ASSURING EFFECTIVE IAEA VERIFICATION OF THE IRAN - P5+1 AGREEMENT[1]

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Prepared with support from SEARCH FOR COMMON GROUND *and* THE PRINCETON UNIVERSITY PROGRAM ON SCIENCE AND GLOBAL SECURITY

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1 An article entitled: "The Verification Challenge: Iran and the IAEA" based on this report was published in the June 2015 issue of Arms Control Today.

ABOUT THE **AUTHOR**

Dr Thomas E Shea served for 24 years in the IAEA Department of Safeguards, helping to design the safeguards system, develop implementation arrangements for enrichment plants and research/isotope production reactors, reactor fuel manufacturing plants, reprocessing plants and power reactors employing HEU and plutonium fuels. Shea supervised inspections at facilities in Japan, China, India, Indonesia and other countries.

After retiring from the IAEA, Shea served as Sector Head, Defense Nuclear Nonproliferation Programs at Pacific Northwest National Laboratory. He is now an independent consultant.

Dr Shea received an AEC Special Fellowship and an AEC Laboratory Fellowship. He received his PhD in nuclear science and engineering from Rensselaer Polytechnic Institute. He was awarded the Institute of Nuclear Materials Management Distinguished Service Award and is an Emeritus Fellow of that Institute.

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FOREWORD

The genesis of this study by Dr. Thomas Shea of the capabilities of the IAEA to monitor the terms of an agreement between Iran and the P5 nations plus Germany was a suggestion made well over a year ago by a senior US senator. The senator expressed the view that support for an agreement in Congress would center on its perception of the ability of the IAEA to effectively monitor Iran's activities. If, for any reason, Iran violated its agreement to confine its activities in the nuclear field to peaceful uses, the United States and the international community would have to be able to take steps in time to respond appropriately and effectively.

It is also widely understood that, alongside the IAEA's own extensive capabilities, the intelligence services of the United States and at least 10 other countries contribute information to the monitoring and verification tasks that will arise from the agreement with Iran.

The choice made by Search for Common Ground and the Princeton University's Program on Science and Global Security of Tom Shea as the principal author of the following study was made on the basis of Shea's impressive credentials. He possesses a substantial academic background in nuclear physics and engineering, spent 24 years in the IAEA as an inspector and key figure in developing the formidable IAEA safeguards program, and conducted cutting edge work at US laboratories on arms control issues. Dr. Shea is highly respected by his colleagues and throughout the arms control community for his objectivity, intellectual rigor, competence, and leadership experience throughout his 45-year career.

We are grateful to Dr. Shea for his generous response to our request for an assessment of the IAEA's legal authorities, structure, operational history and technical ability to verify the agreement between Iran and the P5+1 concluded on July 14th, 2015. We also thank the Ploughshares Fund, the Rockefeller Brothers Fund, Rockefeller Family and Associates, and the New-Land Foundation for their generous support for this project.

We hope that this report proves useful as an independent technical resource during this time of deliberation. We intend to distribute it to the Congress of the United States and to all interested parties and individuals.

Ambassador William Green Miller
Search for Common Ground

Professor Frank von Hippel
Princeton University

PREFACE

I have worked my entire 45-year professional career in nuclear safeguards, including nearly 25 years at the International Atomic Energy Agency (IAEA). In that time, efforts to stop proliferation have been driven by many considerations. Chief amongst these is the fact that no two real-world situations are ever the same.

Now, negotiators have presented the Joint Comprehensive Plan of Action (JCPOA), an accord under which Iran will scrap or mothball much of its nuclear infrastructure, agree to unprecedented limitations on what it can and can't do, and open its doors to the most intensive, intrusive verification ever implemented. It is true that in Iraq, IAEA inspectors had free reign to go anywhere they wished, anytime, and with no advance communications. However, Iraq accepted these arrangements following its unconditional surrender to end the first Gulf War. The JCPOA, on the other hand, is a negotiated settlement, now endorsed unanimously by the UN Security Council.

Having led the negotiations on behalf of the other P5 states and Germany, the JCPOA is an American victory, and also a victory for China, France, Germany, Russia and the United Kingdom. As a negotiated settlement accepted fully by Iran, it is also Iran's victory, as it should be. All of the parties can now celebrate and begin the complex process of implementation with both a commanding sense of optimism and a wary eye.

For the reasons laid out in the report that follows, I enthusiastically support this stunning accomplishment. I am confident that the IAEA will carry out its mission with its usual emphasis on objective science and diplomacy. I am confident that the international community will continue to provide the political, financial, technological and operational support needed for the IAEA to succeed, and that, pursuant to Article VIII.A of the IAEA Statute, member states will continue to provide information to the IAEA that will help it carry out its verification mission.

More than this, I believe that this marks the end of the era in which sovereign states chose to pursue nuclear weapons, with all too many successes. Provided the will of the international community remains intact and verification mechanisms continue to improve, should another state be tempted, it will simply not be able to succeed.

With this milestone, the world can now look with increased expectation to progress toward the eventual elimination of the nine existing nuclear arsenals.

Thomas E Shea

EXECUTIVE SUMMARY

On July 14, 2015, the United States, China, France, Germany, Russia and the United Kingdom concluded a Joint Comprehensive Plan of Action (JCPOA) with Iran. Under this Plan, Iran will limit its nuclear program so as to maximize the warning time the international community would have if Iran decided to develop nuclear weapons. Iran also will accept enhanced IAEA monitoring so that the international community will be able to know whether or not Iran is living up to its agreements. Iran also has committed to respond promptly to the IAEA's questions about past activities that suggest that Iran was exploring the development of nuclear weapons. Assuming the Director General reaches a favorable finding, the sanctions imposed on Iran will be phased out as Iran implements the terms of the agreement.

VERIFICATION BY THE IAEA

The International Atomic Energy Agency (IAEA) will be responsible for verifying the new agreement with technical and intelligence support from its member countries. The IAEA will have access to Iran's declared nuclear activities under the comprehensive safeguards agreement that all 186 non-nuclear weapon states parties to the NPT are required to conclude. Iran also has agreed to comply with the Additional Protocol, under which it will have to provide the IAEA with information on all of its nuclear-related activities and allow the IAEA access to check that those declarations are complete and correct. Finally, under the JCPOA, Iran has agreed to provide the IAEA with routine access to verify key nuclear activities that do not involve nuclear materials, including Iran's production and storage of centrifuges.

In addition, to these on-site verification activities, the IAEA receives relevant intelligence from its member states, including the United States, is open to receiving information from non-governmental organizations and will acquire and analyze satellite images of sites of potential concern in Iran.

If the IAEA becomes concerned about any activities in Iran, its inspectors will first seek clarification. If they are not satisfied by the response, they will refer the issue to higher level IAEA officials and ultimately to the Director General who can request a response from the highest government levels in Iran. Finally, if the Director General is not satisfied, he can refer the matter to the IAEA's Board of Governors (BOG) and the

BOG can refer it to UN Security Council as the IAEA did in 2006 when Iran decided to end its suspension of its enrichment program.

The IAEA will organize its verification strategy by considering the steps that Iran would likely take if it were to decide to pursue nuclear weapons.

The IAEA's verification activities will:

1. Search for any clandestine installations or undeclared nuclear material that could support nuclear weapon related activities, including undeclared plants for producing fissile material and weaponization facilities.
2. Check that declared peaceful nuclear facilities are used solely for peaceful activities and that all operations in those facilities are declared to the IAEA.
3. Assure that nuclear materials subject to IAEA safeguards are not diverted for the manufacture of nuclear weapons, other nuclear explosives, or for any purpose unknown.
4. Verify that Iran does not import equipment or material except as provided in the agreement.
5. Verify that Iran is complying with the limitations on its nuclear program that it committed to under the terms of the JCPOA.

DETECTION OF CLANDESTINE FACILITIES

The most critical and challenging task for the IAEA will be the detection of clandestine facilities. Intelligence sharing by member states will amplify the Agency's limited in-house capabilities. States share information with the IAEA because the agency can pursue evidence of clandestine activities on the ground, using its legal authorities.

The Additional Protocol provides a means for the IAEA to request "complementary access" when it has questions it needs to resolve about non-declared sites. The JCPOA dictates that the maximum time for Iran to agree to an IAEA request for access or satisfy the Agency's concerns in some other way will not exceed 24 days. Even before contacting Iran, the IAEA would start by ordering satellite imagery, perhaps continuing throughout the investigation, and by seeking corroborating information, especially from states willing to share intelligence.

POSSIBLE MILITARY DIMENSIONS

The JCPOA also requires the Director General of the IAEA to make a conclusory report on the "possible military dimensions" of Iran's past nuclear activities by the end of 2015. This step will enable the next phase of implementation to begin, in which most of the sanctions imposed on Iran will be lifted. The Director General will likely conclude that the IAEA has gained a full understanding of Iran's past activities and supports full implementation of the JCPOA.

CONCLUSION

The IAEA has been preparing for its Iran verification role since it first opened for business in 1957, and it will be up to the task.

The IAEA's capabilities have been extended, strengthened and refined over the years in response to real-world proliferation cases in Iraq and North Korea. Its current capacity reflects the international community's decades-long investment in the organization, and the continuing commitment of states around the world to its mission. Unlike the pre-Iraqi nuclear watchdog, the IAEA is now more like a focused information hub, wired to a host of information generating nodes that regularly update what the IAEA knows.

The IAEA will be scrupulously precise, scientific, tactful and demanding in reaching its conclusions, as it is in all states. It will examine all information made available to it, promptly and fairly, and insist on the immediate resolution of any discrepancies or anomalies. Ever mindful of its immense responsibilities, the IAEA will inform the global community should it be convinced that Iran's compliance with its obligations is in doubt, or if Iran hinders verification activities by failing to cooperate and assist the IAEA.

Assuming that the IAEA continues to receive the political, technical, financial and operational support from the international community necessary for its success, and that regional strife does not impede its ability to put its inspectors on the ground, the Agency can and will be able to accomplish the tasks it has been assigned under the JCPOA. It will be able to verify the agreed operational limits on Iran's nuclear programs, and, if the need arises, the IAEA will sound the alarm in time for decisive action to be taken.

FREQUENTLY ASKED QUESTIONS

Together with colleagues from Search for Common Ground, during the week of July 13th, I was able to discuss the merits and potential issues of the JCPOA with numerous Senators, Representatives and staff members that inform the legislative process. I made presentations at events hosted by the Atlantic Council and the Arms Control Association, appeared on CSPAN and MSNBC and was interviewed on NPR. Here are brief answers to ten of the most common questions relating to the agreement and the IAEA's role in verifying Iranian compliance with its requirements:

1. ***In what ways does the JCPOA go beyond the Additional Protocol (AP)? What happens to the JCPOA over time?***

The JCPOA is a comprehensive deal incorporating a renewed pledge by Iran to never acquire nuclear weapons, plus a raft of reductions in its existing capabilities and acceptance of the strongest negotiated verification system ever.

The AP is one of the verification agreements that the IAEA will use to investigate allegations of clandestine nuclear activities in Iran. The JCPOA includes a maximum limit of 24 days to implement the necessary means for the resolution of the issue (a time limit not included in the AP), and the JCPOA includes the right to verify the limits accepted by Iran (on its enrichment capability, low enrichment uranium, inventory, and its production of new centrifuge machines). The JCPOA will cease to have effect at a time specified in UNSCR 2231. However, the comprehensive IAEA Safeguards Agreement and the Additional Protocol will remain in force indefinitely.

2. ***How does the 24-day timeframe for access work? How does this 24-day limit go beyond the implementation of the Additional Protocol in other states? Could this delay prevent discovery of weaponization activities? What measures will the IAEA take in the meantime to make sure that Iran does not cover up suspected activity?***

The AP provides a means for the IAEA to request "complementary access" when it has questions it needs to resolve. There are no restrictions on where it can go, but the IAEA must identify specific questions to be resolved and identify specific locations where it wants to send its inspectors. Importantly, providing the inspected party, in this case Iran, with this information must not help them evade detection or stall the investigation.

There are currently 121 countries that have an AP in force, and 78 complementary accesses were carried out last year. Only in Iran is there a cutoff on how long it can delay before the inspectors show up. The clock starts when a request is made through an established communications channel. It is possible that there will be no delay, and that in response to a request for urgent access by the IAEA, Iran will open the site for immediate inspection. In any case, the IAEA will immediately begin monitoring a site once it becomes suspicious by ordering advanced satellite imagery, perhaps continuing to secure satellite imagery through the investigation, and by seeking corroborating information, especially from States willing to share intelligence information.

When a request involves a building, and especially when it involves uranium (or plutonium), 24 days will generally not be long enough to carry out remediation activities that could prevent detection. Where there is evidence of recent painting or installation of new surfaces, if the results of the first inspection are inconclusive, the IAEA could request scraping away some of the newly applied surfaces for a second round of environmental sample taking, and if deemed necessary, could request core samples to be taken by drilling into the renovated surfaces. It might also install portable air and effluent sampling to find remaining traces of past activity.

To be certain, some activities associated with manufacturing nuclear weapons resemble activities for other purposes. Nevertheless, taking into account all of the actions needed, the JCPOA provides robust opportunities for the IAEA to detect a resurgent nuclear weapons program, should Iran opt to take its chances.

The JCPOA also calls for frequent reports to be provided to the IAEA Board of Governors, and to the Security Council. These reports will provide information on Iran's observance of the provisions of the JCPOA.

In any case, it is unlikely that a grave concern of the IAEA would require 24 days to be resolved; the international community would push for appropriate action immediately, not waiting the 24 days outlined in the JCPOA.

3. ***What is managed access?***

If complementary access is requested for a sensitive location, such as a military base or a high-tech factory with intellectual property to protect, Iran will be able to request that the complementary access be carried out in such a way as to allow the inspectors to gather only the information they need to satisfy their specific request – but not to look around and learn other things that they don't need to know. All APs include this provision, but it is ultimately up to the IAEA to determine if the access meets its requirements. Depending on the circumstance, Iran might want to move military equipment, transport the inspectors to the exact location they've requested in a vehicle with no possibility for the inspectors to see what's around them, and cover sensitive items with tarps, for example. The inspectors must be able to establish that they are at the specific location they have requested by various means, including GPS navigation.

4. ***How does the IAEA deal with intelligence sources from member states/ interested parties? How does it verify this information and how does it protect sensitive information?***

Article VIII.A of the IAEA Statute encourages member states to provide information to the IAEA that the state believes will help the IAEA carry out its responsibilities. The IAEA is free to receive any sensitive information that a state is willing to provide, and handles it with great discretion. The IAEA has a mechanism for classifying information as "SAFEGUARDS CONFIDENTIAL" with different degrees of control depending on the nature of the information. Access is restricted to staff members authorized on a 'need-to-know' basis.

The IAEA may request intelligence, or a state might offer it. It is understood and accepted that the IAEA can receive such information, but the IAEA is not permitted to share its findings other than through official channels, e.g., periodic reports to the Board of Governors.

Recalling that bogus intelligence information was provided to the IAEA during its investigation of Iraq, the IAEA exercises due diligence to avoid being misled in order to advance a political agenda.

5. ***How does the IAEA identify clandestine facilities?***

A suspicion may begin from any one of a number of indicators, possibly from IAEA activities or possibly from an external source. Once begun, the process of seeking clues and evidence continues until the IAEA feels that requesting a complementary access under the AP is warranted. The main method used is visual observation by trained inspectors, coupled with relevant aids, including environmental sampling.

6. ***What is the IAEA Iran Task Force?***

The IAEA's Iran Task Force is unique in that, because of the great importance assigned to Iran, a special group has been formed that is effectively isolated from normal inspection practice. The task force staff now numbers just under 50, about half of whom are inspectors only doing inspections in Iran, and analysts that report to the head of the Task Force rather than to their normal supervisors.

Under the JCPOA, the IAEA will be permitted to authorize between 130-150 inspectors to work on the ground in Iran. The number of inspectors the IAEA actually needs to have on the ground in Iran will include a baseline associated with inspecting declared facilities plus inspectors resolving questions. The numbers will vary, high at the outset and tapering off as the IAEA transitions to a broad conclusion that Iran is complying with the JCPOA.

7. ***How and when does the IAEA send inspectors to Iran? Who are they? What nationalities?***

Inspection teams will be flying from Vienna to Iran probably several times a week. They may stay for a day or longer, but typically less than a month. The work load under the JCPOA will be significantly larger than before, mostly to resolve the many questions that the Iranian AP declaration will generate. As the JCPOA kicks in, one can expect to see a more predictable routine develop.

Inspectors are trained scientists and engineers, and many hold masters degrees and PhDs. By nationality, they may come from any of the 176 IAEA member states. Iran, and all other parties to the NPT, can legally refuse inspectors on an individual basis because of nationality, religion, or any other reasons. The state need not provide an explanation. The inspectors have to be acceptable to Iran; Americans and nationals of other states with whom Iran does not enjoy diplomatic relations are not - at least for now.

Under the deal, Iran needs to provide the IAEA with areas to work near nuclear sites and multiple entry visas.

8. ***Does the IAEA have adequate funding to complete the outlined monitoring and verification activities, and if not, how much will it need? What does the US contribute in terms of budgeting and staffing?***

No doubt they are sharpening their pencils in Vienna now that the JCPOA is official. Expect a request of something on the order of $10 million extra per year, on top of the current safeguards budget of $143 million. The IAEA spent 12.5 million euros on implementation of the interim deal in 2014. Still a bargain: the Washington, D.C. police budget is $514 million.

The United States pays 25% of the total budget of the IAEA. A few years ago, the U.S. cut its payment to 22% for most UN organizations, but the IAEA is important to U.S. national security, so it gets the maximum 25%. This is in addition to extra-budgetary contributions to help the IAEA maintain its cutting-edge capabilities. In 2014, the United States provided extra-budgetary contributions for safeguards implementation totaling about 24 million euros. Budget increases require consensus approval by the Board of Governors, and even with the backing of the P5 and Germany, it could still take some time before whatever added funds are requested show up in the bank.

9. ***What steps could Congress take to help this effort succeed?***

The U.S. Congress should provide a contingency fund of $50M to enable the IAEA to fully implement the JCPOA without cutting back on inspections in other states.

While the budget contributions could allow ¼ of the staff to be American, the U.S. has given up 5% of its allocated positions to developing countries. However, the current American representation is significantly less. Americans cannot carry out inspections in Iran, but they can and do serve as analysts and can become inspectors for other countries. Congress should look to provisions that could facilitate assignments from the DOE national labs, federal agencies, nuclear industry, nuclear technology companies, and from academia.

Additionally, up to now, IAEA reports on Iran have been released to the public, and this practice should continue in the future.

