehr power reactor nearing completion.<sup>9</sup> Weapon design and preparation for weapon fabrication would, of course, have to be under cover, at least so long as Iran remains a member of the Non-Proliferation Treaty (NPT). Clandestine nuclear explosive production activities may take place, too. Still, it is not generally appreciated just how close Iran’s planned nuclear program brings that country to a bomb. And not only would these activities—entirely legal under the current interpretation of the NPT so long as the IAEA can inspect them—bring Iran to the threshold of a bomb, but to the capacity for producing large numbers of them.<sup>10</sup> This report will provide estimates of the formidable potential of the reactor and related fuel cycle facilities.

### **Brief Background to Iran’s Nuclear Program**

Iran was one of the first signers of the NPT. From the first, however, Iran exemplified the hypocrisies embedded in the Treaty. The Treaty started as an effort among non-nuclear states to stem the spread of nuclear weapons capabilities. In its final form it became a deal between the haves and have-nots—the have-nots would promise to forego nuclear weapons and allow the IAEA to inspect their nuclear facilities (a promise reversible on 90 days’ notice) in return for full access to all peaceful applications of nuclear technology just short of bombmaking. The Shah ratified the NPT in 1970 and soon after that started planning a grandiose nuclear power program that at one point included 23 nuclear power plants. It appears though that the Shah had more in mind than generating electricity and that he also started a secret nuclear weapons research program at about the same time.

All this came to a halt with the 1979 Islamic revolution and the Shah’s departure. The new rulers apparently revived nuclear activities in the mid-1980s, when reports once again reached the West of bomb-related interests on the part of Iran. Unlike Iraq, which tried (and failed) to produce nuclear explosives by means of a secret

nuclear weapons project outside of the “declared” sector subject to IAEA inspections, Iran has skillfully exploited the weakness of the NPT. There is nothing illegal from the point of view of the Treaty, for example, in separating plutonium from irradiated reactor fuel, or in producing enriched uranium, so long as the facilities are accessible to IAEA inspectors. Since obtaining the nuclear explosive material is the most difficult part of making a bomb, this permissiveness allows a would-be bombmaker to get very close to his goal. And since an illicit bomb design and manufacturing capability is relatively easy to hide—it does not involve nuclear materials—it can be prepared secretly in parallel with overt explosive material production, so that when the material is ready it can almost immediately be put to bomb use.

That is the assumption the IAEA uses, at least in principle, for the purpose of guiding the timing of its own inspections. Article 28 of the current IAEA-Iran agreement states the “timely detection” principle:

The objective of the safeguards procedures set forth in this part of the Agreement is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection.<sup>11</sup>

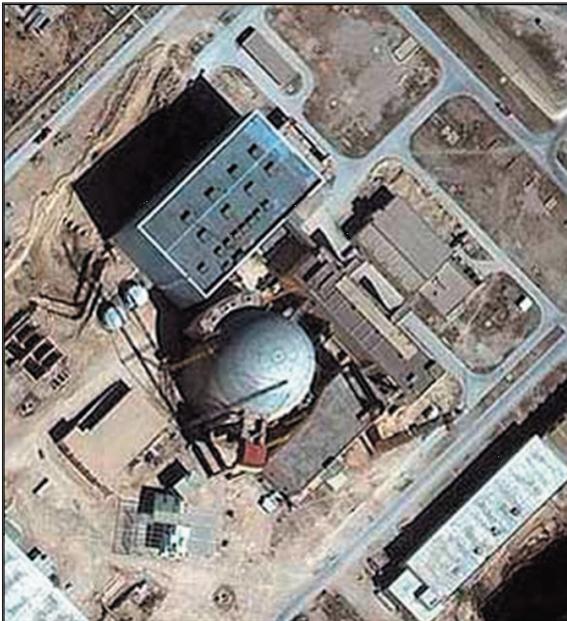
The IAEA estimates that once in possession of the explosive material, a country that is so inclined and has made the necessary preparation in design and manufacturing capability can produce bombs *in a week or two*.<sup>12</sup> Interestingly, the IAEA then sets a goal for inspection frequency for holders of such materials at a month, and even that goal is not met consistently. Obviously, the Agency has given up the ability to provide “early warning” of an attempt to make one or a small number of bombs, and has relied on the deterrence effect of its ability to detect a larger bomb manufacturing effort within a month or so of the start of bomb manufacture. The effectiveness of a deterrent based on such a delayed unmasking of a would-be bombmaker is very much open to question.

