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Open Source Analysis in support to the identification of possible undeclared nuclear activities in a State

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Abstract:

The revelation of Iraq's clandestine nuclear weapons program in the 1990s first made clear the necessity of bringing new tools to bear in the implementation of IAEA Safeguards. The adoption in 1997 of the Additional Protocol by the IAEA Board of Governors paved the way to the introduction of the State Level Approach. The IAEA's quest for such increased transparency regarding nuclear-relevant activities continues to evolve with the adoption of additional sources of safeguards-relevant information. A wide variety of information is available through official publications, academic and technical journals, and other media from which to glean insights on not just the capabilities of a nation-state, but also the direction of research and development along the varied paths to nuclear proliferation. Open source Information can also be found via various blogs that have particular areas of interest relevant to treaty monitoring and verification organizations. Commercial satellite imagery has, since the turn of the new millennium, become an increasingly valuable open source for IAEA Safeguards purposes.

Open source information can play an important role in several aspects related to the implementation of the Non-Proliferation Treaty provisions. The paper will briefly introduce the IAEA State-Level Concept (SLC), the role of Open source information in this context and then focus on some methodological considerations related to the use of open source information to investigate the existence of potential undeclared nuclear activities in a State. Finally, the paper will show how the combination of heterogeneous open source and geospatial information can lead to sig. nificant, but otherwise unknown, information for nuclear safeguards applications. In particular, the paper will present an exemplary application, in which, following-up on a single report from Iranian news, a review of commercial satellite imagery (including that available cost-free via Google Earth©) has made possible the identification of the location of the facility now known as the "Pasmangoor Nuclear Waste Storage and Stabilization Facility" in Anarak, Iran, and a new near-by small (likely pilot scale) ore processing facility that was completed near a previously abandoned, but recently reactivated, mine. The mine is known to contain copper, nickel, cobalt, arsenic, and uranium, making the new facility potentially of safeguards relevance.

Keywords: IAEA State-Level Concept, Open Source Analysis, Non-Proliferation.

1. Introduction

The revelation of Iraq's clandestine nuclear weapons program in the 1990s first made clear the necessity of bringing new tools to bear in the implementation of IAEA Safeguards. That program "*exposed all too clearly the limitations of a safeguards system focused exclusively on declared nuclear material*" [1] and which was only focused upon declared nuclear sites. The adoption in 1997 of the Additional Protocol [2] by the IAEA Board of Governors helped "*to detect deviations from what might be expected in a peaceful nuclear program sooner*" [3] and paved the way to the introduction of the State-Level Concept (SLC). The IAEA's quest for such increased transparency continues to evolve with the adoption of additional sources of information. The Agency "*carries out a comprehensive evaluation of all available safeguards-relevant information – including data provided by the state, the results of the agency's in-field activities and its extensive collection of safeguards-relevant information from open sources (such as scientific publications, conference records, and commercially available satellite imagery) – looking for consistency with the state's declarations*". [4]

Commercial satellite imagery has, since the turn of the new millennium, become an increasingly valuable open source for IAEA Safeguards purposes. Moreover, "satellite imagery is used routinely to evaluate information provided by States on their nuclear activities and to plan inspections, visits to facilities to verify design information and to conduct complementary access under the Additional Protocol." [5]

Open source information can play an important role in supporting several aspects of the SLC [6], integrating and supplementing the information retrieved from States' declarations and infield verification activities. In particular, Open source information has the potential of being the main key source of information for identifying potential undeclared nuclear activities in a State, an area that

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historically proved to be the most challenging of the entire non-proliferation regime.

The paper will briefly introduce the IAEA State-Level Concept (SLC), the role of Open source information in this context and then focusses on some methodological considerations related to the use of open source information to investigate the existence of potential undeclared nuclear activities in a State. Finally, the paper will show how the combination of heterogeneous open source and geospatial information can lead to significant, but otherwise unknown, information for nuclear safeguards purposes. In particular, the paper will present an exemplary application, in which, following-up on a single report from Iranian news, a review of commercial satellite imagery (including that available cost-free via Google Earth) has made possible the identification of the location of the facility now known as the "Pasmangoor Nuclear Waste Storage and Stabilization Facility" in Anarak, Iran and a new near-by small (likely pilot scale) ore processing facility that was completed near a previously abandoned mine. The area is known to contain copper, nickel, cobalt, arsenic, and uranium.