10. ***What would happen to the deal and its verification system if Congress succeeds in blocking implementation?***

If Congress disapproves of the JCPOA and overrides a veto from President Obama, and if that process ends up actually blocking the JCPOA, then the outcome will be dire:

- Iran would be free of any limits on its nuclear capabilities, and judging from what happened in the last decade, would continue to increase its potential nuclear weapon capabilities and decrease the time it would take to build a nuclear weapon;
- The current sanctions regime would be destroyed and it is extremely unlikely that the U.S. could reassemble the coalition of states that has been effective in encouraging Iran to make the compromises it agreed to in the JCPOA;
- The international nonproliferation regime would suffer a severe blow, undermining the stability of the NPT as the foundation for international security; and,
- Iran would reject additional monitoring of its program, and the risk of yet another unnecessary, costly, bloody war in the region would grow.

1. INTRODUCTION TO THE IAEA

On July 14th, the following statement announced the successful conclusion of the prolonged negotiations on Iran's nuclear program.

> *"The E3/EU+3 (China, France, Germany, the Russian Federation, the United Kingdom and the United States, with the High Representative of the European Union for Foreign Affairs and Security Policy) and the Islamic Republic of Iran welcome this historic Joint Comprehensive Plan of Action (JCPOA), which will ensure that Iran's nuclear programme will be exclusively peaceful, and mark a fundamental shift in their approach to this issue. They anticipate that full implementation of this JCPOA will positively contribute to regional and international peace and security. Iran reaffirms that under no circumstances will Iran ever seek, develop or acquire any nuclear weapons."*[2]

The International Atomic Energy Agency (the IAEA) will be responsible for verifying the JCPOA. The IAEA has suspected for decades that Iran was engaging in activities in support of a nuclear weapons program, and its governing body, the Board of Governors, has determined that Iran has been in non-compliance with its safeguards agreement obligations.[3]

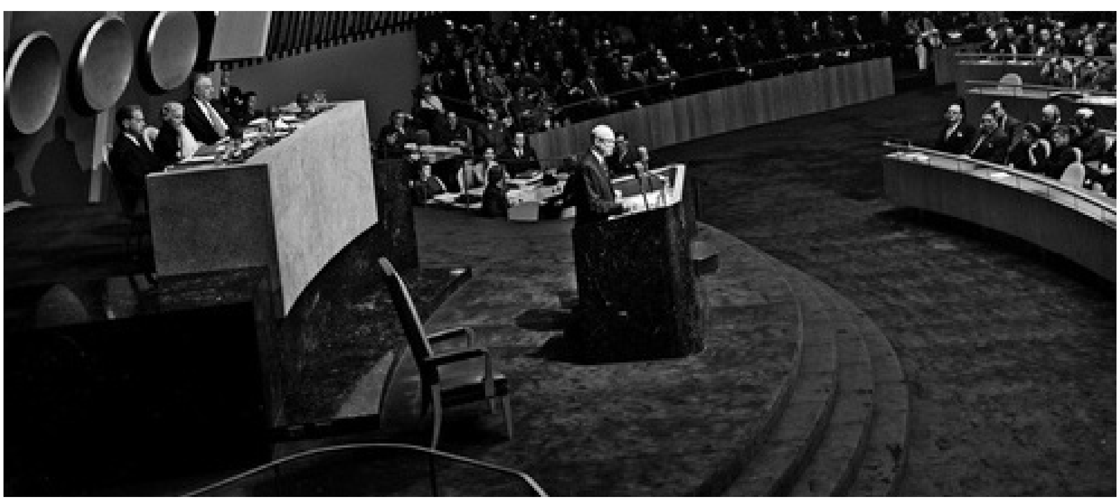

FIGURE 1. U.S. President Dwight Eisenhower proposed creating the IAEA when he addressed the United Nations General Assembly in December of 1953. Photo: United Nations

2 See, for example, http://eeas.europa.eu/statements-eeas/docs/iran_agreement/iran_joint-comprehensive-plan-of-action_en.pdf

3 An IAEA chronology provides a record of key events since 2002 in Iran. See: https://www.iaea.org/newscenter/focus/iran/chronology-of-key-events

This report examines how IAEA verification will be carried out under the JCPOA. To get to that point, this report looks at the IAEA, how its safeguards function, how it is likely to view the possibility that Iran has already achieved significant progress in making nuclear weapons, what it will concentrate on in Iran, what technical means will be applied, what authority it has now, what additional authority it will gain as a result of the new agreement, and how the IAEA would deal with suspected violations.

America's monopoly on nuclear weapons lasted from 1945 until 1949, when the Soviet Union carried out its first test, followed in 1953 by the United Kingdom. Eisenhower's proposal in 1953 to create the IAEA was not the first suggestion to reign in nuclear proliferation, but the earlier proposals were too ambitious and were not accepted.

In 1955, the four powers agreed that Austria would become a neutral state and sent the American, British, French and Russian occupation forces home. Two years later, the IAEA opened for business in Vienna. It operated out of a rented space in the city until Austria completed the new IAEA headquarters and turned it over to the UN for a token annual fee of a few cents.

FIGURE 2. The Vienna International Centre became home for the IAEA in 1979. *Photo: IAEA*

The IAEA has two objectives:

> *"The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose."*[4]

While the IAEA is a member of the UN family, it has its own membership and its own budget. In relation to the first objective, the IAEA carries out voluntary programs at the request of the member states in nuclear power, peaceful applications of radioactivity,

4 See the IAEA Statute, Article 2: https://www.iaea.org/about/statute#a1-2

nuclear safety and security. It has a 'technical cooperation' program intended to allow developing countries to benefit from these programs.

As an independent organization, the IAEA has its own Statute, which states accept when they become member states. The IAEA is governed by two bodies, an annual General Conference of all member states (currently 176), and a Board of Governors (BOG) comprising 35 representatives, some permanent, some alternating. The Director General, who is elected by the Board of Governors to serve a four-year term, heads the Secretariat of the IAEA. Currently, Japanese diplomat Yukiya Amano is Director General.

Below the Director General, the work of the IAEA is organized in six departments: Management, Technical Cooperation, Nuclear Energy, Nuclear Safety and Security, Nuclear Sciences and Applications, and Safeguards. The Safeguards department is the largest, with approximately 800 of the total 2556 IAEA staff. The regular IAEA budget for 2014 was 344 million Euros, about $373M at today's exchange rate.[5]

The safeguards department is headed by the Deputy Director General, currently, the Finnish nuclear expert, Tero Varjoranta. The safeguards department has seven divisions: three divisions of inspection covering the world; an in-house concepts and planning think-tank; a division of information management that handles safeguards data (including state accounting reports and all inspection results); a division of technical support, which manages R&D and the procurement and maintenance of more than 100 approved safeguards systems; and a division of analytical services that operates a world-class analytical laboratory for nuclear material samples and environmental samples crucial to detecting proliferation. The verification budget for 2014 was 132 million Euros, or about $143M.

5 https://www.iaea.org/about/budget

2. LEGAL AUTHORITY FOR IAEA INSPECTIONS IN IRAN

Legal authority for IAEA verification in Iran includes the existing safeguards agreement, Iran's Additional Protocol (AP) and new authority from the UN Security Council Resolution implementing the JCPOA.

COMPREHENSIVE IAEA SAFEGUARDS AGREEMENT

Iran's comprehensive safeguards agreement entered into force on 15 May 1974,[6] predating the 1979 revolution and the creation of the Islamic Republic of Iran. Iran's safeguards agreement is published in INFCIRC/214, which is based on INFCIRC/153, a document adopted by the IAEA Board of Governors that provides the standard safeguards agreement for all NPT non-nuclear-weapon states.

Every comprehensive IAEA safeguards agreement requires the state to "accept safeguards, in accordance with the terms of the agreement, on all source or special fissionable material in all peaceful nuclear activities within its territory, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices." Further, IAEA NPT safeguards agreements provide "the Agency's right and obligation to ensure that safeguards will be applied, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices." Iran is obligated to make a complete and accurate disclosure of its nuclear programs; the IAEA is obligated to verify that Iran's disclosures are complete and correct; IAEA member states are obligated to pay for this verification through the normal budget process.

All comprehensive IAEA safeguards agreements include a provision for a special inspection, under conditions when other inspections do not lead to resolving a suspicion. Unfortunately, the process requires approval by the state to be inspected, and in the one case where it would have made a great difference, North Korea refused and the IAEA has yet to resolve the suspicion. (In the meantime, North Korea has tested prototype nuclear weapons.)

6 https://www.iaea.org/sites/default/files/publications/documents/infcircs/1974/infcirc214.pdf

THE ADDITIONAL PROTOCOL

As part of the JCPOA, Iran is to apply its Additional Protocol (AP) on a provisional basis, seeking formal *Majlis* ratification no later than the transition point 8 years into implementation. While there is no difference in implementation whether provisional or fully in-force, provisional implementation can be cancelled at will, and in fact Iran already applied its AP for two years, and then decided to stop. *Long-term stability requires full completion of the ratification process.*

APs are now in force in 121 non-weapon states; all are essentially identical. All are based on a standard model published in INFCIRC/540 in 1997.[7]

The AP requires the state to detail all of its nuclear activities, including uranium mining and milling, and research and development activities. (This is one example of the expanded scope of the APs, as these disclosures are beyond the requirements of the original comprehensive IAEA safeguards agreements). The information that a state is required to provide to the IAEA is extensive: when Japan submitted its required declaration, it ran to over 6000 pages. Iran's nuclear program is less extensive.

The AP is intended to allow expanded access to information, places and people, to any location within a state when the IAEA has questions regarding the nature of the activities underway. It meant to enable easy access to any location within a state when the IAEA has questions regarding the nature of the activities under way—in effect, to detect clandestine activities.[8] Note that there are no blanket exemptions for any type of installations, including military bases in the AP, and the IAEA has carried out inspections on military bases in several states.

The IAEA is able to request access to any location where it believes proliferation-related activities are being carried out. This access is "complementary" to inspections, and hence is called "complementary access." In 2014, 78 complementary accesses were carried out.[9] The IAEA must make a case for access, as this is not an open permission to go anywhere just to have a look around. While the IAEA would wish for unfettered access, no sovereign state would be willing to allow such intrusiveness. The timing of such activities and the activities to be carried out must be agreed in advance. If the state believes that inspectors could gain access to information that the state deems to be sensitive, access may be "managed," meaning that inspectors may not be allowed to view anything other than a specifically agreed area or item. This sensitivity could have to do with military capabilities, for example, or proprietary secrets.

A request for complementary access should be acted on promptly, but the AP does not provide any deadlines when the IAEA is seeking access to an undeclared site. In

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7 INFCIRC/540, Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards, https://www.iaea.org/sites/default/files/infcirc540.pdf

8 As of 14 May 2015, Additional Protocols are in force in 121 non-nuclear weapon states. See: https://www.iaea.org/safeguards/documents/AP_status_list.pdf

9 https://www.iaea.org/sites/default/files/safeguards_web_june_2015_1.pdf

contrast, the JCPOA provides that, in Iran, the maximum time will not exceed 24 days, meaning that *Iran's AP will be more rigid than that of any other state.*

UN SECURITY COUNCIL RESOLUTION IMPLEMENTING THE JCPOA

In addition to these two mechanisms, the UN Security Council has unanimously endorsed the JCPOA and assigned the IAEA responsibility for its verification under UN Security Council Resolution 2231.[10]

The comprehensive safeguards agreement and the additional protocol, together with new authority given to the IAEA in UNSCR 2231 provide the legal basis for all verification activities to be carried out while the final agreement remains in force. When the final agreement expires, the agency's authority will revert to the comprehensive safeguards agreement and the additional protocol, which are expected to remain in force indefinitely. That said, safeguards practices will continue to evolve and perhaps some of the provisions of the JCPOA will be reflected in the manner in which safeguards are applied in all states where comprehensive safeguards agreements and additional protocols are in force.

10 UNSCR 2231 is available at: http://www.un.org/en/sc/inc/pages/pdf/pow/RES2231E.pdf

3. PREPARING FOR JCPOA VERIFICATION

In a sense, the IAEA has been preparing for its Iran verification role since it first opened for business in 1957. Along the way, it had to overcome several major challenges.

First, setting up the world's first international inspection system required sovereign states to provide reports and information, accept foreign inspectors into their nuclear establishments to question their practices and make independent measurements and observations, all in order to verify that specific facilities, equipment, material – or even knowhow – were not being used to support a military activity.

Second, it has been necessary to invent safeguards methods and procedures for increasingly complicated nuclear facilities, including uranium-enrichment facilities, fuel manufacturing plants and spent fuel-reprocessing plants. Today's nuclear installations range from R&D laboratories to pilot plants to full-scale commercial factories. Voluntary safeguards support programs established in 20 states and the European Union have made it possible for the IAEA to meet these challenges and keep the IAEA capabilities on the cutting edge.

Third, until 1970, all safeguards applied by the IAEA were restricted to verifying that specified items defined in a hodgepodge of safeguards agreements in a state were not used to further any military purpose. In India, for example, at least seven separate, sometimes overlapping agreements had to be applied. No provisions were made for any verification except for the specific facilities, equipment, material and knowledge covered by each distinct agreement, and this limited ability did not anticipate nor did it allow any conclusions regarding what a state might be up to outside of this limited domain.

Fourth, the nuclear Nonproliferation Treaty (NPT) entered into force in 1970,[11] requiring that each non-nuclear-weapon state party to the Treaty undertakes not to seek nuclear weapons and to submit *all* nuclear material and *all* nuclear facilities to IAEA safeguards. To verify the NPT, the IAEA would now have the means to consider each state as a possible adversary and the purpose of its inspections would be to provide assurance that NPT member states honored their nonproliferation commitments.

Fifth, while the scope of the NPT safeguards agreements anticipated that it might be

11 More formally, the *Treaty on the Non-Proliferation of Nuclear Weapons*.

necessary for inspectors to go to locations separate from the declared nuclear facilities, the mechanism provided (special inspections) requires the state to agree. Through the 1970s and the 1980s, the IAEA applied safeguards under the NPT concentrating on declared facilities, attempting to provide a conclusion for the actions of each state on the basis of what it was then allowed to observe. This was all that was required of the IAEA at the time and, in fact, all that was allowed. During the negotiations of the NPT, for a time, the U.S. was prepared to accept a treaty with *no* verification provisions. No one will say that the NPT is perfect, but it could have been fundamentally worse.

Sixth, when nuclear weapons programs were discovered in Iraq and North Korea in the early 1990s, the international community decided that the IAEA safeguards system had to be overhauled to cope with states that would violate the terms of agreement and seek to acquire nuclear weapons. That transformation took time to complete, and new practices, procedures, and new equipment and out-sourced services (satellite imagery) were secured.

Iraq and North Korea showed that some NPT states intent on acquiring nuclear weapons would pursue all options open to them, including taking advantage of their ostensibly *peaceful* programs. Not many, fortunately, but a few. Some would seek foreign support through overt cooperation or false pretenses, make use of black markets, and attempt to obtain critical goods and services from individuals, commercial firms and government officials by buying, stealing or subterfuge. The situations in Iraq and North Korea in effect compelled the international community to modify the IAEA to rise to real-world threats – preparing it for its upcoming role in Iran.

The changes came in two separate steps.

Changes that were deemed to be within the scope of the existing safeguards agreements were implemented immediately, on the authority of the IAEA Board of Governors. (This includes the provisions for declaring new facilities in Code 3.1 of the Subsidiary Arrangements Facility Attachments, considered later in this report.)

Changes that were considered to be outside the scope of the existing safeguards agreements required a mechanism to extend their coverage. Those changes were put into a protocol that became the AP, which states would have to conclude and bring into force through their national practices. IAEA safeguards agreements have the status of treaties and any changes normally require the full processes established by each state. This is a lengthy process, but since the approval of a standard model by the Board of Governors, 121 non-nuclear weapon states and Euratom have completed the formal steps to have an AP in force.[12] During the investigation of Iraq and North Korea, it was recognized that information provided by other states could be of immense value to the IAEA, especially in finding hidden facilities. The Board of Governors accepted this

12 See: https://www.iaea.org/safeguards/safeguards-legal-framework/additional-protocol/status-of-additional-protocol

practice, which was foreseen in the IAEA Statute.[13]

Over the past 20 years, the IAEA has continued to develop its capabilities for detecting clandestine programs, teaching inspectors new skills, making use of growing commercial satellite imagery services and building its own forensic analysis capabilities, including a new IAEA laboratory for environmental sample analysis, which is supported by a network of affiliated national laboratories available to augment and extend the agency's in-house efforts.

The changes made to the IAEA safeguards system encourage IAEA member states to provide information on potential proliferation cases, and require the IAEA to take a broader, more forensic approach to verification. This approach involves identifying various actions that a state could take to achieve each step in the process of acquiring nuclear weapons, whether relying only on indigenous capabilities or by making use of external resources.

Noting that Iran is more that twice the size of Texas, the most daunting challenge is to find possible hidden facilities, both existing or to be constructed in the future.