## Plutonium: Iran's Light Water Reactor at Bushehr.

The light water reactor that Russia is building for Iran, and of which Iran would like to get additional units, is a copious source of plutonium. This plutonium would not be difficult for Iran to extract. Too much has been made of the difficulty of reprocessing light water reactor (LWR) fuel, especially by a country with Iran's industrial base.<sup>13</sup>

The Bushehr nuclear power station based on the Russian LWR, with an electric generating capacity of 1,000 megawatts, is apparently nearing completion and the builders say it will be ready for fueling and testing within a year. Once it starts commercial operation it could produce—like any reactor of its type—about 250 kilograms of plutonium a year in the reactor's fuel. The significance of such an amount is obvious when one considers that the amount needed for a bomb is several kilograms.

To avoid accusations that they are helping the Iranians produce bombs, the Russians have said they have arranged to take back the reactor's spent fuel. In fact, they say they will *pay* Iran to get it back, which is a very unusual arrangement considered from a commercial



**Figure 1. Bushehr Light Water Reactor.**

point of view. Usually, operators of nuclear plants welcome any opportunity to ship it elsewhere. The fact that the Russians had to agree to pay for the spent fuel suggests the Iranians were not eager to get rid of it. The Iranians apparently forced the Russians to pay blackmail in order to revise their contract to one that would protect them against charges of contributing to weapons capabilities in Iran, which raises concerns all by itself. In any case, it is uncertain how such a spent fuel repatriation scheme would work and how effective it would be in the event the Iranians decided they wanted to stop shipping fuel to Russia. The arrangement has been thrown further into question by Iran's statement that it intends to acquire the capability to reprocess LWR fuel to extract plutonium, a capability it would not need to operate the nuclear units economically, and would have no use for if the spent fuel is to return to Russia.<sup>14</sup>

Despite the obvious plutonium production potential of the Bushehr reactor, the conventional concern about how Iran might obtain nuclear weapons has not centered on that plant. It has been that it might conduct a clandestine nuclear weapon program in the "shadow" of its civilian nuclear electric power program. For example, a Washington think-tank report on Iran, written in 2000, says the following under the heading of "Reactors and Proliferation":

It not clear that Iran's reactor purchases are meant to be an integrated part of Iran's nuclear weapons effort, as distinguished from a way of acquiring the necessary nuclear technology. The reactor design Russia is selling Iran produces only very limited amounts of plutonium, and no country has as yet used a similar reactor design to acquire fissile material.<sup>15</sup>

Central Intelligence Agency (CIA) congressional testimony at about the same time conveys pretty much the same message:

Work continues on the construction of a 1,000-megawatt nuclear power reactor at Bushehr that will be subject to International Atomic Energy Agency (IAEA) safeguards. This project will not directly support a weapons effort, but it affords Iran broad access to Russia's nuclear industry.<sup>16</sup>

Plutonium from Bushehr (in fact, from all LWRs) is more significant for weapons use than generally appreciated. A recent

Livermore report calculates that such a reactor can produce about 300 kilograms (about 50 bombs' worth) of near-weapon-grade plutonium produced by the first refueling—about 15 months after startup.<sup>17</sup> As mentioned earlier, the difficulty of extracting such plutonium from the radioactive spent fuel in which it is embedded has also been exaggerated. As put in an earlier 1995 Livermore report, the plutonium “can be separated from spent fuel with *modest facilities and equipment.*”<sup>18</sup>

The utility of bombs made from such near-weapons grade plutonium (“first cycle plutonium,” from LWR spent fuel removed after one normal operation cycle) does not differ much from that of so-called weapons grade plutonium. The difference comes from the higher content of the plutonium-240 isotope (14 percent in the first-cycle plutonium as opposed to about 6-7 percent in weapons grade). The plutonium-240 fissions spontaneously, thus releasing neutrons to start a premature chain reaction in the fissile plutonium-239 as it is compressed in a detonating warhead. The random plutonium-240 spontaneous fissions introduce an uncertainty in yield because the premature chain reactions do not produce the maximum yield. The same problem affects the weapons grade material, only to a lesser extent, at least at the relatively basic weapons design level we assume here.<sup>19</sup> (The problem more or less goes away in advanced weapon designs.) Calculations on the performance of near-weapons grade plutonium performed for NPEC show that—using technology not much beyond that of the first U.S. weapons—the probability is high of attaining yields above the low kilotons with this material. The mean yield would be about 10 kilotons and the probability of exceeding a yield of about 20 kilotons would be about one-third, more or less the yield of the bombs dropped on Japan.<sup>20</sup>

The previously cited 1995 Livermore report stated more generally that “reactor-grade (RG) plutonium, such as that produced in commercial power reactors (after three fuel cycles rather than one as assumed above and thus of lower utility), can be used to construct a nuclear weapon with a yield of “*at least a kiloton.*” The results cited here for the first-cycle plutonium describe performance considerably better than this.