2. The IAEA State-Level Concept

To implement the NPT [7], International Atomic Energy Agency (IAEA) Safeguards saw significant changes in the last 20 years aimed at meeting the verification challenges posed by an evolving nuclear and geo-political context. Through the Additional Protocol (AP), introduced in 1997, verification activities on declared sites aimed at detecting the diversion of material and the misuse of declared facilities were supplemented by additional tools to assure the absence of undeclared nuclear material and activities on both declared sites and undeclared locations.

The IAEA's State-Level Concept (SLC) foresees a holistic approach to nuclear safeguards considering that the State is a whole greater than the sum of its (declared) nuclear-related facilities. The SLC "*applies to all States and involves a comprehensive State evaluation and State-level safeguards approach, including the identification of specific safeguards measures for each State, implemented through an annual implementation plan*." [8]

Within the SLC, the IAEA verification activities are carried out according to a tailored "State-Level Approach" (SLA), adapted to each State, to be able to detect diversion or misuse of declared nuclear material and facilities, as well as the existence of undeclared nuclear material or activities [9, 10].

Central to the State-Level Approach (SLA) for safeguards, the Acquisition Pathways Analysis (APA) allows the IAEA to estimate the possible routes and the time needed to achieve weapons-usable material. The estimates take into account all the available safeguards-relevant information on a State. On the basis of this analysis, the IAEA will then be able to design and plan the specific verification activities needed to reach the safeguards technical objectives in the State, with a schedule informed by acquisition pathways completion times and the effectiveness and efficiency of the available safeguards measures. The State-Level Approach follows an annual implementation plan, and is re-evaluated and adapted yearly [9-11].

3. Open Source Analysis in Non-proliferation

Surprisingly enough, there is no universally accepted definition of "open source information" and "open source analysis". For the purpose of this paper, in line with previous works (see e.g. [12, 13]), "open source information" will be defined as "*publicly available material that anyone can lawfully obtain by request, purchase, or observation*." [14] As it can be seen, it is a very general and inclusive definition, de facto excluding only explicitly classified information. Within the NPT safeguards regime, the IAEA includes in the "open source information" basket "*information generally available from external sources, such as scientific literature, official information, information issued by public organizations, commercial companies and the news media, and commercial satellite imagery*" [15] and trade data [16, 17].

The broadness of the open source information definition above gives room to some fuzziness: for instance it is not clear if grey literature (i.e. non-classified material not meant for unlimited public dissemination and therefore not available through the standard publication channels such as technical reports, working papers, ephemeral publications, etc.), which some studies consider to be open source [18], can be assumed to be included.

If the definition of open source information is not universally shared, the definition of open source analysis is even more fragmented. In this paper, open source analysis will be defined as a process of "*getting the right information (what) to the right people (who) at the right time (when) for the right purpose (why) in the right forum (where) and in the right way (how)*" [19] by "*merging openly available data and information coming from a wide variety of accessible sources into an overall comprehensive and cohesive picture*" [12].

Table 1 reports the four broad analytical areas in which open source analysis in support to non-proliferation can be grouped and presents some possible information sources.

Analytical Area	Sources
Technical/information analysis	Scientific Literature, official information, information from public entities, commercial companies [20]
Media monitoring	News, blogs, social networks [21, 22]
Imagery analysis	Commercial satellite imagery, photographs, video snapshots [23]
Import/export Analysis	Trade data [17, 24], legal/illicit procurement information

Table 1: Open source analytical areas potentially supporting non-proliferation. Adapted from [6].

