CHAPTER 4

WIDE AREA ENVIRONMENTAL SAMPLING IN IRAN

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In 2005 NPEC commissioned me to write this paper on WAES in Iran which I did - after many false starts. The paper was not meant to be any more than a starting point. It contains many gross assumptions and simplifications. There are a number of costs not addressed such as internal transport and security measures for the sampling stations. My rationale was that the overall cost would be so influenced by the actual detection range and practical servicing frequency that the "odd million here or there" would be of little consequence.

Any meaningful negotiated agreement with Iran must, at the very minimum, require Iran to:

1. Unconditionally agree not to acquire or develop nuclear weapons or weapons -useable nuclear material or any subsystems or components or any research, development, support or manufacturing facilities related thereto.

2. Submit to the Secretary General and to the Director General of the International Atomic Energy Agency (IAEA) a declaration containing complete details of its past activities to produce or acquire special nuclear materials (plutonium and enriched uranium) and nuclear weapons technology, including complete details of external assistance, both offered and provided, as well as related procurement activities.

3. Immediately enter into force the "Additional Protocol" and actively cooperate with the IAEA in its robust implementation for the purpose of verifying the accuracy and completeness of the information provided with respect to Iran's past nuclear activities and in building ongoing confidence that Iran's present and future nuclear activities are confined to exclusively peaceful uses.

The IAEA is very well-experienced in the verification of the accuracy and completeness of declarations and, while significant uncertainties remain, has already gained considerable knowledge of Iran's past nuclear activities.

The IAEA has also gained much experience in Wide Area Environmental Sampling (WAES), both through its field and laboratory work in laying the technical groundwork for the Additional Protocol and from the implementation of its plan for the Ongoing Monitoring and Verification (OMV)[1] of Iraq's undertaking in compliance with paragraph 12 of United Nations Security Council (UNSC) Resolution 687 (1991).

This chapter addresses the viability of WAES—as defined in Article 18.g of the Additional Protocol—as a means of gaining assurance that all nuclear activities in Iran are known to the IAEA and are subject to routine verification in accordance with Iran's safeguards agreement with the IAEA.

The context for the implementation of WAES in Iran would be twofold:

- Iran is already a potential nuclear weapons state, and should Iran so choose, it would be merely a matter of time until it fully developed a production capability for weapons-usable nuclear material and its subsequent weaponization.
- Iran's oft-declared peaceful nuclear undertakings might well be genuine, but pragmatism requires that comprehensive verification measures be implemented over a substantial period of time to build the necessary level of international confidence of Iran's compliance with those undertakings.

The Locations and Scope of Monitoring Activities Prescribed by the Additional Protocol.

The Additional Protocol defines, inter alia, the locations to which the IAEA may gain "Complementary Access"[2] and specifies the verification measures the IAEA may implement to gain assurance of the absence of nuclear material or nuclear-related activities. The locations fall into three specific categories:

1. Locations not holding, or no longer holding, nuclear material.

2. Locations holding material that has not been processed to a level of purity for it to be suitable for fuel fabrication or isotopic enrichment, or holding material that has been exempted from safeguards verification measures by virtue of its non-nuclear use or nuclear material (typically in the form of waste) judged to be unrecoverable.

3. Locations hosting nuclear-related activities but not holding nuclear material.

The verification measures for the three categories comprise a subset of the following:

- Visual observation (common to all three categories).
- Collection of environmental samples (common to all three categories).
- Radiation detection and measurement (common to all three categories).
- Nondestructive measurements and sampling.
- Item counting.
- Application of seals…and other tamper indicating devices.
- Examination of records…of [nuclear] material.
- Other objective measures…agreed by the [IAEA] Board.

These locations and verification activities are summarized in Table 1.