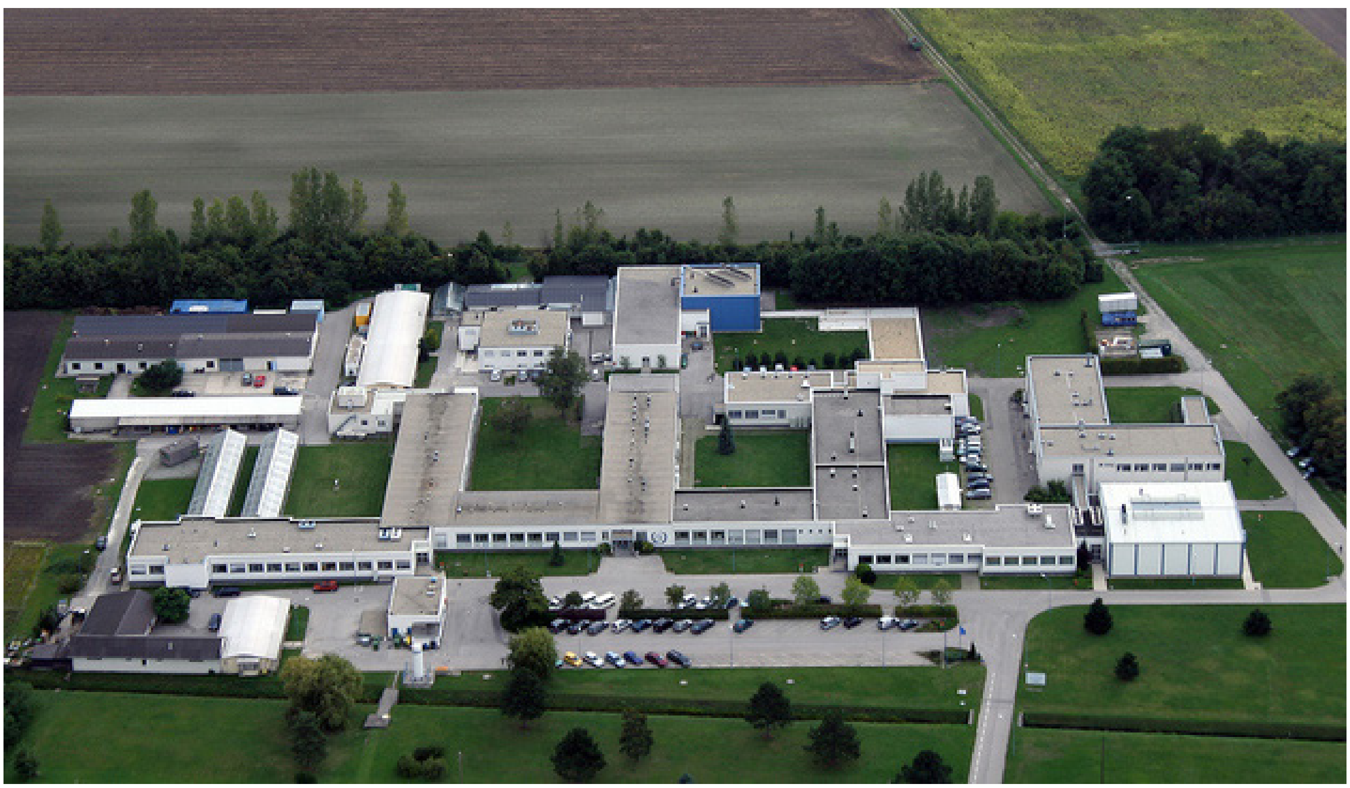


FIGURE 3. The IAEA's laboratories are located in Seibersdorf, Austria, about 35 km from Vienna. Photo: IAEA

13 Article VIII.A of the IAEA Statute anticipates that member states could provide information: "A. Each member should make available such information as would, in the judgment of the member, be helpful to the Agency." https://www.iaea.org/about/statute#a1-8

The IAEA designs and implements its verification activities by imagining how a state might act if it were to decide to break its commitments and attempt to acquire nuclear weapons. This state-level safeguards approach is applied in all non-nuclear weapon states parties to the NPT under their required comprehensive safeguards agreements. The IAEA considers how a state (including Iran) might attempt to succeed without being discovered, and also how it might proceed if it is discovered, proceeding as quickly as possible–regardless of the consequences.

The strengthened safeguards system authorizes the IAEA to take into consideration all information available to it, including information gathered through visits for verification of design of declared nuclear installations, from safeguards inspections and complementary access at declared installations and at other locations of interest identified by the IAEA, information provided by Iran, information the IAEA Safeguards Department obtains from other IAEA programs, from open source information analysis, from reporting on commercial transactions by manufacturers of dual use equipment, and information provided by IAEA Member States, including intelligence information. The safeguards system today includes at its center the activities that the IAEA itself implements, buttressed by all such additional information.

It may include information:

- On exports to Iran of materials and items subject to Nuclear Suppliers Group controls;
- From IAEA programs outside of safeguards;
- Gleaned from open source data mining;
- Provided by vendors of controlled materials and equipment;
- Extracted from commercial satellite imagery from commercial sources; and, most importantly,
- Provided by national intelligence services.

Add to that the clear wishes of many Iranians to find a better future and who should not be counted on to keep nuclear secrets, it is hard for me to believe that Iran would choose not to honor the JCPOA scrupulously. There are no absolute guarantees, but the chances of hiding something now, especially in Iran where everyone is now looking, makes proliferation very risky.

While earlier the approach had been to check the boxes for each type of facility, the safeguards today resemble a criminal investigation, seeking clues and evidence to support any suspicion related to proliferation.

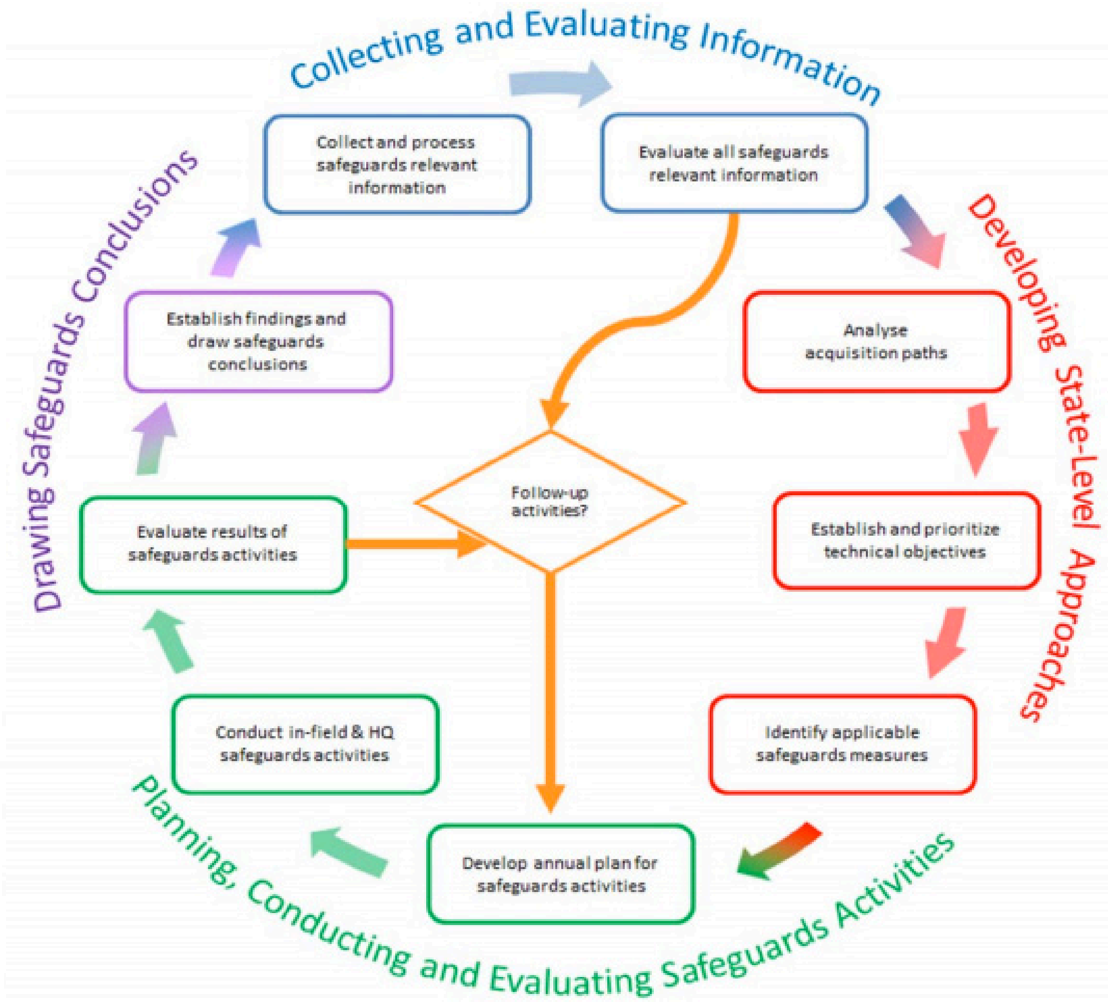


FIGURE 4. IAEA safeguards implementation under the State Level approach. *Photo: IAEA*.

Imagining how Iran might violate its commitments, the IAEA will organize its monitoring activities to take into account Iran's past noncompliance and the "possible military dimensions" that the IAEA has identified among Iran's past nuclear activities, based largely – but not only upon national intelligence information provided by more than 10 IAEA member states. [14]

14 The following excerpts are from the 2013 IAEA Annual Report: "During 2013, the Director General submitted four reports to the Board of Governors entitled Implementation of the NPT Safeguards Agreement and relevant provisions of Security Council resolutions in the Islamic Republic of Iran (GOV/2013/6, GOV/2013/27, GOV/2013/40 and GOV/2013/56). In 2013, contrary to the relevant binding resolutions of the Board of Governors and the United Nations Security Council, Iran did not: implement the provisions of its Additional Protocol; implement the modified Code 3.1 of the Subsidiary Arrangements General Part to its Safeguards Agreement; suspend all enrichment related activities; or suspend all heavy water related activities. Neither did Iran resolve the Agency's serious concerns about possible military dimensions to Iran's nuclear programme that is necessary to establish international confidence in the exclusively peaceful nature of that programme."

4. NUCLEAR WEAPON ACQUISITION PATHWAYS

The IAEA understands what is required to make nuclear weapons and how each requirement might be met by a state committed to such a goal. The IAEA does not teach its inspectors how to make bombs. It is not a nuclear weapon design laboratory, like Los Alamos, for example. But it is able, with assistance from nuclear weapon states when needed, to carry out its verification responsibilities.

If Iran, having mastered the technical ability to enrich uranium were to decide to acquire nuclear weapons, it would most likely opt for implosion weapons using highly enriched uranium (HEU) probably containing 90% or more of the isotope ^{235}U. Eventually it might pursue plutonium warheads,[15] but the JCPOA has effectively made that route essentially impossible. Iran has agreed that the reactor at Arak will be modified so that it will produce only a fraction of the plutonium it would have made without the JCPOA, and what plutonium is produced will be shipped in the spent fuel where it was created from Iran (probably to Russia). Maybe there is a twin, somewhere, but infrared monitoring has previously detected reactors, (including the Soviet underground production reactors at Krasnoyarsk during the Cold War) and hiding a reactor with appreciable power – enough to make weapon quantities of plutonium – would be a risky undertaking. Furthermore, the reprocessing that would be required to extract the plutonium is a messy process and very difficult to hide.

Any state would need to complete all essential steps in the pathway (or pathways) it selects to produce nuclear weapons. The blocks are illustrated in the FreezeFrame diagram shown in Figure 5 below.[16] FreezeFrame shows what it takes to make bombs. It illustrates the critical importance of acquiring the essential fissile material, i.e., weapon-grade plutonium or highly enriched uranium. It also illustrates the other elements required: a workable design, manufacturing the various components, the fusing and firing system, etc.

15 Plutonium is more efficient, meaning that for the same explosive yield, the size and weight of the warhead would be substantially less.

16 FreezeFrame is an information system used by U.S. intelligence organizations to track proliferation-related progress in all states using all sources of information available. The FreezeFrame diagram is shown in A. Seward, C. Mathews and C. Kessler, *Evaluating Nonproliferation Bona Fides*, in **Nuclear Safeguards and Nonproliferation**, Ed. J.E. Doyle, Elsevier, ISBN: 978-0-7506-8673-0, 2008, p. 276.

To choose a pathway through this maze, a state would need to define the skills and capabilities it would require and do a trade-off analysis to see how it could maximize its chances for success while minimizing its chances for being detected. It would take into consideration any capabilities it has acquired through its peaceful nuclear programs, what it can acquire from others through cooperation or guile, and what it has already learned from any clandestine efforts (possible military dimensions) already completed. It would plan how to meet the remaining obligations perhaps by pursuing several alternatives to assure success. It would define the additional technological capabilities and special materials it would need to succeed, and decide whether it should concentrate on its might indigenous capabilities and resources, or whether it should seek help from foreign suppliers, possibly through other states with whom it enjoys friendly relations, or through trade, black market or other means.

If a state were to decide to produce its own nuclear weapons, it would need to meet each challenge.[17] On the one hand, the more a plan includes alternative steps, the more it can tap proven suppliers, the better its chances would be for success. But this cuts both ways – the more alternatives a state selects, the more suppliers it engages, the better the chances are that the IAEA and/or the international community would detect its actions. The state needs to successfully complete all steps in at least one pathway to acquisition; the IAEA (or the international community) need only detect one such activity to raise the alarm. Detecting more than one would be better, but detecting a single action from a single acquisition path might be enough to conclude that a state is engaged in a nuclear weapons program. Any indication is likely to prompt follow-on activities that could bring greater clarity, or intervention.

A nuclear weapons program requires a large-scale industrial enterprise involving multiple sites, multiple processes, some of which are not so difficult to detect now, and thousands of people, all of whom will have to keep the existential secret. When we consider Iran's PMDs, it would be prudent to assume that Iran had a nuclear weapons program with efforts that could be associated with the FreezeFrame diagram. We should remember that Iran got caught. If it resumes some activities, now that it has accepted the JCPOA, now that all of the JCPOA states and some others in the region are going to be watching it like hawks, now that the Iranian public is celebrating being able to move towards normal intercourse with the international community, if Iran were to decide that it must have nuclear weapons, that it must break its commitments, then it will get caught again and suffer intervention that is not likely to be limited to sanctions, snap-back or not.

17 It is possible that a state may obtain nuclear weapons or critical parts from cooperating states, or through unauthorized sales, or by theft. Those possibilities would not be within the scope of IAEA verification activities, per se.

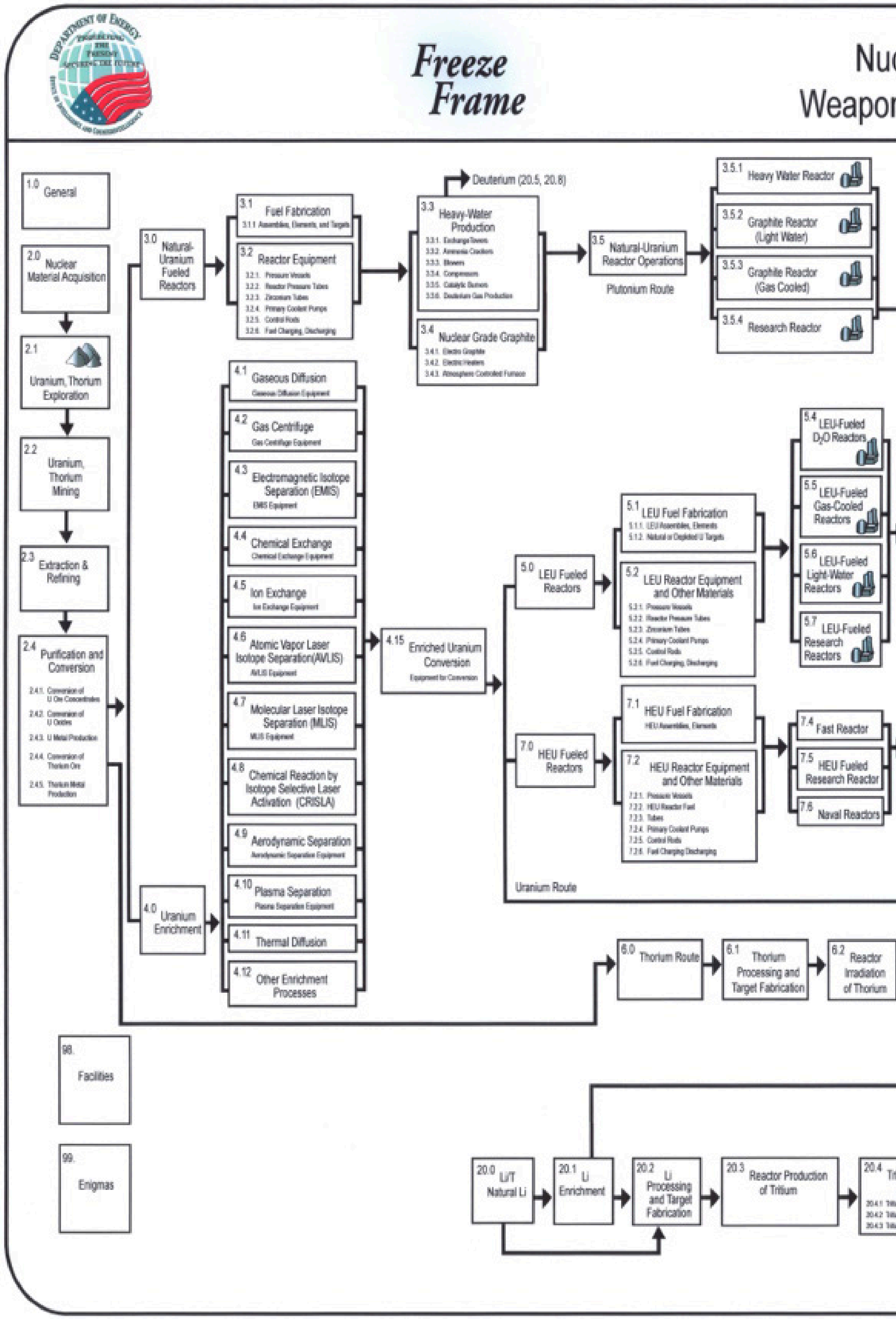
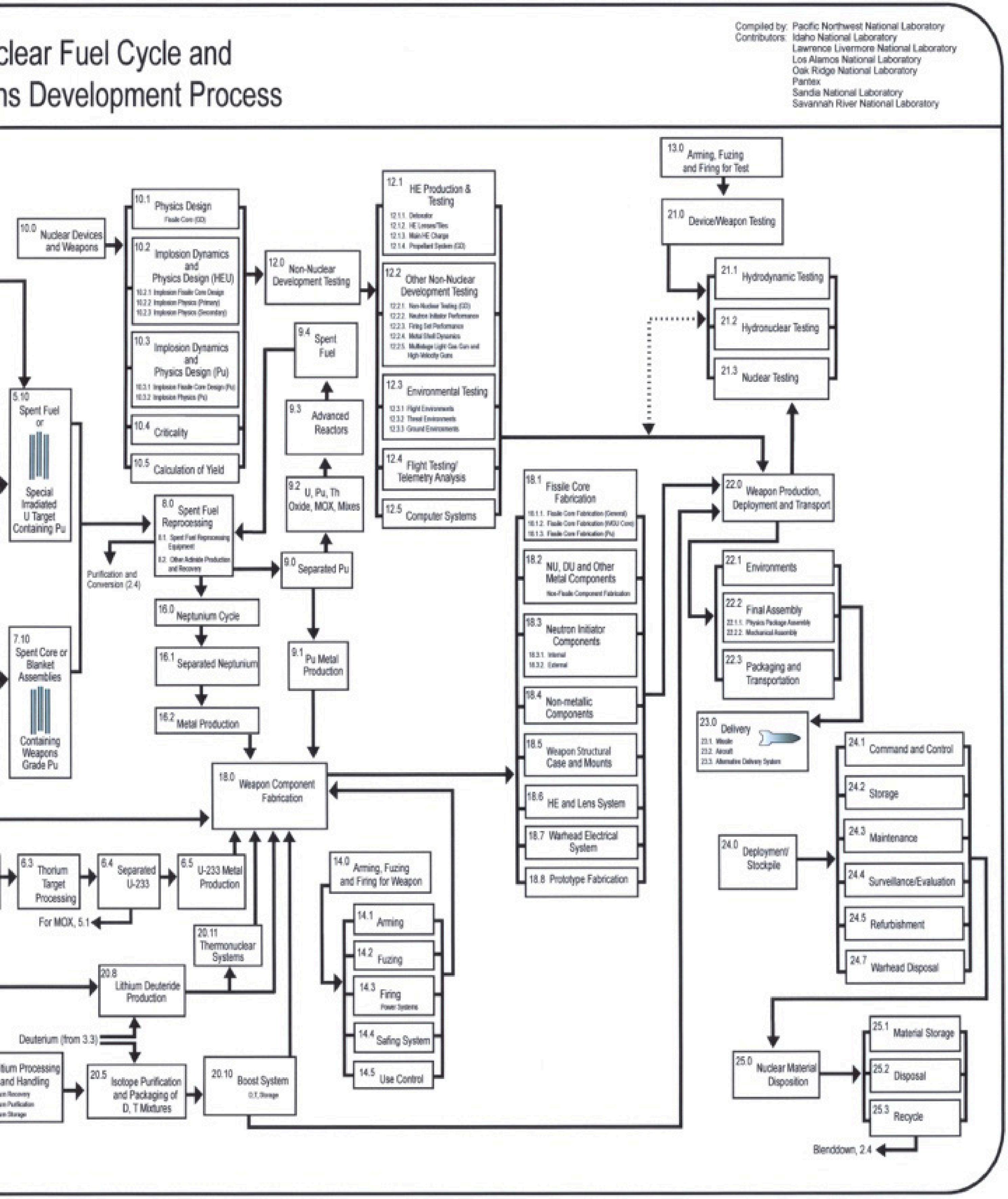