**Figure 2. Enrichment Plant Construction.**

## **Uranium Enrichment.**

Iran is also developing uranium enrichment technology. It has pilot centrifuge facilities and has plans for building fairly large plants. Iran's claim is that it is interested in uranium enrichment for the production of LWR fuel. The centrifuges in the enrichment plants could also easily be reconfigured to produce highly enriched uranium.

It came as a surprise to the IAEA, and apparently to intelligence agencies as well, that Iran has a substantial uranium enrichment program. It took dissident groups within Iran to directed intelligence to a pilot plant at Natanz. The IAEA visited this plant and found a pilot facility using a cascade of more than 100 centrifuges. The IAEA officials reported seeing components for about another 1000 centrifuges. There are now public photographs available of a larger facility being built partially underground with two meter thick walls. It isn't clear whether the technology was an indigenous adaptation, or whether another country supplied it. An obvious candidate is Pakistan.

## **Weapons Significance of the Enrichment Facilities Iran is Building and Planning.<sup>21</sup>**

To get an idea of the scale of Iran's uranium enrichment capacity and its significance in terms of weapons, it is useful to consider

the enrichment capacity that is needed to support the refueling of a single large power reactor of the type the Russians are building at Bushehr. This requires a technical digression on the subject of enrichment as it applies here. Readers uninterested in the technical details can skim to the result without loss.

The core of a typical 1000 megawatt LWR such as the Bushehr reactor contains about 75 tons of low enriched uranium (LEU) fuel, a third of which is replaced at each refueling, about every 18 months. That means the requirement for fresh LEU fuel amounts to about 17 tons per year. Such LWR fuel is typically enriched to about 3-4.5 percent in uranium 235. (Recall that natural uranium contains about 0.7 percent uranium-235, the rest being uranium-238.) For the purpose of this calculation let us assume the fuel enrichment is 3.6 percent uranium-235.

Enrichment capacity is expressed in units of “separative work units” (SWU)-kilograms per year, or sometimes in tons SW per year. (These kilograms and tons are *not* amounts of material—unfortunately a somewhat confusing point.)

To produce 17 tons of 3.6 percent LEU fuel requires about 75 tons of separative work per year.<sup>22</sup> The separative work requirement is not precise because it depends on how the enrichment plant is run. This result assumes that the plant feed is natural uranium at 0.7 percent uranium-235 and that the “tails assay,” the enrichment of the rejected material, is at 0.3 percent uranium-235. By raising the tails assay, by “skimming the cream” of a larger amount of feed material, one can reduce the amount of separative work required.

The total enrichment capacity of the plant is the sum of the individual enrichment capacities of the components—in this case, centrifuges. If we assume a nominal individual centrifuge capacity of 5 kilograms of separative work per year (or 5 SWU per year), such a plant would contain about 15,000 centrifuges. This is roughly in the range, within a factor of two or three, that the Iranians seem to be talking about for the large plants that are in the initial stages of construction.

Now consider how much highly enriched uranium such a plant could produce if the centrifuge cascade—the grouping of individual centrifuges—is reconfigured for that purpose. A similar enrichment

calculation, assuming natural uranium feed and a 0.3 percent tails assay, shows that the same plant reconfigured could produce nearly 400 kg of 90 percent uranium-235, say 20 bombs' worth, per year.<sup>23</sup>

### **Using LEU as Feed Material Reduces Need for Enrichment Capacity.**

Even more interesting is the possibility of using LEU as feed, that is, starting with uranium already enriched to, say, 3.6 percent rather than starting with natural uranium. Such low enrichment uranium could be either material imported for fueling LWRs or material previously enriched in Iran. Perhaps counter-intuitively, it turns out that most of the separative work to obtain HEU is already done in bringing natural uranium to the level of LEU because there is so much material to deal with at the lower enrichment levels. It turns out that if one starts with LEU feed, the nearly 400 kilograms of HEU per year (at about 90 percent uranium-235) could be turned out by an enrichment plant with a capacity of slightly over 15 tons SW/yr, or about *one-fifth* of the capacity needed for starting with natural uranium feed. This calculation assumes a 1.5 percent tails assay and therefore 16 tons of LEU feed per year, or about the amount of LEU needed annually to fuel a reactor of the Bushehr type. With a lower tails assay the separative work requirement would go up but the feed requirement would go down, and similarly for the reverse.