SUMMARY OF LOCATIONS SUBJECT TO COMPLEMENTARY ACCESS AND PERMITTED VERIFICATION MEASURES

Main para	Sub para	Generic description		Permitted verification measures
		Locations not holding or no longer holding nuclear material		
5.a (i)		Any place on a *site* (co-located with a declared nuclear facility)	6.a	visual observation
5.a.(iii)		Any decommissioned facility or location outside facility (LoF)		collection of environmental samples
				radiation detection and measurement
				seals
				other objective measures - BoG approved
		Locations holding material that has not been processed to a level of purity for it to be suitable for fuel fabrication or isotopic enrichment or holding material which has been exempted from safeguards by virtue of its non-nuclear use or nuclear material for which safeguards has been terminated (Waste)		
5.a (ii)	2.a (v)	Any uranium mine or uranium or thorium concentration plant	6.b	visual observation
	2.a (vi) (a)	Any location holding source material quantities exceeding 10Te uranium and/or 20Te thorium		collection of environmental samples
		and other locations holding more than 1Te of such material where the collective holding of all such		radiation detection and measurement
		other locations exceeds 10Te uranium or 20Te thorium respectively		examination of records
	2.a (vi) (c)	Any location of the import of uranium and thorium in the above actual or cumulative quantities		(material quantities, origin and disposition)
	2.a (vii) (a)	Any location holding exempted material		NDA and sampling
	2.a (vii) (b)	Any location holding exempted material not yet in non-nuclear use form		item counting of nuclear materials

	2.a (viii)	Any location storing or processing high-level waste on which safeguards have been terminated		other objective measures - BoG approved
		Locations hosting nuclear- related activities but not holding nuclear material		
5.b	2.a.(i)	Any location of nuclear fuel cycle-related activities not involving nuclear material	6.c	visual observation
	2.a.(iv)	Any location engaged in Annex I activities		collection of environmental samples
	2.a.(ix) b	Any location holding imported Annex II materiel		radiation detection and measurement
	2.b	As 2.a (i) but where activities are not state funded or carried out on behalf of the state		examination of safeguards relevant records
				(production and shipping records)
				other objective measures - BoG approved
5.c		**Any location specified by the IAEA to carry out location specific environmental sampling**	6.d	collection of environmental samples
				AND IF QUESTION UNRESOLVED
				visual observation
				radiation detection and measurement
				other objective measures - BoG approved

Table 1. Summary of Locations Subject to Complementary Access and Permitted Verification Measures.

It is clear that, under the Additional Protocol, the IAEA's right of (complementary) access and freedom of choice of verification activities are considerably less than was provided in the case of its OMV plan implemented in Iraq. Nonetheless, given Iran's active cooperation, there is enough flexibility in the text of the protocol for the IAEA to be able to implement a verification process that would provide substantial assurance of Iran's compliance with its undertakings.

In the special context of this chapter, two Articles of the Additional Protocol are of fundamental importance:

1. Article 5.c, which would require Iran to ". . . provide the Agency [IAEA] with access to any location specified by the Agency . . . to carry out *location-specific environmental sampling* . . .," and

2. Article 9, which would require Iran to ". . . provide the Agency with access to locations specified by the Agency to carry out *wide-area environmental sampling* . . ."

Article 9, however, goes on to state that "The Agency shall not seek such access until the use of *wide-area environmental sampling* and the procedural arrangements therefore have been approved by the Board and following consultations between the Agency and [the state]."

Wide-area environmental sampling is defined in Article 18.g as meaning the collection of environmental samples (e.g., air, water, vegetation, soil, and smears) at a set of locations specified by the Agency for the purpose of assisting the Agency to draw conclusions about the absence of undeclared *nuclear material* or nuclear activities over a wide area. *Location-specific environmental sampling* differs only in its application being confined ". . . at, and in the immediate vicinity of a location . . ." and that the Agency's conclusions are drawn with respect to that ". . . specific location . . ."

It is clear from the foregoing that a legal basis for the implementation of WAES in Iran exists and, with the approval of the IAEA Board of Governors and the cooperation of Iran, could be implemented. Furthermore, the text of the Additional Protocol underwrites the fundamental value of environmental sampling as a contributing technology to the IAEA's ability to draw conclusions regarding the absence of undeclared *nuclear material* or nuclear activities. However, it is clear that a prerequisite to the implementation of WAES is a reasonable understanding of the costs involved and the technical resource requirements.

A Notional Plan for the Implementation of WAES in Iran.

There is no particular complication to the "front-end" of environmental sampling, it is simply a matter of determining what kind of sample is most appropriate and at which and how many locations the samples should be taken. The premise on which WAES is based is that any significant activities related to the processing of nuclear material would result in a detectable impact on the environment—either from chronic low-level releases or an acute high-level release following a processing malfunction.