FIGURE 5.
FreezeFrame identifies the steps and alternative means to manufacture nuclear weapons.


clear Fuel Cycle and
ns Development Process
Compiled by: Pacific Northwest National Laboratory
Contributors: Idaho National Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
Oak Ridge National Laboratory
Pantex
Sandia National Laboratory
Savannah River National Laboratory
10.0 Nuclear Devices and Weapons
10.1 Physics Design
10.2 Implosion Dynamics and Physics Design (HEU)
10.3 Implosion Dynamics and Physics Design (Pu)
10.4 Criticality
10.5 Calculation of Yield
12.0 Non-Nuclear Development Testing
12.1 HE Production & Testing
12.1.1 Detonator
12.1.2 HE Lenses/Tiles
12.1.3 Main HE Charge
12.2 Other Non-Nuclear Development Testing
12.2.2 Neutron Initiator Performance
12.2.3 Firing Set Performance
12.2.4 Metal Shell Dynamics
12.3 Environmental Testing
12.3.1 Flight Environments
12.3.2 Threat Environments
12.3.3 Ground Environments
12.4 Flight Testing/ Telemetry Analysis
12.5 Computer Systems
13.0 Arming, Fuzing and Firing for Test
21.0 Device/Weapon Testing
21.1 Hydrodynamic Testing
21.2 Hydronuclear Testing
21.3 Nuclear Testing
5.10 Spent Fuel or Special Irradiated U Target Containing Pu
7.10 Spent Core or Blanket Assemblies Containing Weapons Grade Pu
9.4 Spent Fuel
9.3 Advanced Reactors
9.2 U, Pu, Th Oxide, MOX, Mixes
9.0 Separated Pu
9.1 Pu Metal Production
8.0 Spent Fuel Reprocessing
8.1 Spent Fuel Reprocessing Equipment
8.2 Other Actinide Production and Recovery
Purification and Conversion (2.4)
16.0 Neptunium Cycle
16.1 Separated Neptunium
16.2 Metal Production
18.0 Weapon Component Fabrication
18.1 Fissile Core Fabrication
18.2 NU, DU and Other Metal Components
Non-Fissile Component Fabrication
18.3 Neutron Initiator Components
18.3.1 Internal
18.3.2 External
18.4 Non-metallic Components
18.5 Weapon Structural Case and Mounts
18.6 HE and Lens System
18.7 Warhead Electrical System
18.8 Prototype Fabrication
22.0 Weapon Production, Deployment and Transport
22.1 Environments
22.2 Final Assembly
22.2.1 Physics Package Assembly
22.2.2 Mechanical Assembly
22.3 Packaging and Transportation
23.0 Delivery
23.1 Missile
23.2 Aircraft
23.3 Alternative Delivery System
24.0 Deployment/ Stockpile
24.1 Command and Control
24.2 Storage
24.3 Maintenance
24.4 Surveillance/Evaluation
24.5 Refurbishment
24.7 Warhead Disposal
25.0 Nuclear Material Disposition
25.1 Material Storage
25.2 Disposal
25.3 Recycle
Blenddown, 2.4
6.3 Thorium Target Processing
6.4 Separated U-233
6.5 U-233 Metal Production
For MOX, 5.1
20.11 Thermonuclear Systems
20.8 Lithium Deuteride Production
Deuterium (from 3.3)
20.5 Isotope Purification and Packaging of D, T Mixtures
20.10 Boost System
14.0 Arming, Fuzing and Firing for Weapon
14.1 Arming
14.2 Fuzing
14.3 Firing
Power Systems
14.4 Safing System
14.5 Use Control

5. POSSIBLE MILITARY DIMENSIONS

In October 2014, IAEA Director General Amano made the following statement:[18]

> *"I would like to be very clear on this issue, because there have been some misunderstandings: the IAEA has not said that Iran has nuclear weapons. We have not drawn conclusions from the information at our disposal about possible military dimensions to the Iranian nuclear programme. What we have said is that Iran has to clarify these issues because there is broadly credible information indicating that it engaged in activities of this nature. In other words, Iran has a case to answer.*
>
> *In response to my report, both the IAEA Board of Governors and the UN Security Council adopted resolutions asking Iran to cooperate to clarify the issues relating to possible military dimensions in order to restore international confidence in the exclusively peaceful nature of its nuclear programme."*

As illustrated in the FreezeFrame diagram, many of the steps required to acquire nuclear weapons do not involve fissile material. While the IAEA does not have the specific authority or specialized capabilities to detect weaponization activities that do not involve nuclear material or nuclear facilities, if provided with information regarding such activities, the IAEA will attempt to clarify the information. It will be aided by briefings from nuclear weapon state experts so that IAEA inspectors will be able to find the truth.

If such activities are known to exist, or suspected, the IAEA could not conclude with confidence that all nuclear material in the state was under safeguards, or that no declared nuclear material had been diverted from peaceful use. That nexus provides a sufficient legal basis for the IAEA to pursue suspicions. The IAEA Board of Governors has accepted this domain of enquiry on repeated occasions.

In 2011, the IAEA identified a number of suspicious activities that Iran may have carried out.[19] Its suspicions were based largely, but not exclusively on information provided by member states. These "potential military dimensions" (PMD) to Iran's nuclear program activities potentially relate to:

18 Y. Amano, "Challenges in Nuclear Verification: The IAEA's Role on the Iranian Nuclear Issue," 31 October 2014 | Washington D.C., USA, Brookings Institution, http://www.iaea.org/newscenter/statements/2014/amsp2014n20.html

19 See Annex C of IAEA GOV/2011/65, 8 November 2011.

1. Nuclear material acquisition
2. Nuclear components for an explosive device
3. Detonators
4. Initiation of high explosives & associated experiments
5. Hydrodynamic experiments
6. Modeling and calculations
7. Neutron initiators
8. Preparations for a nuclear explosive test
9. Integration into a missile delivery system[20]
10. Fusing, arming and firing systems

In the negotiations, Secretary of State Kerry downplayed the importance of the PMDs in reaching an understanding to enable the JCPOA to be agreed. In the months leading up to the agreement, he said "We know what they did. We have no doubt. We have absolute knowledge with respect to the certain military activities they were engaged in." Furthermore, the term "possible military dimensions" does not appear in the JCPOA.

However, the IAEA allegations stand and the JCPOA requires that the Director General make a positive report by year's end to enable the next phase of implementation to begin, in which most of the sanctions imposed on Iran will be lifted. Iran would only have agreed to the JCPOA if it were absolutely certain that the Director General would issue a positive report. Anticipate that the Director General and the Government of Iran have agreed on a detailed plan of discovery involving all ten of the alleged PMDs. Almost certainly the Director General will conclude that the IAEA has gained a full and comprehensive understanding of the activities carried out in the past, and that it recommends that implementation of the JCPOA proceed.

The IAEA will likely never be able to draw a conclusion with certainty that weapon-design activities were not carried out, or that the information gained is or is not sufficient to enable Iran to manufacture nuclear weapons if it were able to acquire the necessary quantities of highly enriched uranium and/or plutonium. Eventually, if Iran continues to honor its nonproliferation commitments, its past activities may be seen differently.[21] Until then, to be prudent, the IAEA should assume that Iran acquired sufficient information to enable it to move quickly towards the manufacture of nuclear weapons, and assure that its inspections and the evaluation of all data is carried out at short time intervals, adequate to provide sufficient time for the international community to react if the IAEA becomes convinced that Iran is taking decisive steps towards a nuclear program.

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20 The IAEA mandate is limited to design features that would allow nuclear warheads to be deployed.

21 Other states had nuclear weapon programs that came under scrutiny during the implementation of the Additional Protocol, including Sweden and Switzerland. The Additional Protocol made it possible for the IAEA to effectively conclude that such early programs were defunct.

6. IAEA INSPECTIONS IN IRAN

The strengthened safeguards system authorizes the IAEA to take into consideration all information available to it, including information gathered through visits for design information verification at declared nuclear installations, from safeguards inspections and complementary access at declared installations and at other locations of interest identified by the IAEA, information provided by Iran, information the IAEA Safeguards Department obtains from other IAEA programs, from open source information analysis, from reporting on commercial transactions by manufacturers of dual use equipment, and information provided by IAEA Member States, including intelligence information. The safeguards system today includes at its center the activities that the IAEA itself implements, buttressed by all such additional information.

INFORMATION SOURCES

Information relevant to Iran includes:

- Information the IAEA obtains from inspections, complementary accesses and design information verification visits at declared facilities;
- Information Iran provides as part of its safeguards obligations;
- Information provided by other states when they ship nuclear materials to or receive them from Iran.
- Information concerning exports to Iran of materials and items subject to the JCPOA Procurement Working Group, the Nuclear Suppliers Group or the Zangger Committee controls;
- Information from IAEA programs outside of safeguards;
- Information from open source data mining;
- Information from vendors of controlled materials and equipment;
- Commercial satellite imagery; and, most importantly,
- Information from national intelligence services.

Since its early 1990s experience with Iraq and North Korea, the IAEA's capabilities have improved enormously.

Add to that the many Iranians who are intent on finding a better future, and hence should not be counted on to keep nuclear secrets. It is hard to believe that Iran will fail to honor the JCPOA scrupulously. There are no absolute guarantees, but the chances of hiding something, especially in Iran where everyone is now looking, makes proliferation very risky.

While earlier the approach had been to check the boxes for each type of facility, the safeguards today resemble a criminal investigation, seeking clues and evidence to support any suspicion related to proliferation.

IRAN TASK FORCE

An *Iran Task Force* has been created within the Safeguards Department to plan, execute and evaluate all verification activities in Iran. The *Iran Task Force* reports directly to the Deputy Director General for safeguards. The task force staff now numbers just under 50, about half of whom are inspectors only doing inspections in Iran, and analysts that report to the head of the Task Force rather than to their normal supervisors. Other inspectors who are designated to Iran and hence able to be assigned will be sent on missions when specialized skills are needed, or when additional manpower is required. The Task Force has been authorized to choose the IAEA's most capable inspectors and analysts.

FIGURE 6. Massimo (Max) Aparo heads the Iran Task Force, responsible for planning and carrying out all inspections in Iran. Aparo came to the agency from Italy with a background in nuclear instrumentation. *Photo credit: IAEA*

The IAEA will organize its verification activities under five headings. Four involve field inspections, some at declared facilities or other locations specifically identified in the new agreement. Other field inspections may take place at any location where IAEA needs information to determine whether Iran is continuing to honor its commitments. (In addition to the following descriptions, additional information is provided in Annex 1 and Annex 2 on safeguards implementation at declared enrichment plants and isotope production reactors, respectively.)

DETECTING CLANDESTINE NUCLEAR FACILITIES

Iran has mastered centrifuge enrichment technology and has, in the past, constructed undeclared enrichment plants. It is possible that Iran already has other facilities that have not been detected, possibly including additional centrifuge production plants; plants to convert concentrated uranium ore (known as yellowcake) into uranium hexafluoride (UF_6), the chemical form required for enrichment; perhaps one or more enrichment plants; plants to convert the product to highly enriched uranium (HEU) metal; machine shops to produce warhead components; and the plants required to produce all of the remaining warhead components.

Because natural and depleted uranium are identical to HEU in chemical and metallurgical properties and are relatively easy to acquire, the steps required to produce nuclear warheads from HEU can be rehearsed well in advance so as to be ready when required.

Although the risks of being discovered by dissidents, national intelligence services, or the IAEA will be substantial, Iran could choose to construct new facilities after the new agreement enters into force, using its experience to conceal the construction and operation of such sites. The expertise developed at its declared enrichment plants and centrifuge-manufacturing plants would give it an enormous head start.

Iran is more than twice as large as Texas, and finding carefully hidden locations will likely always be the most difficult IAEA verification task. When member states share their intelligence, the IAEA's limited in-house capabilities are amplified to a remarkable extent. National intelligence services employ methods that are beyond the capabilities of the IAEA, such as spying and intercepting communications. States share their findings with the IAEA in part to allow the agency to pursue inspections on the ground, using its legal authority under the watchful eye of the international community. Combining detection efforts in these ways would increase the chances that clandestine facilities would be detected if Iran (or any state) were to choose to construct such facilities.

FIGURE 7. Jacques Baute heads the Division of Information Management in the IAEA Safeguards Department. Baute joined the IAEA during the Iraq investigations, coming from the French nuclear weapon program. *Photo: IAEA*

When a state shares its intelligence findings with the IAEA, the IAEA can pursue its investigations and confront the state whose activities are at issue when it feels that any explanation given is questionable.

The international community respects the IAEA because it bases its findings on sound scientific information. Having independent means to assure itself that information provided by States is accurate is vital to maintaining that trust. Recognizing that a state might provide incorrect or false information to the IAEA – as happened in the run-up to the U.S. invasion of Iraq when the U.S. provided a falsified letter from an official in Niger (on the wrong stationary and signed by a former official who had not been in that job for some years--and suggestions that aluminum tubing was suitable for use in centrifuge plants, which it clearly was not), perhaps believing it to be true, or knowing that it is not – the IAEA must be cautious in its use of the information provided, and not provide states with confidential information obtained through any of its sources.

Several states and the IAEA keep a close eye on Iran, looking for undeclared nuclear facilities. The agency has established its own satellite imagery analysis unit, which purchases imagery from commercial imaging services. Satellite imagery is still a new technology and further improvements of this capability including enhanced optical resolution, infrared and radar imaging, automated change detection, and ultra-high definition video streaming are being pursued through IAEA support programs.

Knowing today's satellite imagery capabilities, if Iran or any state were to create a new clandestine facility, it might decide that construction at a remote location would attract too much attention and try to hide it in cities—possibly under industrial facilities, hospitals, or shopping malls—or on military bases[22] instead.

FIGURE 8. An IAEA safeguards analyst using a data wall to bring together diverse information on a proliferation threat to determine where inspectors should go and what they should look for. *Photo: IAEA*

22 The Additional Protocol does not allow a non-nuclear weapon state to exclude any facility from inspections, including military bases. States may request that managed-access arrangements be employed as a means to prevent IAEA inspectors from gaining information regarding unrelated military capabilities. The IAEA has conducted complementary-access visits at military bases in several states pursuant to an additional protocol.

Current technologies available to the IAEA for detecting clandestine enrichment plants or plutonium production reactors and associated reprocessing capabilities are significant and new methods mastered in-house by the IAEA and obtainable through commercial services continue to enhance the IAEA's capabilities.[23] The IAEA will ask questions and identify locations of interest if it suspects that clandestine activities may be underway. Satellite imagery would almost certainly be organized early on, and when the IAEA believes that additional information is needed to resolve a question, it will request a clarification and complementary access under the provisions of Iran's AP, or a special inspection,[24] as may be required. Inspectors visiting a requested location will carry out an on-site examination, collect environmental samples (smears, water, soil or vegetation) and come prepared to consult responsible Iranian officials.

Continuing satellite imagery may provide a means to detect efforts to sanitize a site after a request for complementary access has been made, perhaps with radar imagery and infrared to enhance capabilities. Following the collection of environmental samples, if there is any evidence of sudden renovation or if the samples are inconclusive, the IAEA might request core samples to be taken from the surfaces in question, getting underneath any new surface covering.

CODE 3.1 OF FACILITY ATTACHMENTS

The specific provisions of the safeguards agreement (INFCIRC/214) require Iran to provide design information to the IAEA "as early as possible before nuclear material is introduced into a new facility."[25] However, under the strengthening measures adopted by the IAEA Board of Governors after the discoveries in Iraq and the DPRK, the Board clarified this to mean that consultations in relation to design information should begin *before construction*, so as to allow both time and opportunity to incorporate features into a new facility as appropriate for effective and efficient safeguards.

In the past, Iran refused to begin consultations with the IAEA on any new facility or modification before construction work begins. Under the JCPOA, Iran has now accepted the requirement for the early notification provisions of Code 3.1 of its subsidiary safeguards arrangements, and is henceforth committed to provide information on all new nuclear facilities before construction gets started.

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23 As noted in the 2013 IAEA Annual Report, "In the Environmental Sample Laboratory, the Agency's first multi-collector inductively coupled plasma mass spectrometer, introduced in 2012, further improved the precision of analysis of uranium and plutonium in environmental swipes. A laser ablation module was procured to complement this technology for the analysis of micrometer-sized particles. In its second full year of operation, the Agency's large geometry secondary ion mass spectrometer (LG-SIMS) provided a significant increase in the precision of measurements of environmental samples collected during safeguards inspections, design information verifications and complementary access."

24 Provisions for special inspections are provided in para. 73(b) of the safeguards agreement between Iran and the IAEA, shown in INFCIRC/214.

25 See para. 42 of INFCIRC/214.

MISUSE OF DECLARED NUCLEAR INSTALLATIONS

Three complementary methods are used by the IAEA to detect the misuse of a declared nuclear facility.

- Inspectors re-verify the facility design information to determine if there have been any changes that have not been declared;
- Inspectors observe ongoing operational activities and make use of monitoring systems to ensure that there are no undeclared activities. The monitoring systems might include video surveillance or measurement systems that track activities or plant performance.