The separative work requirements scale with the amount of product. Starting with LEU, a smaller quantity of HEU, say, 100 kilograms of HEU per year, enough for about five nominal bombs per year, could be produced by a plant with an enrichment capacity of less than 4 tons of separative work per year. With the same assumptions as used previously that would amount to less than 1000 centrifuge units, roughly the level of equipment that the IAEA inspectors saw on hand in the form of components in a recent visit to Iran.

### **Summary: Iran's Two "Legal" Paths to Nuclear Explosives.**

To summarize, the technical possibilities, all "legal" under the NPT, include both plutonium and highly enriched uranium. In terms

of physical capability, once Bushehr is operational, which is slated for the end of 2004, Iran would have the possibility of using the Bushehr reactor plus a reprocessing capability it would have to develop. That could give it a bomb capability to produce dozens of warheads, though likely no earlier than, say, 2006. Another possibility, in light of Iran's construction of a heavy water plant, would base a military plutonium production capability on a heavy water reactor, but that could only come to fruition several years later.

The other, or possibly complementary, course would be based on highly enriched uranium produced in centrifuge plants, either the known plants or clandestine ones. A very small facility involving, say, 1,000 machines of modest capability, that could probably be hidden effectively, could produce several HEU warheads a year. If Iran made full use of a larger facility of the sort it appears to be building, the bomb production capacity would scale accordingly.

Of course, either course would involve treaty violations from which would follow diplomatic and possibly military consequences. The violation would not be mitigated by a withdrawal from the treaty. A country cannot legally gain the fruit of treaty adherence by accumulating the wherewithal for a bomb and then withdrawing. (That reflects a standard principle in contracts, but it would be helpful if the NPT members would say so explicitly.)

### **Changing the System of Protection in Terms of Allowable Technology, Inspections, and Enforcement.**

Iran illustrates the vulnerabilities of the current international system of protection against proliferation. A major difficulty is that the present international norm is too permissive. The NPT has been read to say that all technologies and materials are acceptable so long as the owners declare them to be peaceful and allow IAEA inspection. But we know it is dangerous to allow members to get arbitrarily close to a bomb, or to have nuclear explosives around that others could steal. So we have tried to plug the holes in the treaty with various export controls over what we delicately call "sensitive" technology. Yet if North Korea had not been so foolish as to cheat, but instead had let the IAEA watch its pre-1992 reprocessing, there would not have been grounds for objection, at least under

the treaty. Iran has taken a more sophisticated approach and is cleverly exploiting the weaknesses of the NPT. We cannot keep our fingers in the nuclear dike forever. We need a rule that limits what is acceptable in terms of civilian nuclear power technology to that there is a greater safety margin between it and possible military application. It will likely have to be a common rule applicable to all. That may sound unrealistic, but the alternative is unsustainable.

The once-through LWR fuel cycle is sometimes called “proliferation-resistant.” It is a considerable improvement, in terms of security, over some of the alternatives, but it has its problems, too, and requires a very tight system of inspection, at least in suspicious places. At a minimum we need the upgrading in IAEA inspections that would follow from adoption of the “Additional Protocol” that most countries have signed and Iran has resisted.

Improved inspection will not be worth much as a deterrent unless behind it is a credible and effective reaction to violations. It used to be said years ago that, whatever the deficiencies of IAEA inspections, if there was ever a serious violation, there would be an immediate and tough international response. We have discovered enforcement is a complicated matter and there are always reasons to hold off. Consider the North Korean affair that has dragged for over 10 years after the IAEA found a serious violation. A chief problem is that the NPT has no enforcement mechanism so the matter is left to individual members. We need some kind of permanent international arrangement.

## ENDNOTES - CHAPTER 2

1. State Department briefing, May 9, 2003. <http://www.state.gov/r/pa/prs/ps/2003/20439.htm>.

2. Highly enriched uranium (HEU) is uranium enriched in the isotope uranium 235 (the fissile fuel and explosive). For weapon use the proportion of uranium 235 has to be over, say, 80 percent. Natural uranium contains only about 0.7 percent uranium 235 and about 99.3 percent uranium 238. The uranium 238 is more or less inert in this context but when irradiated by neutrons, as it would be sitting in an operating power reactor, it can get turned into plutonium 239, the other nuclear explosive. Water-cooled power reactors use low enriched uranium (LEU) fuel with about 4 percent uranium 235. Most of the world’s LEU is enriched in large plants in the United States, Russia, and Europe. The water-cooled reactors

are called LWRs, or light water reactors, to distinguish them from heavy water reactors.

3. U.S. intelligence apparently first learned of previously secret nuclear facilities—including a uranium enrichment plant at Natanz based on centrifuge technology—from an Iranian opposition group. If that is correct, it raises questions about the quality of U.S. intelligence.