In the context of a clandestine enrichment facility, WAES would be focused mainly on the detection of uranium but also on related processing elements such as fluorine. Due to its ubiquity, the mere detection of uranium is of little significance unless it is detected in concentrations markedly different from those occurring naturally in the area sampled or the relative abundance of the ^{235}U isotope is greater than .71 percent.

WAES is further complicated by the fact that in a state such as Iran with a history of uranium processing activities, analysis of deposition samples (such as surface smears or vegetation) would not be able to readily distinguish whether the material deposited was a result of current nuclear activities or originated from past activities. Although vulnerable to resuspension complications, it is now widely accepted that the sampling of air for the collection of particulate and gaseous matter is the most reliable and unambiguous means of detection of current nuclear activities. A variety of designs of air samplers exist, ranging from those little more sophisticated than a domestic vacuum cleaner to those capable of continuous analysis of the collected matter combined with the capability to transmit the results of that analysis to a headquarters control room.

However, the IAEA's experience in Iraq shows that simplicity of design and robustness of construction are likely to provide the most reliable performance. Ideally, the air sampling equipment would be housed within a small trailer or road vehicle and would have battery back-up and the capability to transmit alarm annunciations to an appropriate IAEA control and supervision location in the event of loss of power supplies or tampering. The transportability of the air sampling station enables the grid to be readily adjusted or, if appropriate, completely redesigned.

Nuclear forensics have achieved such extraordinary sensitivities that it is virtually impossible to sanitize radioactively contaminated surfaces or to avoid the detection of leakages of radioactive airborne or liquid discharges. For example, analysis of environmental samples—airborne particulate matter, water, deposited or sedimented materials—is capable of detecting the presence of uranium down to a few millionth, billionth, billionth parts of a gram. However, even with such sensitivities, it has to be recognized that the concentration of any environmental contamination reduces inversely and nonlinearly with the distance from the point of release. The actual reduction would be a function of terrain and the prevailing meteorological conditions.

A detailed topographical/meteorological study would thus be required to determine a practical detection range based on an assessed notional release and the practical limits of sample analysis. It is, of course this "detection range-R" that will determine the grid array of the air sampling stations and thus the related capital equipment costs, in-field service personnel resources costs, and analytical costs.

For purposes of this notional plan, it is assumed that air sampling stations would be set up on a regular square grid with the diagonal separation of the air sampling stations equal to the detection range. It follows that the grid would be of side $R/\sqrt{2}$ with a corresponding grid-element area of $R^2/2$. As a first approximation the number of air sampling stations could be calculated by dividing Iran's superficial area by the area of a single grid element. However, it would also be necessary to recognize the need for additional sampling stations to cover the perimeter of the grid. Again, for purposes of illustration, the number of additional air sampling stations is derived from the state's land boundary divided by $R/\sqrt{2}$.

Iran is not a small country and covers an area of some 1.65 million square kilometers with a land boundary of 5,400km. Based on the foregoing assumptions, a sampling network designed around a detection range of 10km would require an unmanageable 33,764 air sampling stations and even stretching the detection range to 100 kilometres would still require some 400 air sampling stations. As was the case in Iraq, it is likely that the relatively high levels of atmospheric dust would require frequent sample changing to avoid blockage of the collecting media. Assuming, therefore, that samples were changed on a bi-weekly basis, a 400-station network would generate some 10,400 samples per year.

A cost assessment of a 400-station network is shown in Table 2.

Operation	Cost
Detection range (km)	100
Number of air sampling stations	400
Equipment and installation cost per unit	$10,000
Amortization period (years)	3
Equipment and installation costs per year	$1,333,000
Number of service visits/year per installation	26
Servicing capacity (units/day-2 person team)	3
Servicing resources required (person-years[1])	40
Field Office resource requirements (person-years)	4
Personnel costs including travel and accommodation	$5,000,000
Number of samples collected for analysis	10,400
Cost per analysis	$1,000
Total analytical costs	$10,400,000
Total annual costs including equipment amortization	$16,733,000
Notional overall annual cost/air sampling station	$41,833
Notional overall cost per analytical result	$1,610

Table 2. Notional Cost Assessment of a 400-Air Sampling Station Network.

The data in Table 2 are produced simply to illustrate operational costs and should not be interpreted to suggest that the exampled network is capable of providing meaningful detection sensitivities. Indeed, the mountainous nature of much of the Iranian terrain will complicate the country-specific topographical and meteorological study and is likely to indicate the need for a nonuniform grid including areas requiring a more closely spaced grid.