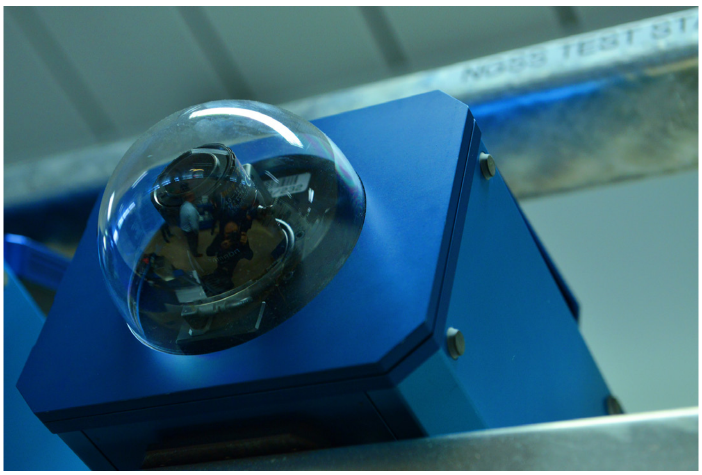

FIGURE 9. An IAEA video surveillance camera includes provisions to detect tampering and to assure that the images taken are authentic. IAEA surveillance began with home movie cameras modified to stop and start so as to provide coverage for up to three months. In the digital era, both image quality and equipment reliability have been greatly improved. *Photo: IAEA*

- Inspectors collect environmental samples to check for HEU particles within or nearby declared enrichment plants, which would be in violation of the agreement.[26]

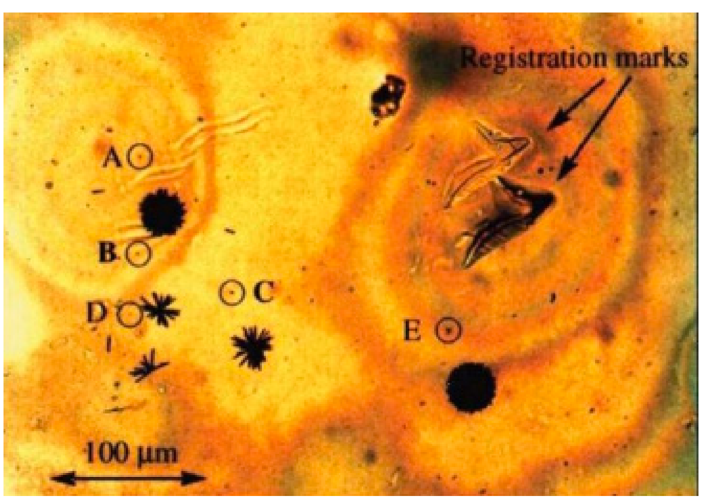

FIGURE 10. An environmental sample taken in an enrichment plant may contain several minute particles with picogram amounts of uranium. (A picogram is 0.000000000001 grams, or 10-12g. It goes gram, milligram, microgram, nanogram, picogram, femtogram.) Placing the sample in a nuclear reactor will cause the uranium to fission, leaving observable tracks. Individual particles can then be extracted and analyzed to determine the elements present, the chemical composition, the isotopic ratios and the morphology of the particle. *Photo: IAEA*

26 Inspectors are finding that particles of 20% enriched uranium are being found in locations where Iran had enriched to that level, and in addition, in other locations where equipment exchanges have been made. Additional R&D may enable the IAEA to control sample deposition, determine the date when a particle is formed, and enable analysis of the particle source morphology.

At the Natanz enrichment plant, the IAEA has been carrying out daily inspections, including environmental sampling. Under the JCPOA, the IAEA also will employ remote monitoring at other facilities to acquire essentially real-time information to determine whether the operations carried out there conform to official declarations.

DETECTING DIVERSION OF DECLARED NUCLEAR MATERIALS

A key goal of IAEA inspections is to verify that no declared stocks of nuclear material are diverted, especially nuclear material that might be quickly converted to weapon-usable forms under a breakout scenario. Under the JCPOA, Iran has agreed to drastically limit the number of centrifuge machines it has in operation, and limit the amount of enriched uranium it would have available if it were to decide to breakout. The JCPOA has made it implausible that Iran would rapidly scale up its enrichment operations from the known capabilities on hand.

There are a number of ways in which the IAEA typically is alerted to the diversion of declared nuclear material. It can detect the removal or alteration of objects containing nuclear materials that the IAEA has sealed or placed under video surveillance, or it can employ accountancy methods to detect shipper-receiver differences and material unaccounted for (MUF) exceeding limits set by measurement uncertainties.[27,28] These practices are cumbersome and expensive to implement, but given the limited quantities of nuclear material currently in Iran, these procedures could detect a diversion of a fraction of the amount necessary to manufacture even one nuclear warhead. If Iran's enrichment throughput increases in future years, then nuclear material accountancy methods may be limited by measurement uncertainties and exacerbated by process losses such as UF_6 plating out onto the surfaces of equipment and piping.

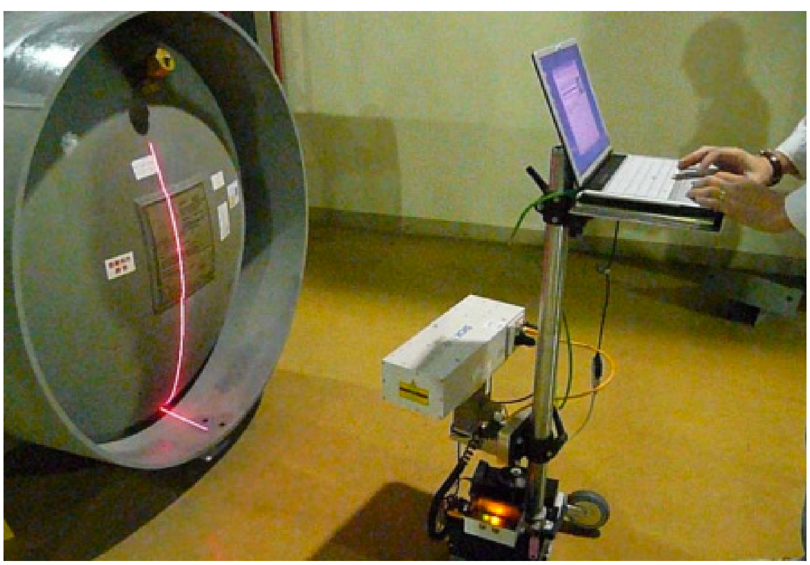

FIGURE 11. A laser scan shows a unique geometric signature for each UF6 cylinder, thereby enabling individual cylinders to be tracked and accounted for. *Photo: IAEA*

27 See definition 6.1 in the IAEA Safeguards Glossary, http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf

28 IAEA Safeguards Technical Report STR-368, International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Material, November 2010.

Annex 1 presents a more detailed explanation of how safeguards are applied at enrichment plants, including some of the specialized equipment used. Similarly, Annex 2 presents a more detailed explanation of safeguards applied at research / isotope production reactors.

MONITORING SUPPLY ARRANGEMENTS

The JCPOA provides for a procurement control activity to be operated under the JCPOA Commission. The IAEA will be informed of imports that have been approved and whose end use has been verified. The IAEA will include this information in its data banks for use in planning design information, inspections and complementary access visits.

In principle, it might be possible for Iran (or any state) to secure assistance for a nuclear weapon program from other states or from commercial companies. Such assistance might be overt, if the supplier state or states politically support Tehran. Or Iran – or any state – could use deception, black markets or front companies, offer substantial payments or threaten violence to acquire specialized material, equipment, or know-how. Some commercial suppliers of dual-use equipment notify the IAEA when they receive suspicious orders for their products.[29] How likely is it that Iran might pursue such actions? It would depend on how desperate it becomes, because the risk and consequences of discovery are very high.

MONITORING LIMITATIONS ON IRANIAN CAPABILITIES

Under the JCPOA, Iran has accepted limitations on existing nuclear capabilities and materials and has accepted monitoring of activities beyond those accepted by any other state.

Under the existing safeguards agreement and the AP, the IAEA will have the authority to verify most of the agreed provisions. Some of the accepted limitations (like the number or models of centrifuges installed at declared facilities) can be considered as design information and hence subject to on-site design information verification.

Others, such as monitoring the centrifuge machine manufacturing, go beyond the current scope of any other IAEA safeguards. The UN Security Council resolution tasking the IAEA with verifying the provisions of the JCPOA include clear authority for the IAEA to carry out all of the verification activities foreseen, including the limitations on capabilities and inventories that Iran has accepted.

29 Ralf Wirtz, "Role and Responsibility of the Civil Sector in Managing Trade in Specialized Materials," in *Cultivating Confidence: Verification, Monitoring and Enforcement for a World Free of Nuclear Weapons*, ed. Corey Hinderstein (Stanford, CA: Hoover Institution Press, 2010).

7. BREAKOUT SCENARIOS

Much of the focus in the negotiations leading to the JCPOA was on preventing Iran from obtaining enough nuclear material for a weapon within one year if Iran were to breakout of its obligations and proceed at top speed. A possible breakout time will depend on the feed stock available to Iran at any given time, especially enriched uranium; the desired enrichment level for possible nuclear weapons;[30] and the mass of highly enriched uranium required, taking into account both the weight of the bomb components and the scrap and waste that would inevitably result during their manufacture. Using HEU gives a state an advantage vs. plutonium, as it is easier to work and the availability of natural or depleted uranium makes it possible to rehearse the various uranium conversion and machining processes so as to be ready to go as soon as the HEU becomes available.

While plutonium is more efficient than HEU when used in nuclear weapons, plutonium is not an option for Iran, unless there already exists a hidden production reactor, reprocessing plant, metal conversion plant, and the specialized machining required for forming plutonium metal. Under the new agreement, Iran has committed to modifying the design of the heavy water moderated reactor at Arak so that the amount of plutonium that it could produce would be greatly reduced. It will take years to accumulate the amount of plutonium needed for a single weapon using that reactor. Later, Iran might pursue plutonium weapons, but it would likely not be able to do so for several years because it will take that long to produce weapon quantities of plutonium using the IR reactor at Arak with its modified design. Creating a clandestine reactor and the associated reprocessing operations would provide a risk of detection that would be substantially more perilous for Iran than clandestine enrichment.

The IAEA considers two extreme cases when designing its verification programs. The first is called *abrupt diversion*, in which the state attempts to advance as quickly as possible with little regard to being detected. This is similar to the concept of *breakout* used in the negotiations. The second is called *protracted diversion*, under which the state stretches out its activities to avoid detection. This is sometimes referred to as *trickle diversion*, meaning that small amounts would be removed from safeguards over a

30 While 90% is frequently used as the target enrichment, there is no cutoff enrichment below which nuclear weapons could not be manufactured. The mass difference for 80% would not be very great. Even 20% and below could be used, but the weight and size of the weapon would make it impracticable.

prolonged period, the amounts being within the margins of measurement error, which would make detection difficult.

Iran's declared uranium conversion and enrichment plants are currently too small, however, to hide a protracted diversion strategy, at least one that could provide opportunities for diverting one or more significant quantities of natural, low enriched or even depleted uranium in a year, or at the present scale, a much longer time.

How much HEU Iran would need would depend on how many deployed weapons it would consider it needed.

The term "significant quantity" (or "SQ") as used by the IAEA defines the minimum amount of nuclear material from which the IAEA believes a first nuclear weapon could be manufactured. For HEU, that SQ amount is 25 kgs of ^{235}U contained.[31] At 90% enrichment, the total amount of uranium needed for one SQ would thus be 25/0.9 = 27.8 kgs, or 62.2 lbs.

The amount of HEU needed will depend on the design yield of the nuclear weapon and the efficiency of the implosion system. For any design amount, allowances will have to be made for process losses, which, for a first weapon, are likely to be substantial. The SQ recommendation reflects the assumption that the state would not have a proven warhead design and that more uranium therefore would be required than would be the case if a proven design is available.

The design yield for a nuclear weapon is chosen to provide a certain explosive force on a target. If the warhead targeting is accurate, then a lower explosive force will be adequate, meaning less HEU per weapon. Similarly, the explosive yield of an HEU weapon can be increased without increasing the amount of HEU contained by using high efficiency implosion compression methods or by boosting.[32] The amount of HEU required per weapon will also decrease as experience is gained, especially when the results of testing are available.

It takes on the order of 5000 separative work units (SWUs)[33] to produce 90% enriched HEU containing one SQ (25 kgs) of ^{235}U. If a lower amount is sought, the required SWUs would be reduced, or, for a given SWU capacity, the time required to obtain the target amount could be reduced accordingly. The actual quantity of SWUs required

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31 This value comes from recommendations made by P5 experts at the United Nations in 1968. The corresponding significant quantity amount for plutonium is 8 kg (of any isotopic composition containing less than 80% ^{238}Pu).

32 "Boosting" involves introducing the isotopes of hydrogen into the fission assembly. As fission heats up the device, the deuterium and tritium fuse, providing additional explosive force. Deuterium (D) exists in nature and is extracted, for example, fertilizer plants. Tritium is produced in a nuclear reactor, either by irradiating lithium targets or as a byproduct of the use of heavy water (D_2O).

33 A Separative Work Unit (SWU) is the standard measure of enrichment capabilities. The effort expended in separating a mass F of feed of assay xp and tails of mass T and assay xt is expressed in terms of the number of separative work units needed, given by the expression: SWU = TV(xt) + PV (xp) - FV (xf), where V(x) is the "value function," defined as V(x) = (1-2x) ln ((1-x)/x). http://www-pub.iaea.org/mtcd/publications/pdf/te_1452_web.pdf

would depend on the specific product enrichment and the tails assay,[34] and the time required to produce the amount of HEU required would depend on the installed operational enrichment capacity. The efficiency of each centrifuge will determine the number required to produce a specified amount of product, and will also determine the cost and size of the plant.

As shown in the following figure, for a given amount of uranium feed, the separative work required rises sharply with the enrichment of the product and then flattens out. Most of the separative work required to produce HEU is used to raise the enrichment from natural uranium (0.712% ^{235}U) to a few percent. So if low enrichment or 20% enriched uranium were to be used as *feed* to produce HEU for nuclear weapons use, the amount of feed required to produce a given amount of HEU product would be dramatically reduced. Alternatively, the rate of HEU production by a given enrichment capacity would be much greater if the feed material were already enriched to a few percent.

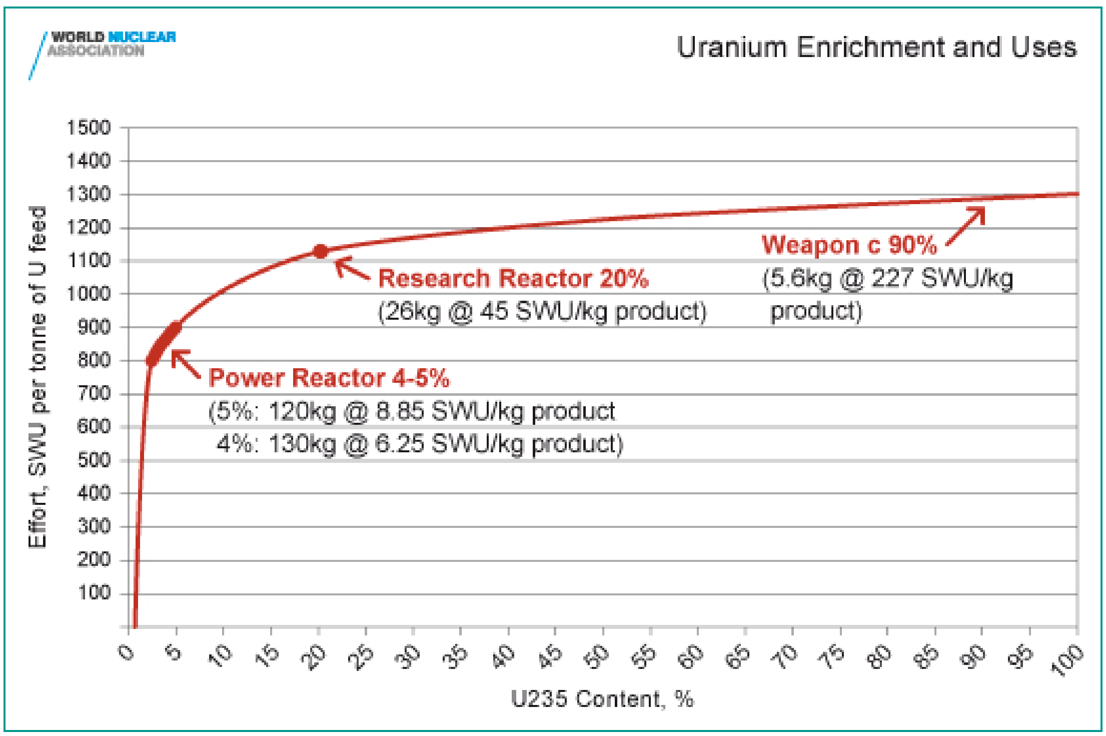

FIGURE 12. The figure "shows how one tonne of natural uranium feed might end up: as 120-130 kg of uranium for power reactor fuel, as 26 kg of typical research reactor fuel, or conceivably as 5.6 kg of weapons-grade material. The curve flattens out so much because the mass of material being enriched progressively diminishes to these amounts, from the original one tonne, so requires less effort relative to what has already been applied to progress a lot further in percentage enrichment. The relatively small increment of effort needed to achieve the increase from normal levels is the reason why enrichment plants are considered a sensitive technology in relation to preventing weapons proliferation, and are very tightly supervised under international agreements." *World Nuclear Association, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Conversion-Enrichment-and-Fabrication/Uranium-Enrichment/*

34 The tails assay is the fraction of ^{235}U left in the uranium waste after going through the enrichment process. In a commercial enrichment operation, starting with natural uranium feed with 0.712% ^{235}U, the tails assay may be 0.25%. In a crash program to produce HEU as part of a breakout scenario, the enrichment tails would be adjusted to provide the greatest chance of success.

If Iran were to breakout, enrichment capacity known to exist would be limited to the operating capacity, and any other machines that Iran could commission on an urgent basis. This is why the JCPOA limits Iran's operational and standby enrichment capacity.

Eliminating Iran's reserves of uranium enriched to 20% means that possible breakout time for a given level of allowed separative work would be greatly extended. Imposing restrictions on the amount of uranium enriched to a few percent means that, if Iran were to breakout, it would be required to use natural uranium feed stock in its centrifuge plants, again, extending the breakout time.

If Iran were allowed to operate an enrichment capacity of about 5000 SWU per year, then the time required to produce a weapon quantity of weapon grade (above 90%) uranium would be on the order of a year. If Iran already has other, unknown enrichment facilities, then the corresponding times would be shorter.

If Iran were to use its centrifuge plants that are designed for low enrichment uranium to produce HEU, then the plants would have to be modified so as to prevent an accidental chain reaction in a so-called 'criticality accident'. This would be especially so as the enrichment levels rise, and particularly where solid forms of UF_6 might arise in normal operations (such as product accumulators and load-out stations) and in other cases (such as cold traps).