One of the main problems with open source analysis in non-proliferation is the fact that only a very small part of the information collected can be considered to be relevant. Typically the analyst needs to collect and then filter out substantial quantities of information to assemble a sparse and incomplete set, not necessarily contributing to knowledge [25]. In addition, the quality of the information might result to be dubious and the risk of deliberate deception high [26-28]. Despite all these problems, open source analysis has the potential of being one of the most promising sources of discovery and detection of undeclared nuclear activities on undeclared sites in a State. The following sections will focus on the possibility to use open source analysis to derive new insights on potentially undeclared nuclear activities[1] in a Non-Nuclear Weapon State (NNWS) that signed the NPT.

4. Some Methodological Considerations

While no verification activity is without issues, the detection of undeclared activities on undeclared sites faces formidable technical and epistemological challenges that would require dedicated research. The following paragraphs will provide a brief overview of some of them, highlighting the complexity of the task the IAEA has to carry out.

4.1 IAEA Safeguards Implementation Statements

According to the NPT, The task of the IAEA is to implement safeguards on Non-nuclear-weapon States (NNWSs) "*for the exclusive purpose of verification of the fulfilment of its obligations assumed under this Treaty with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices*" [7]. Currently, NNWSs can be broadly categorized in four groups:

1. States with a Comprehensive Safeguards Agreement and the Additional Protocol in force, for which the Agency already drew a broader conclusion;
2. States with a Comprehensive Safeguards Agreement and the Additional Protocol in force, for which the Agency has not already drawn a broader conclusion;
3. States with a Comprehensive Safeguards Agreement but no Additional Protocol;
4. States without a Comprehensive Safeguards Agreement.

For group 1, in 2017 the Agency concluded that for 70 States "*all nuclear material remained in peaceful activities*" [29]. For groups 2 and 3 the Agency concluded that, "*declared nuclear material remained in peaceful activities*" [29]. For group 4 the Agency "*could not draw any safeguards conclusion*" [29]. As it can be seen, the IAEA was able to exclude the presence of undeclared nuclear material and activities only for group 1, limiting itself to a statement over the *declared* nuclear material for groups 2 and 3.

The pivotal difference between the States in group 1 and those in group 2 is the broader conclusion of absence of undeclared material and activities. To reach a broader conclusion, the IAEA "*must draw the conclusions of both the non-diversion of the nuclear material placed under safeguards (as described above) and the absence of undeclared nuclear material and activities for the State as a whole*" [30]. The broader conclusion allows the entry into force of the Integrated Safeguards regime.

The evaluation and verification of declared nuclear material and activities is conceptually straightforward (even though it might be extremely resource-intensive), and is mainly based on onsite verification activities and measurements. The confirmation of the termination of past nuclear activities and the dismantlement of the related facilities (e.g. a decommissioned civilian nuclear fuel cycle programme or part of it) is usually performed through information gathering and complementary accesses, foreseen under the Additional Protocol, and does not represent unsurmountable conceptual challenges as it is known that there was a programme and the conditions of its termination have been stated and could in principle be verified. The Agency concludes that there is no undeclared nuclear material or activity in a State when "*the activities performed under an additional protocol have been completed, when relevant questions and inconsistencies have been addressed, and when no indications have been found by the IAEA that, in its judgement, would constitute a safeguards concern*" [30].

The sentence there is "*no indication of undeclared nuclear material or activities*" [29] can be read as "given the verification activities planned and performed on the basis of our past and present knowledge of the State, we found

[1] For an overview on what are nuclear materials and activities to be declared (and how they should be declared), see e.g. [8].

'*no indication of undeclared nuclear material or activities'* [29]" and therefore it is possible to conclude that "*all nuclear material remained in peaceful activities*" [29]. The last *therefore* relies on the inductive inference: "The n verification activities performed did not find evidence of an undeclared activity, and they are considered to be sufficient to state that any additional verification activities would not find evidence of undeclared activities". Hence we can conclude that there is no undeclared activity. Since "*[t]he very nature of an inductive argument is to make a conclusion probable, but not certain, given the truth of the premises*" [31], it becomes extremely important to discuss how the strength of this conclusion can be characterized and made explicit, i.e. characterize its *dependability*.