4. *Reuters* dispatch from Tehran, June 12, 2003. “In a confidential report obtained by *Reuters* in Vienna last week, the IAEA said it had requested permission to take samples at a workshop at Kalaye where Iran had admitted to constructing components for centrifuges designed for enriching uranium.”

5. *Reuters* report from Vienna, June 15, 2003.

6. IAEA Safeguards factsheet, [http://www.iaea.org/worldatom/Periodicals/Factsheets/English/S1\\_Safeguards.pdf](http://www.iaea.org/worldatom/Periodicals/Factsheets/English/S1_Safeguards.pdf).

7. The Text Of The Agreement Between Iran And The Agency For The Application Of Safeguards In Connection With The Treaty On The Non-Proliferation Of Nuclear Weapons, entered into force on May 15, 1974. Article 42, contains the following:

Pursuant to Article 8, design information in respect of existing facilities shall be provided to the Agency during the discussion of the Subsidiary Arrangements. The time limits for the provision of design information in respect of the new facilities shall be specified in the Subsidiary Arrangements and such information shall be provided as early as possible before nuclear material is introduced into a new facility.

8. *United Press International*, Tehran, Iran, May 30, 2003. Iranian Foreign Minister Kamal Kharrazi said on Friday Iran would sign the Additional Protocol pertaining to the International Atomic Energy Agency if sanctions against it were lifted and nuclear technology for peaceful purposes was put at its disposal, the official Islamic Republic News Agency reported.

9. For background on the Iranian nuclear program, see Nuclear Threat Initiative web site at [www.nti.org](http://www.nti.org). The CIA addresses the issue of the possibility of an Iranian nuclear weapons program in a periodic report to Congress. A recent edition contained an increased appreciation of the significance of Iran’s planned fuel cycle facilities: *Unclassified Report to Congress on the Acquisition of Technology Relating to Weapons of Mass Destruction and Advanced Conventional Munitions, July 1 Through December 31, 2001*, CIA, January 2003.

10. In this connection, a June 11, 2003, *Reuters* report from Tokyo states “Iranian experts on nuclear issues secretly visited North Korea this year, possibly to ask North Korean officials for advice on how to handle international inspectors, a Japanese newspaper said on Wednesday.”

11. The Text Of The Agreement Between Iran And The Agency For The Application Of Safeguards In Connection With The Treaty On The Non-Proliferation Of Nuclear Weapons, Entered Into Force on May 15, 1974.

12. IAA Safeguards Glossary (2001), p. 22. See *www.iaea.org*.

13. The issue arose in the context of the U.S.-supplied LWRs for North Korea (built and mostly paid for by South Korea) that were part of the 1994 U.S.-DPRK Agreed Framework, and which in many ways parallel the Russian-supplied LWR for Iran. The State Department decried the Russia-Iran deal but defended the U.S.-DPRK one, ultimately on the claim that the DPRK wouldn’t be able to extract the plutonium produced in the LWRs, a pollyannaish assumption.

14. Khatami speech February 9, 2003.

15. A. H. Cordesman, “Iran and Nuclear Weapon,” Center for Strategic and International Studies (CSIS) report, 2000. This report, available at <http://www.csis.org/mideast/reports/irannuclear02072000.pdf>, contains a good deal of interesting background.

16. Statement by John A. Lauder, Director, DCI Nonproliferation Center to the Senate Committee on Foreign Relations on Russian Proliferation to Iran’s Weapons of Mass Destruction and Missile Programs, October 5, 2000.

17. Livermore, 2000.

18. 1995 Livermore report: “Extraction and Utility of Reactor-Grade Plutonium for Weapons” (U) (see for example, [http://www.thoriumpower.com/files/tech\\_percent20plutoniumblications/reactor\\_plutonium.pdf](http://www.thoriumpower.com/files/tech_percent20plutoniumblications/reactor_plutonium.pdf)).

19 The first plutonium weapons—Trinity and Nagasaki—got around this by using plutonium that had only about 1 percent plutonium-240, which means it was extracted from uranium fuel that had been lightly irradiated. Even then, there was some slight chance that the weapon would produce a low yield.

20. The design improvement amounts to, in effect, a doubling of 1945 bomb assembly speed. Sixty years later, that should be within the capabilities of first-time entrant into the bomb club.

21 See, for example, [http://www.urengo.de/trennarbeit/swucal\\_e.html](http://www.urengo.de/trennarbeit/swucal_e.html).

22. Not to be confused with the mass of the uranium core which happens to have the same figure.

23. The exact number is 388. The figure is rounded to 400 because the numbers are all approximate. The bomb equivalent assumes a nominal 20 kg of Uranium-235 per warhead.