If Iran were to proceed on a breakout scenario, all actions must proceed as quickly as possible, without failure. Each step would provide the IAEA and Iran's adversaries opportunities for detection and – if caught – interdiction.

The IAEA will likely anticipate that, if Iran were to pursue development of nuclear weapons, it would first attempt to avoid or delay discovery, and, if it is discovered, could decide to announce its intention and attempt to make as many weapons as quickly as possible using all means available to it. The course Iran actually chooses would likely be a combination of actions chosen to optimize its chances of getting to a position in which it could blunt diplomatic sanctions or military intervention aimed at forcing it to stop. It would most likely build in feints and fallback options, depending on how events would unfold. The IAEA must continue to reassess its findings and adjust its verification activities accordingly.

Iran or any state may attempt to delay detection, for example, by denying IAEA inspectors access to declared installations. It might cause the inspectors to crash en route to a site, or claim that access is unsafe due to a nuclear accident, or that civil unrest or terrorist activities make it essential to stop all foreign access because the government is unable to guarantee the safety of the inspectors. Little imagination would be required to come up with a plausible excuse. The IAEA needs to anticipate such steps and implement backup measures that provide continuity for its monitoring tasks, relying both on human surveillance and installed equipment employing remote monitoring capabilities.

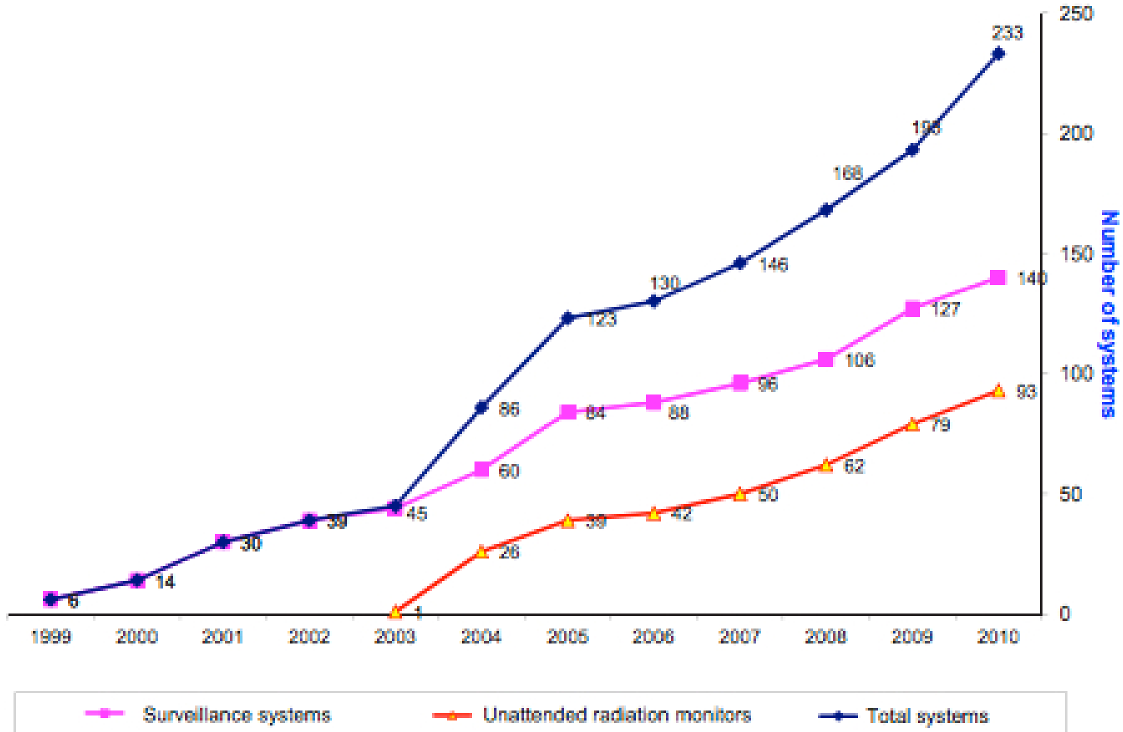

FIGURE 13. The IAEA continues to increase the number of monitoring systems equipped for remote communication to IAEA Headquarters. *Photo: IAEA*

Any breakout would most likely be detected very quickly, possibly the same day it began the process of breakout. While the negotiations aimed at assuring that it would take Iran at least one year to succeed in producing its first nuclear weapon, the actual time will depend on what progress Iran or any state has made up to the point when it commences its breakout plan, how well rehearsed its preparations and processes are, how many weapons it decides it must have to protect itself from intervention, and how much highly enriched uranium and/or plutonium it requires per weapon.

If Iran or any state implements a breakout plan it likely will marginalize the IAEA by withdrawing permission for IAEA inspectors to enter the country. And the world will know.

8. RESPONDING TO SUSPICIONS

The IAEA faces a dilemma. On the one hand, its findings must be available as quickly as possible to enable the international community to act in a timely manner when there is an actual threat. On the other hand, it must be wary that the information available may be imprecise, or that it might not be authentic. The risk of false accusations leading to unwarranted military intervention will require caution, and that caution will frustrate those who are cocked and ready to act.

The IAEA has a system of checks and balances to ensure that each legitimate suspicion is systematically pursued in a step-by-step manner. Accusing a state falsely may have serious consequences, but overlooking legitimate grounds for suspicion could be far worse.

Maintaining precise order in an operating nuclear facility is expensive and is complicated by the nature of the operations and their scale. Discrepancies are discovered on nearly every inspection and anomalies less frequently. A 'discrepancy' is generally an innocent mistake that can be quickly corrected, for example, transposed numbers in a record, or mislabeled inventory items. Discrepancies are normally remedied during the inspection.

'Anomalies' are more serious. Anomalies may be attributable to innocent actions (as with cross-contaminated environmental samples) but they may also point to non-compliance, even to attempts to acquire nuclear weapons.

Each case depends on the specifics but, in general, the initial investigations are technical in nature and intended to assure that any allegations made are based on solid evidence. If the issues remain unresolved, diplomatic consultations begin, advancing within the IAEA's Secretariat to its Board of Governors (and to the JCPOA Commission). Ultimately, the Board could – as has happened in the past – ask the Director General to report the matter to the Security Council.[35]

1. At the inspector level, internal reviews and consultations with national authorities could lead to an innocent explanation or alternatively to finding

35 Under the provisions of Chapter VII of the UN Charter, the Security Council can vote to impose sanctions or to engage in a military intervention. However, given that China, France, Russia, the United Kingdom and the United States have the right to veto any Security Council action, any of these five countries can block implementation. Because each is a full partner in the JCPOA, the likelihood of cheating, or of engineering a stalemate seems unlikely.

corroborative evidence for a suspicion and seeking further explanations.

2. Senior IAEA Safeguards officials, i.e. technical managers on the IAEA staff, could ask their counterparts in the state government for additional information, after presenting their findings and demanding explanations.
3. The IAEA Director General (DG) could meet with the most senior members of the national government to attempt to find a solution to a growing crisis, both before and during ongoing consultations with the IAEA Board.
4. The Board of Governors could call upon the Government of Iran to address outstanding issues. It could determine that Iran or any state was in non-compliance with the commitments it had accepted under its Safeguards Agreement (for Iran, INFCIRC/214) or its Additional Protocol, or in relation to the additional extraordinary measures Iran has accepted in the new agreement. The Board may call upon Iran to reconsider its actions, by a date certain.
5. In this process, the P5+1 would become aware of the IAEA suspicions and could determine that Iran had failed to meet the terms of its negotiated agreement and, for example, reinstate sanctions.
6. The Board of Governors could at any time report the matter to the Security Council. Under its extraordinary authority under Chapter VII of UN Charter, the Security Council might take additional steps as necessary to prevent a state from acquiring nuclear weapons, including military intervention, if an enabling Security Council resolution passes without a veto.

At some point in this process, the "snap-back" provisions to re-apply the sanctions on Iran defined in the JCPOA may be put into effect.

9. END GAME: THE TRANSITION TO NORMAL

Much of this report has addressed how the IAEA should carry out its activities in case Iran might decide to acquire nuclear weapons in spite of the new agreement. But what if Iran honors its obligations and makes no attempt to acquire nuclear weapons? What will *normal* look like, and will Iran ever be considered *normal*?

On the one hand, the possibility that suspicions will arise is reasonable and likely to be long standing. On the other, Iran signed the agreement to rid itself of the sanctions imposed by the UN, the European Union and by the United States. Without some guarantee that there will be relief, why would Iran sign?

For IAEA safeguards to be applied in Iran in the same way as in any other non-weapon state party to the NPT, the IAEA must achieve two outcomes:

1. As long as the IAEA reports that all verification objectives are being met, continued progress toward removing the sanctions in place can proceed;
2. The inspection results attained will determine the nature of the conclusions that the IAEA is able to reach in the future. If the IAEA is eventually able to conclude that Iran has no undeclared nuclear material and no non-peaceful nuclear activities, that conclusion will go a long way towards transitioning the safeguards to be no different from those of any other non-nuclear weapon state party to the NPT.[36,37]

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36 Iran is not unique in having engaged in activities that caused proliferation concerns: other states including South Africa, Sweden and Switzerland had nuclear weapon programs, but today are considered strong supporters of nonproliferation.

37 The following excerpt is taken from the IAEA 2013 Annual Report, p. 71. See: http://www.iaea.org/Publications/Reports/Anrep2013/verification.pdf

"With regard to States with comprehensive safeguards agreements (CSAs), the Agency seeks to conclude that all nuclear material has remained in peaceful activities. To draw such a conclusion, the Agency must ascertain that: first, there are no indications of diversion of declared nuclear material from peaceful activities (including no misuse of declared facilities or other declared locations to produce undeclared nuclear material); and second, there are no indications of undeclared nuclear material or activities in the State.

To ascertain that there are no indications of undeclared nuclear material or activities in a State, and ultimately to be able to draw the **broader conclusion** that all nuclear material has remained in peaceful activities, the Agency assesses the results of its verification and evaluation activities under CSAs and additional protocols (APs). Thus, for the Agency to draw such a broader conclusion, both a CSA and an AP must be in force in the State, the Agency must have completed all necessary verification and evaluation activities, and found no indication that, in its judgment, would give rise to a proliferation concern.

For States that have a CSA but not an AP in force, the Agency draws a conclusion only with respect to whether declared nuclear material remained in peaceful activities, as the Agency does not have sufficient tools to provide credible assurances regarding the absence of undeclared nuclear material and activities in a State.

For those States for which the broader conclusion has been drawn, the Agency implements integrated safeguards: an optimized combination of measures available under CSAs and APs to maximize effectiveness and efficiency in fulfilling the Agency's safeguards obligations. Integrated safeguards were implemented during 2013 for 53 States.

In 2013, safeguards were applied for 180 States with safeguards agreements in force with the Agency. Of the 117 States that had both a CSA and an AP in force, the Agency concluded that all nuclear material remained in peaceful activities in 63 States; for the remaining 54 States, as all the necessary evaluations remained ongoing, the Agency was unable to draw the same conclusion. For these 54 States, and for the 55 States with a CSA but with no AP in force, the Agency concluded only that declared nuclear material remained in peaceful activities."

10. FINAL THOUGHTS

The P5+1 and Iran deal is a strong deal because it:

- Radically reduces Iran's uranium enrichment capacity and puts it at least 12 months away from having enough material for one weapon for over a generation;
- Eliminates the plutonium path to the bomb;
- Puts in place a rigorous monitoring system, including timely inspections of military sites when necessary, would detect and deter cheating and will last indefinitely;
- Strengthens the nonproliferation resolve of the international community making any future attempts very risky; and
- Heads off a nuclear arms race in the region.

If Congress disapproves of the JCPOA and overrides a veto from President Obama, and if that process ends up actually blocking the JCPOA, then the outcome will be dire:

- Iran would be free of any limits on its nuclear capabilities, and judging from what happened in the last decade, would continue to increase its potential nuclear weapon capabilities and decrease the time it would take to build a nuclear weapon.
- The current sanctions regime would be destroyed and it would take a miracle to ever recreate this magic coalition.
- The international nonproliferation regime would suffer an earthquake, undermining its stability of the NPT as the foundation upon which all nuclear control rests; and
- Iran would reject monitoring of its program, and thereby increase the risk of yet another unnecessary, costly, bloody war.

The new agreement marks the beginning of a new era. Having come to the difficult acceptance of the conditions of the agreement, I believe that Iran will honor its commitments and cooperate with and assist the IAEA in carrying out its verification responsibilities. Whatever disruptions threaten the region and the agreement, I believe that ways will be found to enable the IAEA and Iran to work together to demonstrate

Iran's continued compliance.

Iran has signed an unprecedented agreement with six of the most important states on Earth. Iran would know that, if it pursues nuclear weapons, it will be discovered and that the intervention will leave Iran isolated and probably under attack.

I believe that Iran has likely concluded that its future does not include nuclear weapons and hence it has agreed to the extraordinary provisions of the agreement in order to escape from the sanctions, perhaps anticipating that exiting nuclear would open other venues for regional engagement. While continued regional strife is not attractive under any circumstance, eliminating the nuclear option was the fundamental goal for these P5+1 negotiations and with success in hand - an American victory to celebrate - we should now turn to the task at hand and make it work.

I am confident that the IAEA will be continue to receive the political, financial, technical and operational support it needs to succeed – from the P5+1 and from the international community – and hence that the IAEA will be able to maintain the capabilities required to effectively verify Iran's commitments. The IAEA will confirm with confidence that Iran deserves to have the sanctions removed, and that it is earning the trust of the international community.

While I trust that Iran will comply and earn respect, the IAEA will be scrupulously correct, scientific, tactful and demanding in reaching its conclusions, as it is in all states. The IAEA will examine all information made available to it, promptly and fairly, and insist upon immediate resolution of any discrepancies or anomalies. Ever mindful of its immense responsibilities, the IAEA will inform the global community should it be convinced that Iran's compliance with its obligations is in doubt, and in the event that Iran is hindering the verification activities by failing to cooperate and assist the IAEA.

The IAEA's capabilities have been extended, strengthened and refined over the years, taking into account real-world proliferation cases – especially in Iraq and North Korea. The current level of IAEA capabilities reflects the global investment for decades and the continuing commitment of states, especially the 20 states and Euratom that have voluntary support programs.

The U.S. Congress should help to assure that the IAEA is able to maintain the capabilities needed for success:

1. **Provide Adequate Financial Resources**

   The IAEA will require ample financial support to implement the provisions of the new agreement. The normal budgetary process requires the 35 member IAEA Board of Governors to agree, which can be a lengthy process with no guarantee of success. Creating an Iran Verification Contingency Fund would assure that the IAEA is not prevented from implementing the actions it believes necessary due to a lack of funds, or from being required to raid other programs for such purposes.

An initial allocation of $50M should suffice, with provisions for additional funds if this amount process to be insufficient.

2. **Increase American Expertise**

American experts remain underrepresented on the IAEA staff, due in part to arrangements that make such service unattractive to American professionals. For example, experts working at U.S. Department of Energy national laboratories face different rules governing whether and for how long they might serve on the staff of the IAEA. Qualified federal employees, academics and industry workers all face conditions that provide no positive framework encouraging such assignments. Creating an arrangement to encourage American experts to participate would benefit U.S. interests by enhancing the technical competence of the IAEA, by signaling to Iran the commitment of the Congress to assuring that the IAEA maintains exacting standards of professionalism, and by encouraging other states to follow U.S. leadership. Iran does not currently permit Americans to carry out inspections in Iran. While that could change, increasing American representation will allow more Americans to serve as safeguards analysts supporting the inspection effort and free-up other highly qualified inspectors that can carry out inspections in Iran.

3. **Enhance Transparency**

Inspections in Iran should continue to be carried out under enhanced transparency measures. Ideally, the IAEA should report on all requests made for complementary access, the timing and conditions imposed for the IAEA, and the outcome of each such effort. The U.S. should insist that those reports are open to public scrutiny.

The IAEA is an international organization. It is expected to respect the sovereign rights of its member states, and not to respond to unsubstantiated suspicions. The IAEA – especially the Director General – must be certain before acting on any allegations involving any state. This is emphatically so under the present circumstances, as a determination by the IAEA that Iran is not complying – or perhaps is not cooperating with the IAEA in carrying out the verification mission – could lead to violent consequences.

* * *

All things considered, serious and thoughtful observers should trust that Iran has entered into this agreement with the intention to honor it, and have confidence that, if Iran changes course, IAEA verification will work in time for effective intervention.

ANNEX 1.
IAEA SAFEGUARDS AT DECLARED ENRICHMENT PLANTS

Uranium is found in many locations and is present in seawater at a concentration high enough to recover but at a cost somewhat more than mining concentrated ores. As found in nature, only 0.712% of the uranium is the isotope ^{235}U, the one needed for nuclear weapons and for nuclear power. As illustrated in Figure 5, there are many possible ways to enrich the fraction of ^{235}U present uranium and some success has been obtained by electro-magnetic, gaseous diffusion, centrifuge, aerodynamic nozzle, chemical exchange, molecular laser, atomic vapor laser and plasma enrichment processes. But of all of the technologies explored, gaseous centrifuge technology is by far the industry standard today, and Urenco is the industry leader.[38]

While no two centrifuge designs are the same, the following figure shows the general layout and principal components.[39]

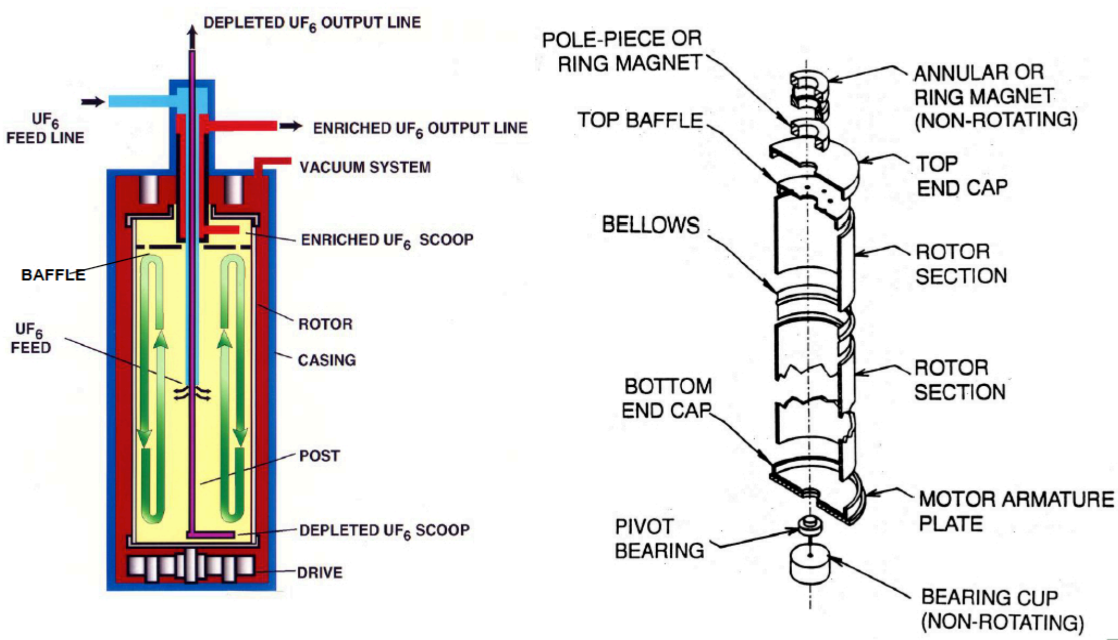


FIGURE A.1.1. A cutaway view of a centrifuge. Specialized materials including maraging steels and carbon fiber technology are used to achieve the very high rotational speeds necessary for efficient enrichment. (See ref. 43.)