While "*Truth with a capital T is an attribute of statements that correspond to facts in all possible contexts*", *dependability* is an attribute of statements that correspond to facts in a "*specified (but often not clearly identified) context*" [19]. A statement is considered to be more or less dependable subject to the degree to which it has been tested. Having to rely on dependability rather than on truth implies that the aspect of uncertainty management is important to make sure the decision-maker obtains an accountable message.

Although there are several ways of describing uncertainty (see e.g. [32]), here uncertainty will be set to include two main aspects: *aleatory* and *epistemic* [33] Aleatory uncertainty, also called randomness, is related to data exhibiting an intrinsic lack of a specific pattern, and is investigated by classical probability theory. This source of uncertainty is intrinsic and cannot be eliminated. Epistemic uncertainty describes the analyst's less than perfect knowledge of the data, and could theoretically (but de facto not practically) be reduced to zero. In every analysis entailing uncertainty, aleatory and epistemic uncertainties are intertwined and need to be dealt with [34].

4.2 Dependability of Open Source Analysis in identifying an undeclared nuclear activity is still an unknown

Excluding the provision of third-party information and assuming no open anomaly or discrepancy arising from declarations and inspections, the main source for discovering potential undeclared nuclear activities in a State at the Agency's disposal is open source information collection and analysis. To understand the degree of dependability of the statement "no undeclared nuclear activity exists in the State as a whole", one would need to identify, for each nuclear activity:

1. Which are the potential indicators one might aim at to identify its presence and what is their strength;
2. Which are the tools that would be able to identify the existing indicators and what is their efficiency in detecting them;
3. What is the effectiveness of the available detection methods in detecting an existing signal in a real world scenario. This implies the knowledge of, *inter alia*, the size of the search space and the share of the search space the safeguards staff can reasonably cover with a given technique.

Some information about which are the potential indicators of existence of a particular nuclear technology in a State is available to the IAEA in the Physical Model [35] (point 1), and, although to the authors' knowledge it has never been published in the open Literature, it is possible to create a catalogue of potential tools able to detect the various indicators (point 2). The task of producing this catalogue is not without challenges as, for a given technology, the scientific community has contrasting opinions about their difficulty of implementation and detection [36, 37].

Understanding the size of the search space and the share of the search space the safeguards staff can reasonably cover with a given technique still represents a challenge. To make things worse, deliberate deception and signal suppression by the proliferator could lower the detection efficiency (Table 2 reports examples of concealment techniques that a proliferator could adopt to suppress/scramble potential signals available in the open source).

Gathering evidence for the presence of indicators of a nuclear engineering programme in a State, especially when related to military aspects and therefore with active efforts to keep it concealed, means having to deal with additional epistemological issues [39]:

- The analyst is out to detect something whose existence is uncertain. Making a parallelism with any classic measurement performed by an inspector on declared nuclear material in a declared facility [40, 41], while the three postulates of the theory of measurement [42] inform the inspector that he will never know the absolute true value of the characteristics he is measuring, they also inform him that the true value does exist and it is -within the limit of the typical safeguards measurement campaigns - de facto constant. In contrast, when searching for indicators of a possible clandestine nuclear programme, the analyst does not know whether such a programme really exists.
- Assuming that the clandestine programme exists, the analyst does not know its characteristics, and therefore would not be in the position to choose the best detection method for finding indicators of its presence[2]. This not only impacts effectiveness and efficiency, but also adds considerable epistemic uncertainty about the outcome of the verification activities.

[2] One of the purposes of the Acquisition Pathways Analysis step of the State Level Concept is to guide the analyst to the most likely characteristics of a possible clandestine programme.