Regardless of these complications, the table does show that the most critical component of overall cost is sample analysis, contributing, as it does to more than 60 peercent of the costs in the illustrative model. Furthermore, the data do not include the complementary environmental samples (herbage, smears, water, etc.) that should be collected. Although these samples could be collected without additional labor or equipment costs, they could potentially more than double the analytical load, pushing the total annual cost towards $30 million. Even without this extra burden, the number of samples generated in the Table 2 example far exceeds the currently available international analytical resources at the very highest level of sensitivity.

It should also be recognized that at $30 million these notional costs represent about 25 percent of the total annual operating budget of the IAEA Department of Safeguards, including voluntary contributions from motivated member states. At first glance, such costs seem inordinately high. However, it is merely necessary to change the comparator to, for example, the annual cost of the military action in Iraq or the "replacement costs" of Manhattan following the explosion of a 50 kiloton device to make the costs appear to be an entirely worthwhile investment.

The notional case outlined in Table 2 will clearly contain inaccuracies and is presented merely to arrive at an "order of magnitude" costing of WAES in the Iran context. However, many obvious refinements are available.

One such refinement would be to carry out a detailed analysis of Iran on the basis of a 10km grid, and to weight each grid section with respect to any attributes therein that could contribute to sustaining clandestine nuclear activities. Such attributes would include, for example, access to power and water supplies, population centers, road and rail transport, and geological conditions compatible with undergrounding. On the basis of this analysis, it would be possible to determine those "high-potential" areas of the country worthy of continuous and intensive monitoring activities—probably less than 10 percent of the total area. Within the so-termed high-potential areas, air sampling stations would be positioned in conformity with location-specific detection range calculations. Areas of significantly lesser potential would be subject to less intensive sampling and analysis.

Another simple refinement is available in the analytical process in that portions of samples from contiguous locations could be blended and analyzed as a composite batch sample. Should analytical results from the composite sample so indicate, the individual sample portions could then be analyzed. It should also be recognized that WAES serves, at least in part, as a deterrent and provided the "target" is unaware, its effectiveness is undiminished regardless of whether all or only a fraction of the samples collected are actually analyzed.

Yet another refinement would be to either complement or entirely replace WAES by multiple location-specific environmental sampling wherein the locations would be chosen of the basis of their high-potential to support undeclared nuclear activities or on the basis of information provided to or independently developed by the IAEA. It is clear that motivated member states should be investing considerable resources in gathering information relevant to Iran's professed peaceful uses of nuclear energy; for example, by aerial/satellite surveillance, telecommunications monitoring, and export/import monitoring. It is equally clear that those states should be in a position to provide "cues" to the IAEA to identify *locations worthy of location-specific environmental sampling* and, as appropriate, *complementary access*.

Recommendations.

1. If not already "work in progress," the IAEA should commission a working group of internal and external experts to design a plan for the implementation of WAES in Iran based on a detailed analysis of the topographical and meteorological characteristics of its various regions. The plan should include realistic cost analyses and address the various options available between full-scope WAES and the targeted/cued implementation of multiple *location-specific environmental sampling* campaigns.

2. Motivated IAEA member states should reevaluate their relevant information gathering system and establish formal pathways for the prompt transmission of information to the IAEA.

3. Those states having high sensitivity analytical capability—principally the United States, the United Kingdom, and France—should invest significantly in the expansion and further development of those capabilities to ensure that the international community will be in a position to satisfy the demand in the event that it becomes necessary/appropriate to implement WAES in Iran or elsewhere.

4. The IAEA Board of Governors should address the question of funding for the implementation, as necessary, of WAES. Too often in the past, too many

IAEA Member States have been more focused on the financial savings that could result from the evolution of safeguards technologies and approaches. It is time to recognize that the cost of international nuclear material safeguards is trivial when compared to the financial burden of pragmatic "worst case scenarios" that might result from failure to implement robust safeguards measures at the leading edge of technological excellence.

ENDNOTES

1. As approved in United Nations Security Council Resolution 715, October 11, 1991.

2. Access to locations other than those containing declared nuclear materials.

3. Assuming a 3-month tour of duty and a 6-day working week and taking into account annual leave, official holidays, and compensatory time off, 1 person-year equates to 170 inspection days.