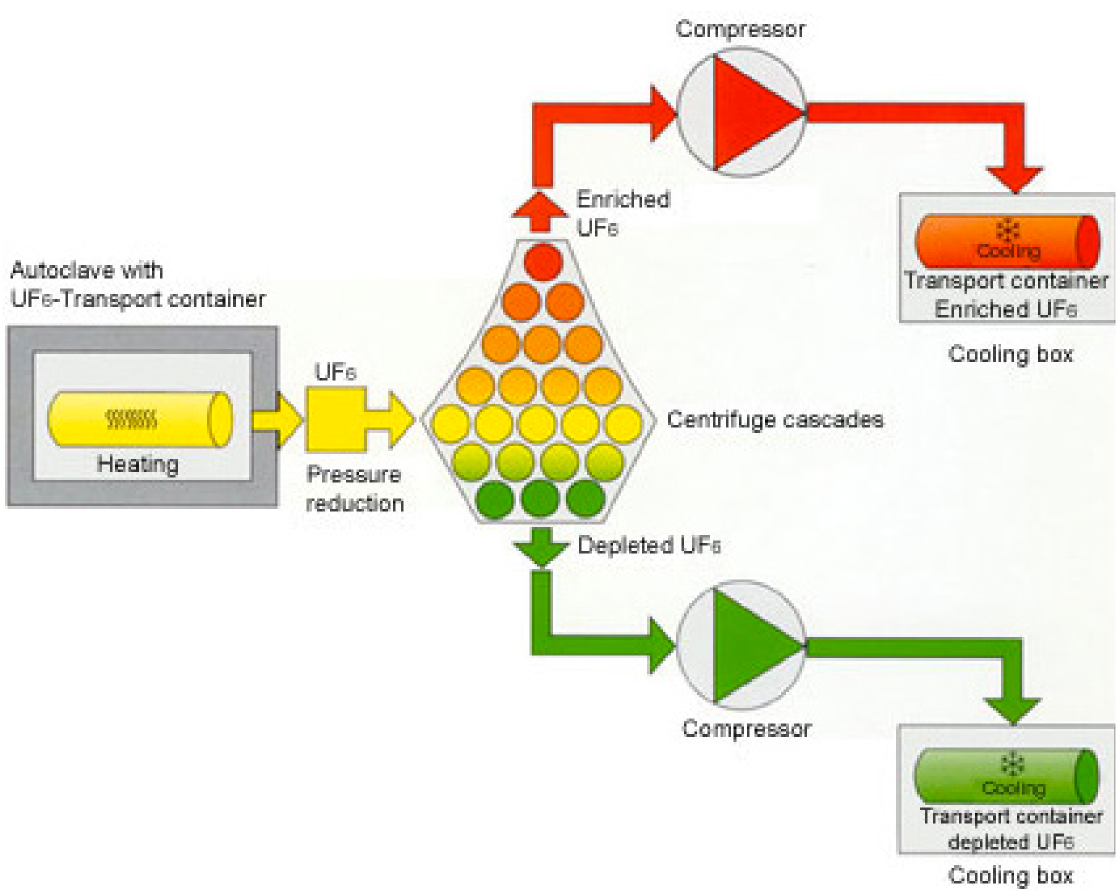
38 A detailed description of centrifuge plants is provided in M. Whitaker, Uranium Enrichment Plant Characteristics: A Training Manual for the IAEA. ORNL/TM-2005/43, ISPO-310/R1, May 2005.

39 See: M. Whitaker, http://web.ornl.gov/sci/nsed/outreach/presentation/2011/Whitaker.pdf

FIGURE A.1.2. The Urenco Almelo Plant in the Netherlands. An enrichment plant operates by ganging thousands of machines in stages to raise the fraction of ^{235}U present to the desired level. The same machines can be used to make uranium enriched to a few percent to fuel light water power reactors, or to produce very highly enriched uranium for nuclear weapons. *Photo credit:* http://abkennisnet.blogspot.co.at/2013/06/bedrijfsbezoek-urenco-nederland-almelo.html

Figure A.1.3 shows a schematic layout of an enrichment plant. Solid UF_6 in a cylindrical shipping container is heated to the point where the UF_6 becomes a gas that is then fed to the centrifuge machines. When the enrichment reaches the desired level, it is put into smaller product cylinders and cooled down to the point that solid UF_6 is again produced. Separately, the uranium "tails" with depleted levels of ^{235}U is put into larger cylinders that are then stored for future disposition.

FIGURE A.1.3. A schematic layout of an enrichment plant. Photo source: "The Uranium Enrichment Plant Almelo," published by Urenco Nederland B.V.



A state having uranium enrichment capacity would be able to divert natural uranium feed, enriched uranium product, or depleted uranium tails as part of a nuclear weapons program. For example, it could over-produce low enrichment that could then be fed to another plant, or it could modify its operations to produce highly enriched uranium at a declared low enrichment plant, or it could hide a clandestine enrichment plant within a declared plant. The safeguards measures employed at a given plant are intended to provide detection capability and assurance that none of these actions could occur without detection.[40]

The experience gained by building and operating a declared low enrichment uranium plant could be used to build a clandestine plant. (That concern is addressed through the means described in the body of the paper.)

The safeguards activities carried out at declared enrichment plants include:

- Design Information Verification,
- Detection of any possible diversion of declared nuclear material,
- Detection of any possible undeclared activities at a declared enrichment facility.

FIGURE A.1.4. At complex facilities, the IAEA may use a 3D laser-scanning device to map the configuration of equipment and interconnected piping. Once a reference is created, later scans can be used to determine whether or not any modifications have been made. *Photo: IAEA*

Design information verification (*DIV*) serves as the basis for routine inspections. The initial DIV activities establish the basis for the safeguards approach at the facility, including defining material balance areas, key measurement points for verifying flows and inventories, and strategic points for the application of containment and surveillance measures. During this activity, IAEA verification equipment is selected, procured and installed by the facility operator, as agreed. Facilities are increasingly designed to facilitate effective safeguards, yet modifications may be required when the IAEA identifies implementation problems. Ongoing DIV activities provide assurance that that approach remains valid, especially in relation to detecting undeclared facility modifications that could enable diversion or undeclared enrichment of undeclared feed UF_6.

40 The IAEA follows one of two model approaches when applying safeguards at gas centrifuge plants. One applies to all centrifuge plants except those equipped with Russian centrifuges; the other was developed for plants equipped with Russian centrifuges. The first is referred to as the Hexapartite approach, which is described in W. Bush, D. Langlands, N. Tuley and J. Cooley, "Model safeguards approach for gas centrifuge enrichment plants", IAEA CN-148/98, October 2005. The second was developed under a Tripartite Project involving the Russian Federation, the People's Republic of China (as this applied first to the plant at Hanzhong) and the IAEA, and is described in "Tripartite Enrichment Project: Safeguards at Enrichment Plants Equipped with Russian Centrifuges," A. Panasyuk, et.al., IAEA-SM-367/8/02, October 2001.

FIGURE A.1.5. A portable high-resolution gamma ray spectrometer can measure the enrichment of the uranium in a cylinder to high accuracy. *Photo: IAEA*

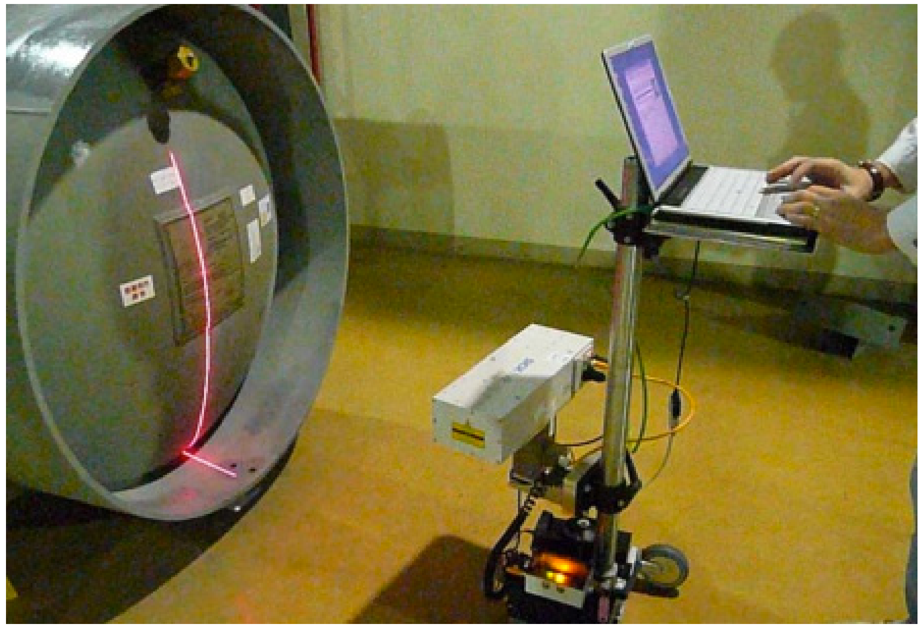


FIGURE A.1.6. A laser scan shows a unique geometry for each UF6 cylinder, thereby enabling cylinders to be tracked and accounted for. *Photo: IAEA*

Enrichment plants are divided into separate material balance areas for feed storage, the process area and the product and "tails" (depleted uranium) storage areas. In the feed, product and tails storage area, inspectors focus on verifying UF_6 cylinders, counting individual cylinders, identifying cylinder serial numbers, applying and checking the integrity of Agency seals, weighing cylinders, checking whether cylinders are empty or full by using a wooden hammer, and measuring the ^{235}U enrichment level using gamma ray spectroscopy.

New methods under development will allow laser fingerprinting to identify individual cylinders, tracking capabilities to follow the movement of each cylinder from facility to facility, and quantitative nondestructive assay methods to measure the total amount of uranium and ^{235}U in a cylinder.

The emptying of each UF_6 cylinder is normally monitored by the use of containment and surveillance methods, and samples of the feed UF_6 are taken (infrequently) for analysis at the IAEA Safeguards Analytical Laboratory. The same arrangements are followed for each product cylinder being loaded, and after loading, being stored pending shipment. Feed UF_6 is normally natural uranium, which contains 0.712% ^{235}U and is homogeneous in isotopic composition. The LEU product UF_6 is homogenized in a special vessel before loading into a cylinder, and hence, each cylinder contains a single isotopic mixture. The UF_6 tails are typically not homogenized because they have no further commercial value, so UF_6 samples from tails are not normally taken for laboratory analysis.

DETECTION OF DIVERSION OF DECLARED NUCLEAR MATERIAL

Detection of possible violation of agreements is carried out by the IAEA by the use of traditional nuclear material balance accountancy at the plant.[41] On the basis of the annual physical inventory and the measurement of feed, product and tails, the operator computes the material balance for the year,

Material Unaccounted For (MUF)
= Beginning Inventory + Receipts – Shipments – Ending Inventory

In any application involving discrete items (like currency in your pocket), MUF should be zero and any loss (or gain) merits further investigation. However, in applications involving bulk materials such as solutions or powders, measurement errors produce non-zero MUF values, and in some facilities, such as enrichment plants, some UF_6 may escape, or plate out inside the process piping contributing to MUF. In those situations, IAEA inspectors verify MUF and determine whether the amount is significant in terms of the propagation of measurement uncertainties and the defined values of significant quantities used as the basis for IAEA material balance verification.[42]

FIGURE A.1.7. A thermal ionization mass spectrometer is routinely used to measure the isotopic abundances of samples sent to the IAEA Safeguards Analytical Lab. *Photo: IAEA*

41 IAEA Nuclear Material Accounting Handbook, IAEA Services Series 15, Vienna, May 2008.
42 Significant quantities (SQs) are defined in the IAEA Safeguards Glossary. The SQ for natural uranium is 10t, for depleted tails is 20t, and for LEU is 75 kgs ^{235}U. See http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/PDF/NVS3_prn.pdf

Analytical technique	Analysed for:	Type of material	Uncertainty (% rel.)	
			Random	Systematic
		Elemental analysis		
Alpha spectrometry	Np, Am, Cm	High active liquid waste (HALW), Spent fuel input	5.0	5.0
Controlled potential coulometry	Pu	Pure Pu solutions	0.10	0.10
Ignition gravimetry	U, Pu	U, Pu oxides	0.05	0.05
Isotopic dilution mass spectrometry (IDMS)	U, Pu	Spent fuel input solutions, Pu and U–Pu materials, HALW[a]	0.20	0.20
Hybrid K-edge densitometry (HKED)	U, U:Pu ratio	Spent fuel solutions[b]	0.60	0.30
K-edge densitometry (KEDG)	U, U:Pu ratio	U, U–Pu solutions	0.20	0.15
New Brunswick Laboratory Davies and Gray titration	U	U (pure compounds)	0.10	0.05
Plutonium (VI) spectrophotometry	Pu	Pu process solutions	2.0	2.0
		Isotopic analysis		
Alpha spectrometry	^{238}Pu	Pu materials	0.2	0.3
Gamma ray spectrometry (NaI detector)	^{235}U	Low enriched U materials	0.3	0.3
High resolution γ ray spectrometry (Ge detector)	Pu isotopes, Am, Np	Pure U and Pu materials	0.5–2.0	0.5–2.0
Thermal ionization mass spectrometry (TIMS)	U and Pu isotopes	All Pu and U materials, and spent fuel input solutions	0.10[c]	0.05[c]

[a] Hot cell conditions.
[b] Typically 150–250 g/L uranium with U:Pu 80–150.
[c] For the major ratios of uranium and plutonium.

TABLE A.1.1. Measurement uncertainties for IAEA analytical measurements. See: Safeguards Techniques and Equipment, 2011 Edition. http://www-pub.iaea.org/books/IAEABooks/8695/Safeguards-Techniques-and-Equipment-2011-Edition

Mass accounting involves measuring the weight of UF_6 in cylinders or sample vials, determining the uniformity of the UF_6, and determining the amount and isotopic composition of the uranium in a sample. The IAEA, in cooperation with the nuclear industry, determines international accuracy standards for all nuclear materials accountancy measurements.[43]

Once each year, the plant operator takes a physical inventory and IAEA inspectors verify the inventory based on random sampling plans. UF_6 is pure and analytical measurements of very high accuracy (on the order of .1% or better) are routine. Because of the operating characteristics of enrichment plants and the low density of the UF_6 gas within the cascades, the IAEA assumes a constant, non-zero inventory within the cascade and the centrifuges.

43 STR-368, International Target Values 2010 for Measurement Uncertainties for Safeguarding Nuclear Materials, IAEA, Vienna, November 2010.

DETECTION OF UNDECLARED ACTIVITIES AT A DECLARED ENRICHMENT FACILITY

Undeclared activities could be carried out in support of a proliferation effort by:

a. Producing excess LEU by feeding undeclared uranium into the plant which might then be further enriched to HEU in a clandestine plant; or

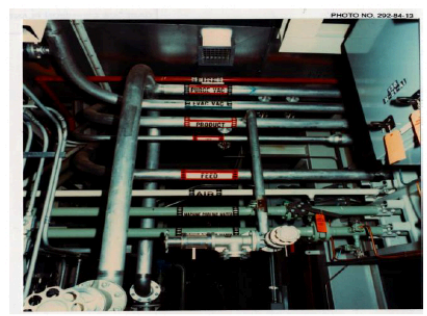
b. Producing HEU within an LEU plant by either recycling the product for further enrichment or creating a clandestine plant within the declared enrichment facility.

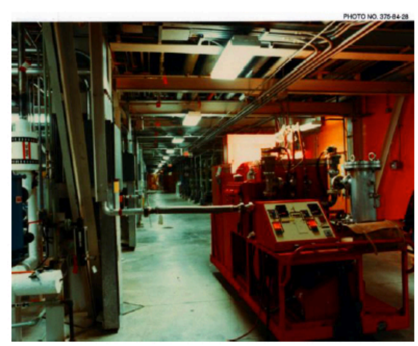
Excess natural uranium feed and excess LEU production would be detected by IAEA inspections under the activities described above to detect the diversion of declared nuclear materials.

The following chart illustrates potential indicators that would arise if an enrichment plant were to be used for undeclared HEU production.[44]

Indicators Associated with HEU Production

- **Reduced throughput**
- **Portable feed and withdrawal equipment/stations in cascade area**
- **Extra UF_6 cylinders in cascade area**
- **Valve settings**
- **Piping reconfigurations (e.g., inter-cascade piping, feed/withdrawal points)**
- **Radiation signatures indicating HEU**
- **Ratios of minor isotopes**





44 M. Whitaker, op.cit.

At enrichment plants, microscopic particles of uranium leak from the piping network and adhere to the surfaces of nearby piping, walls, floors and any other surface. Environmental sampling will pick up some of those uranium particles and this method is employed routinely within declared enrichment plants as part of the ongoing DIV activities. The smears are analyzed to detect the presence of ^{235}U levels above the declared enrichment values.