OS Analysis	Type of Signature	Possible Concealment
• Technical/official information analysis • Media monitoring	R&D activities	• Manage publication activities • Use widely available technical information • Claim legitimate applications • Cover stories
	Environmental monitoring, public health records	• Suppress effluents • Suppress reporting
Imagery Analysis	Security features of infrastructure	Conceal or place within other secure facilities
	Functional and Operational design features	Mask true use through signature suppression
Import/Export analysis	• Patterns of material acquisition • Special equipment acquisition • Imports of dual-use equipment	• Shuffle, divert acquisitions • Obtain from multiple suppliers/intermediaries • Mix with legitimate uses • Develop clandestine networks • Produce indigenously • Divert equipment from legitimate activities • Claim legitimate uses

Table 2: Examples of concealment techniques to suppress/scramble potential signals in the open source. Adapted from chemical and biological weapon program signatures and concealment actions [38] as presented in [6].

Actions	Possible Sources
1. Monitor the New Media for cueing insights (cast a wide net for new information)	Blogs, news aggregators, pushed emails from topical interest groups, paid subscription services
2. Search area of interest on virtual globes based on cueing from collateral information	Google Earth, Here, Bing Maps, Flash Earth, Yandex Maps, Arc GIS (online base map imagery)
3. Review all related geospatial labeling	Wikimapia, Google Earth Community forums
4. Review all available ground imagery on social media, photo–sharing sites, videos for additional possible insights	Lookr, Flickr, Worldflicks, Instagram, YouTube, etc. Some of them available as Google Earth layers
5. Follow-up with search of cues and cues derived from labeling, including imagery and news	Google, Bing, Yahoo, Yandex, Baidu, Armscontrolwonk, ISIS-online, etc
6. Review all available historical overhead imagery on Google Earth	Google Earth Historical Layer
7. Cross-reference images with commercial satellite imagery vendor archives to: a. Determine acquisition dates b. Review most recent imagery in archives for any significant changes c. Determine if additional imagery purchase is warranted	Digital Globe, Airbus, etc. Metasearch engines as Image Hunter are sometimes useful.
8. Determine if enough information is available to make an assessment	Make determination with appropriate caveat (definite, probable, possible, suspect, etc) or not enough information.

Table 3: Possible actions for promoting imagery-related discoveries in the Open Source [22].

- In addition to the above-mentioned issue, even in the case in which the analyst chooses the appropriate method for detecting the existence of a given indicator, as previously discussed the actual detection probability of the presence of an indicator given its existence when using a given detection/measurement technique is often not known as no dependable attempts to investigate this aspect are available.

As a consequence, it is very difficult to tell the real, effective degree of dependability of verification activities for undeclared activities on undeclared sites.

Despite the current efforts in trying to systematize the possibility of making new discoveries [43, 44], until the above aspects are exhaustively investigated, it is likely that the discovery of undeclared activities on undeclared sites will remain serendipitous [22].

4.3 Potential actions for Deriving New Insights from Open Source Imagery Information

Table 3 proposes a potential set of actions for promoting discoveries in the Open source that might reveal potential undeclared nuclear activities on undeclared sites as presented in [22].

With all the caveats previously expressed, open source analysis can provide insights on previously unknown aspects of a nuclear fuel cycle in a State, and the above actions can potentially enhance the possibility of making new discoveries combining open source information and high resolution satellite images. The next section will provide an example of a new discovery in the field of potential nuclear-related activities in a State. Where relevant, references to the above actions will be made.

While some of the above actions are usually performed in sequence (e.g. actions 2-3, sometimes actions 2-7), they should not be intended as a rigid ordered sequence: depending on the nature of the initial cue (e.g. a high-resolution image in a virtual globe or a blog post), the other actions will follow according to the most suited sequence.

5. Exemplary Application of Heterogeneous Open Source Fusion for Deriving New and Potentially Safeguards-Relevant Information

By following-up on a single media report of the construction of a national radioactive waste storage facility located near Anarak, Iran, it was possible to correctly locate and characterize the radioactive waste site with commercial satellite imagery (starting with Google Earth), but it also became possible through subsequent open source analysis of the geological setting of that radwaste site to discover that a nearby, previously abandoned, mine – known to be in an area containing copper, nickel, cobalt, arsenic, and uranium – that had been reactivated, and, moreover, that an ore processing facility (likely pilot-scale) had been newly-established nearby to process ore from that mine. This is illustrated in the following sections. Reference is made of the “Actions” mentioned in Table 3.