FIGURE A.2.6.A. A kit for inspectors to collect environmental samples. The foil is spread around the collection area to minimize the chance of cross-contamination. *Photo: IAEA*

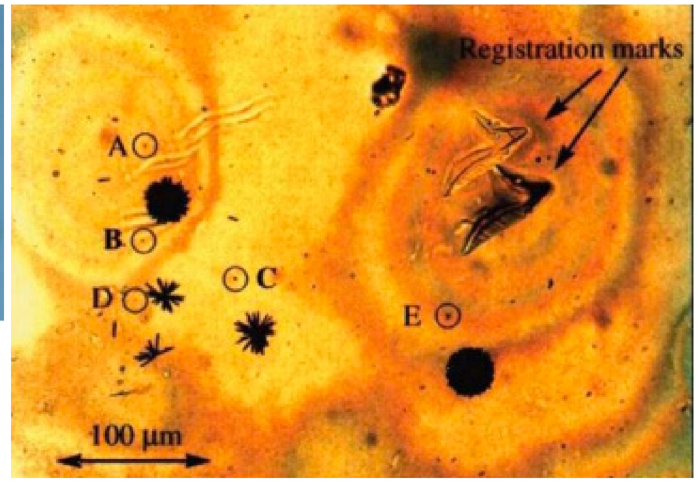


FIGURE A.2.6.B. An environmental sample is transferred to a clear plastic and irradiated in a nuclear reactor. The dark blotches show damage caused by fission taking place in particles on the sample. The particles, weighing about 10-12 grams, are then analyzed for element, chemical compound, isotopic composition and morphology. *Photo: IAEA*

Larger plants are more difficult to safeguard than small plants, and safeguards at declared enrichment plants continue to be given high priority and IAEA member states are investigating several promising methods to improve the methods and techniques.[45]

45 The 2014 IAEA Safeguards Symposium included sessions specifically devoted to new developments in this area. See: http://www.iaea.org/safeguards/symposium/2014/home/index.html

ANNEX 2.
IAEA SAFEGUARDS AT RESEARCH/ ISOTOPE-PRODUCTION REACTORS

Any reactor with appreciable power could produce significant amounts of plutonium.[46] A research reactor producing 25 MWth is considered by the IAEA to be capable of producing 1 significant quantity (i.e., 8 kgs) of plutonium per year. Some research reactors still use HEU as fuel, and for them, diverting the fresh fuel could – depending on the amount of fresh fuel available – provide a quick means to build a bomb. Smaller reactors would also work, but take longer. According to the IAEA, there are today 116 research/isotope production reactors in operation.[47]

A state with a research/isotope-production reactor could divert fresh, core or spent fuel to obtain nuclear material to support a weapons program. It also could use the reactor to irradiate undeclared "fertile" material (natural uranium or thorium) within the reactor core, or immediately adjacent to the reactor core to produce plutonium for a nuclear weapons program.[48] Finally, it might also remove some or all of the declared fuel from the reactor core and replace it with undeclared fuel, operate the reactor to produce plutonium, shut down the reactor to remove the undeclared fuel, and return the declared fuel to the reactor. The safeguards measures employed at a given nuclear power, research or isotope-production reactor are intended to provide assurance that none of these actions occur.

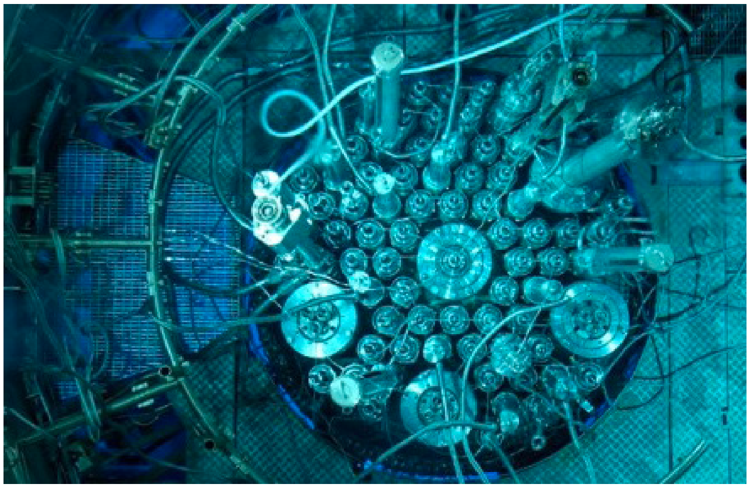


FIGURE A.2.1. A reactor designed to support research or to produce medical isotopes must provide for flexible operation to introduce and remove irradiation targets. The blue glow is from Cerenkov radiation from the reactor core. Photo: SCK-CEN, http://www.world-nuclear-news.org/RS_Isotope_reactor_steps_up_to_the_plate_0205131.html

46 Or ^{233}U, if thorium is irradiated instead of uranium.
47 http://nucleus.iaea.org/RRDB/Content/Pow/PowHigh.aspx
48 It would also be possible to irradiate thorium to produce ^{233}U, which could also be used to make nuclear weapons. Because of greater radiation safety problems, this possibility is far less likely.

Alternatively, the experience gained by building and operating a nuclear reactor could be replicated in a clandestine reactor. That concern is addressed through the means described in the body of the paper.

The safeguards activities carried out at declared research/isotope-production reactors can be grouped into the following categories:

- Design information verification (DIV),
- Detection of diversion of declared nuclear material, and
- Detection of irradiation of undeclared nuclear material.

DESIGN INFORMATION VERIFICATION

As for enrichment plants, DIV serves as the foundation for regular inspections at a research / isotope production reactor. The initial DIV activities establish the basis for the safeguards approach at the facility, including defining material balance areas, key measurement points for verifying flows and inventories, and strategic points for the application of containment and surveillance measures. Ongoing DIV activities provide assurance that that approach remains valid, especially in relation to detecting undeclared refueling operations or the placement and removal of undeclared fertile material[49] within or adjacent to the reactor core.

Research and isotope-production reactors are divided into separate material-balance areas for fresh fuel storage, reactor core and spent fuel storage. Spent fuel storage may be further divided if dry storage is provided.

DETECTION OF DIVERSION OF DECLARED NUCLEAR MATERIAL

Possible detection of an agreement violation is carried out by the use of item accountancy at the reactor, which assumes that fuel elements remain intact at the reactor. If fuel elements can be dismantled and reconstituted at the reactor, then additional safeguards measures would be required to assure that such activities would be detected.

- Fresh fuel elements are normally stored where inspectors are able to count them, identify serial numbers and measure their uranium enrichment and the length of the fuel column within each fuel plate or element.
- Core fuel is verified upon each refueling by counting fuel elements being replaced and verifying serial numbers, and thereafter by containment and surveillance to confirm that the core remains untouched.

49 "Fertile" materials are natural uranium and thorium. In a nuclear reactor, the ^{238}U in natural uranium absorbs a neutron and converts by β decay first to ^{239}Np, then to ^{239}Pu. If thorium is placed in a reactor, ^{232}Th absorbs a neutron and converts to ^{233}U. ^{239}Pu, ^{241}Pu, ^{233}U, ^{235}U, ^{237}Np and ^{241}Am can be used in nuclear weapons.

FIGURE A.2.2. Inspectors verify fresh fuel assemblies stored at a nuclear reactor awaiting loading into the reactor core.

- Counting and the use of Cerenkov radiation viewing verify spent fuel elements stored in a pond at the reactor. Surveillance of the storage area provides assurance that each spent fuel element remains in its declared storage position. If, after some time, spent fuel is moved from the storage pond to dry storage canisters, then inspectors need to verify the identities of the spent fuel elements, witness their placement into dry storage canisters, and then apply two seals for containment/surveillance so that future re-verification can rely on the dual C/S results.

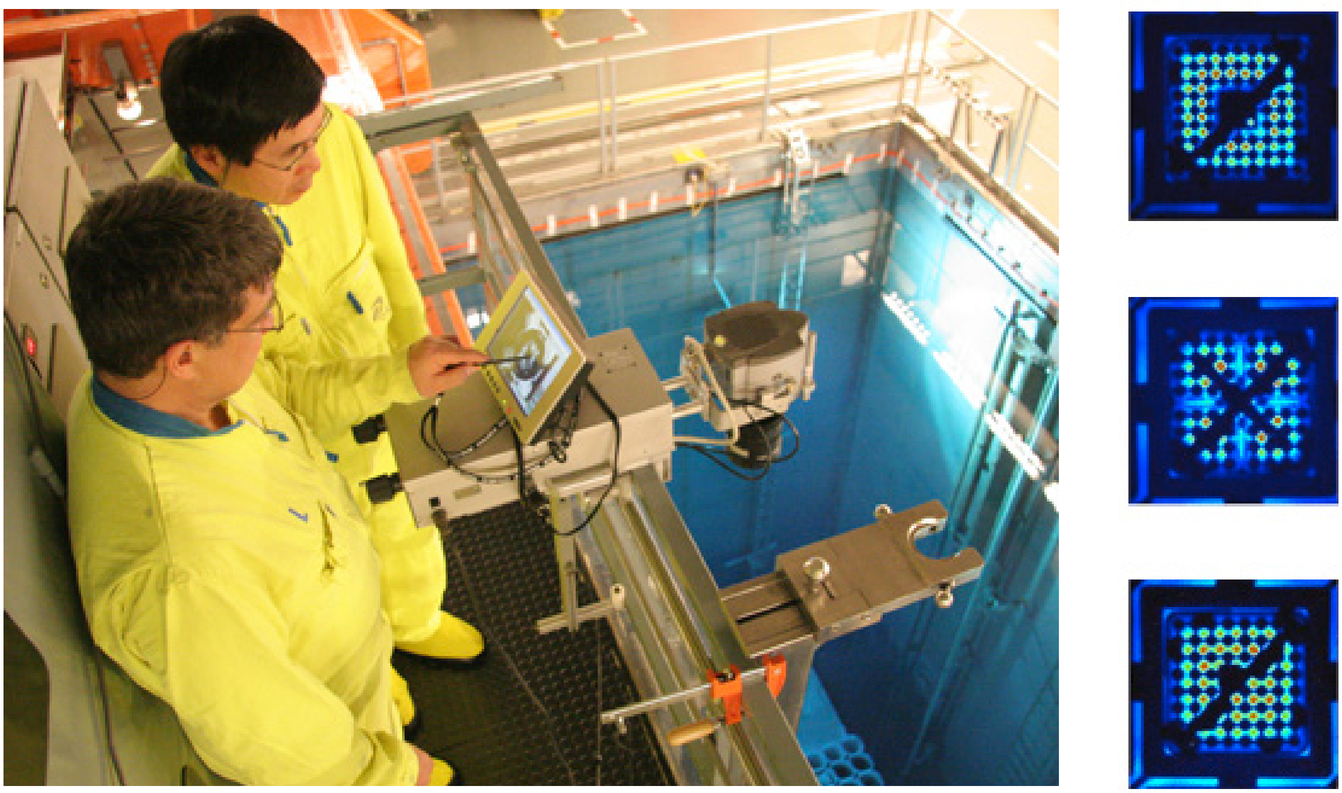


FIGURE A.2.3. A modern Cerenkov viewing device allows inspectors to see the pattern of emissions from single fuel rods within a fuel assembly, decades after the assembly has been discharged from the reactor and placed in an underwater storage rack. The three examples shown on the right are from different reactors with different fuel designs. This method can detect missing fuel rods and provide a uniformity check, without moving the fuel assemblies. http://www.channelsystems.ca/DCVD.cfm

DETECTION OF IRRADIATION OF UNDECLARED NUCLEAR MATERIALS

Irradiation of undeclared materials at research/isotope production reactors may be carried out in support of an effort to producing undeclared Pu (or ^{233}U) for use in nuclear weapons. Depending on specific design features, this may be accomplished by:

- Removing declared fuel from the reactor, replacing it with fresh fuel and running the reactor for a time adequate to produce weapon-grade Pu in the replacement fuel, then removing that fuel and replacing it with the original fuel; or
- Removing the fuel elements at a point where the burn-up is such that the Pu is still weapon-grade, then replacing it with new fuel elements with the same identification markings; or
- Placing natural or depleted uranium irradiation targets inside the core or immediately adjacent to it where the neutron flux levels remain sufficient to produce a significant amount of plutonium, then removing those targets before the next inspection.

The IAEA routinely employs thermo-hydraulic reactor power monitors at research reactors to determine the reactor operating history as a means to detect undeclared refueling, as shown in Figure A.2.3, below. This method can determine when the reactor is or is not operating, and how much thermal power is produced at any moment or over any period of time. The equipment is manufactured by major light water reactor suppliers and is used by the operators of such reactors to complement their core instrumentation. It requires professional installation, and special consideration to assure that the sensors are not bypassed or tampered with.

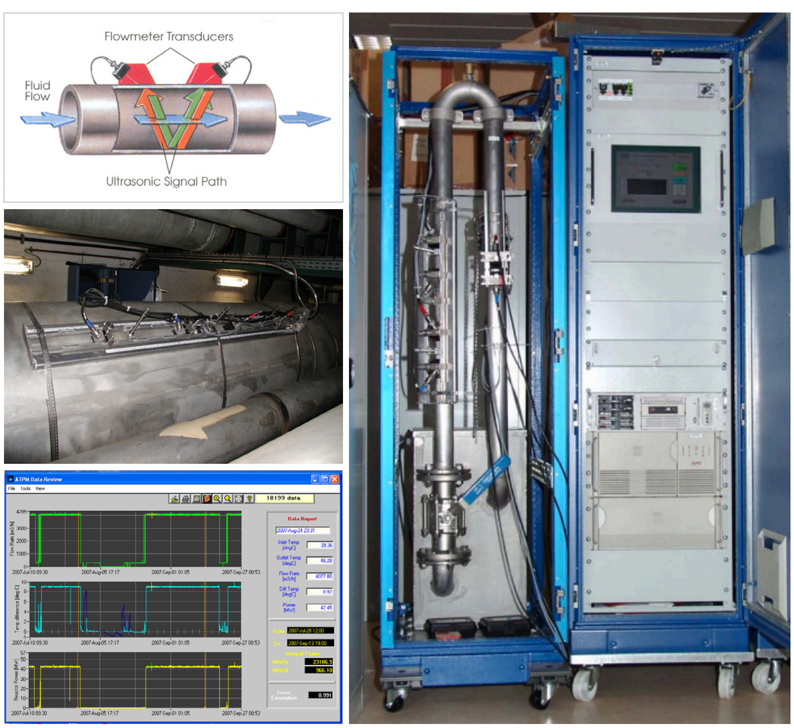


FIGURE A.2.4. An IAEA thermo-hydraulic reactor power monitor. The equipment in one installation is shown on the right side. On the left, the principles are shown: piezo-electric crystals and thermistors are mounted on the outside of the coolant piping. The piezo-electric crystals measure the coolant flow rate, and the thermistors measure the temperature drop across the heat exchanger. The two measurements combine to give the power production. Images courtesy of C. Liguori, IAEA.

Research underway by elementary particle physicists show that monitoring antineutrinos emitted by research / isotope production reactors could be used to determine not only when a reactor is in operation and how much power it produces, but also when it is refueled, and what the composition of spent fuel or irradiated fertile material targets would be. Theoretical predictions indicate, for example, that had such a monitor been installed at the DPRK 5 MWe reactor, it would have provided information on the refueling operations undertaken in the DPRK.[50,51]

About six antineutrinos are produced in each fission reaction. They rarely interact, but enough can be detected to make measurements practical. Additional R&D is needed to prove the utility of this method. Ideally, an international project could be created involving the international community of applied antineutrino physicists. Perhaps Iran might consider hosting such a project at its Arak reactor.

Figure A.2.5 below shows an antineutrino detector developed for such a purpose.[52]

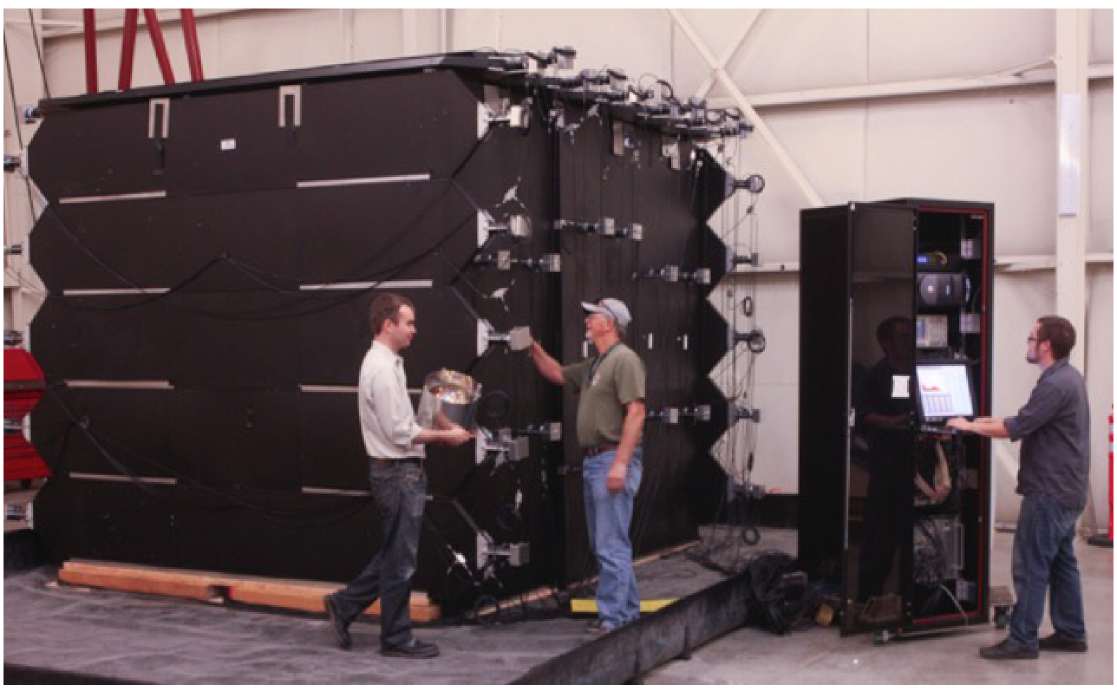


FIGURE A.2.5. Physicists at Lawrence Livermore National Laboratory prepare an antineutrino detector for installation at a nuclear reactor. The detector will be installed in a container and placed outside the reactor containment building. The detectors operate with no connection to the reactor. Continuing research is aimed at smaller detectors that provide more information and hence greater sensitivity.

50 The DPRK reactor produced about 25 Mega Watts of thermal energy. Most nuclear power reactors produce 1000 or more Mega Watts electric, on the order of 3500 MW thermal.

51 E. Christensen, P. Huber, P. Jaffke and T. Shea. 2014 *Phys. Rev. Lett.* **113** 042503.

52 T. Classen, et.al., "Deployment of an Anti-Neutrino Monitor at the PLGS CANDU6 Reactor," Proceedings of INMM Annual Meeting, July 2012.

Search for Common Ground is the world's largest conflict resolution and prevention organization, working to transform the way the world deals with conflict-- away from adversarial approaches and towards cooperative solutions. Search has been engaged since 1996 on US-Iran relations, providing channels of communication, identifying mutual interests, and promoting people-to-people exchanges. Search has been a longtime supporter of the nuclear negotiations, offering impartial analysis of technical data on nuclear issues, working to strengthen the non-proliferation regime, and contributing creative ideas to the negotiation processes.

Princeton University's Program on Science and Global Security works to develop the technical basis for initiatives that would facilitate the reduction of global stockpiles of nuclear warheads and nuclear-weapon-usable materials and the dangers of accidental nuclear war, nuclear proliferation and nuclear terrorism. It also works to reduce dangers from natural and man-made pathogens.