5.1 Background

Anarak, Iran, is identified in the open literature as having historically been the site of three nuclear-related sites. Two were former uranium mines (identified as Talmessi and Meskani) with the third a small interim solid radioactive waste site. The mines have long been considered to have been mined-out and abandoned. The interim solid radioactive waste site was decommissioned in 2004. The solidified radioactive waste previously stored there, was generated during operations on small amounts of imported UO_2 that had been prepared for targets at Jabr Ibn Hayan Multipurpose Laboratories (JHL), irradiated at the Tehran Research Reactor (TRR), and sent to a laboratory belonging to the Molybdenum, Iodine and Xenon Radioisotope Production Facility (MIX) in Tehran for separation of ^{131}I in a lead-shielded hot-cell. Iran had informed the IAEA that the remaining nuclear waste was solidified and eventually transferred to a waste disposal site at Anarak. Upon request by the IAEA, that waste was removed and transferred from Anarak to JHL in January 2004 for inspection. As of that time, no more nuclear material was known to be at the Anarak facility.[3] However, in October 2014, Iran media reported that “*[c]hief of the Atomic Energy Organization of Iran (AEOI) Ali Akbar Salehi paid a visit to a long-term nuclear waste storage facility in the central province of Isfahan…to get update in the on the construction of the nuclear waste stabilization and storage facility.*”[4] (Action 1)

5.2 The Pasmangoor Nuclear Waste Stabilization and Storage Facility

In early-2015, a search was conducted of commercial satellite imagery of the Anarak area, which made possible the identification of a likely candidate for the “Nuclear Waste Stabilization and Storage Facility” nearing completion near Anarak, Iran [45]. Having first located that candidate site on the most recent imagery available from Google Earth at that time (July 16, 2013) and having seen on the historical layer of Google Earth that the site was first underway by October 2011 (Action 2 and 6), a review of Digital Globe imagery archives revealed multiple acquisitions centered on that same site, indicating that this site first began attracting continuing interest by unknown others in early 2014 (Action 7). The facility exhibited the requisite features for a secure storage vault-type radwaste structure situated in a dry and stable area that is not susceptible to flash flooding (see Figure 1 and Figure 2) [46]. Available geological reports and a cross-section of the area, which highlight previously abandoned uranium mines located nearby, describe the geological setting as that of a “graben-syncline”[5], providing additional evidence for the site being appropriate for the storage of radwaste, as the subsurface geology is also stable. [47] (see Figure 3).

On April 7, 2016 (as part of the celebration of the tenth “National Nuclear Technology Day” in Iran), Iran inaugurated the “Pasmangoor Nuclear Waste Stabilization & Storage Facility”[6] and videos were presented by the Iranian government and subsequently posted on YouTube, which verified the above analysis (Action 4).[7] Those videos provided both aerial drone imagery of the site and interior views of the main storage vault building with radioactive waste storage canisters shown being off-loaded from a delivery truck by an overhead crane and into one of the concrete vaults. (see Figure 4 and Figure 5)

3 http://www.globalsecurity.org/wmd/world/iran/anarak.htm
4 http://www.tasnimnews.com/English/Home/Single/543275
5 A ‘graben syncline’ is a concave fold of rock layers with its limbs lifted by faults, as a result of which the core of the fold becomes displaced downward relative to the rock layers on either side, as in a rift valley.
6 http://www.tasnimnews.com/en/news/2016/04/07/1042135/iran-unveils-12-nuclear-achievements-includingnew-n-waste-facility
7 https://www.youtube.com/watch?v=YbzzVeXlVOA and https://www.youtube.com/watch?v=_bQTYpz3ylg. The first mention of the Pasmangoor radioactive waste storage site was in an IAEA report from 2000, which reported that it was under preliminary site investigation. See: IAEA Waste Management Database: Report 2 - L/ILW-SL, March 28, 2000. http://www .pub.iaea.org/MTCD/publications/PDF/rwmp-3/Report_2.pdf. The plans called for “near surface disposal” in a “simple storage building.”

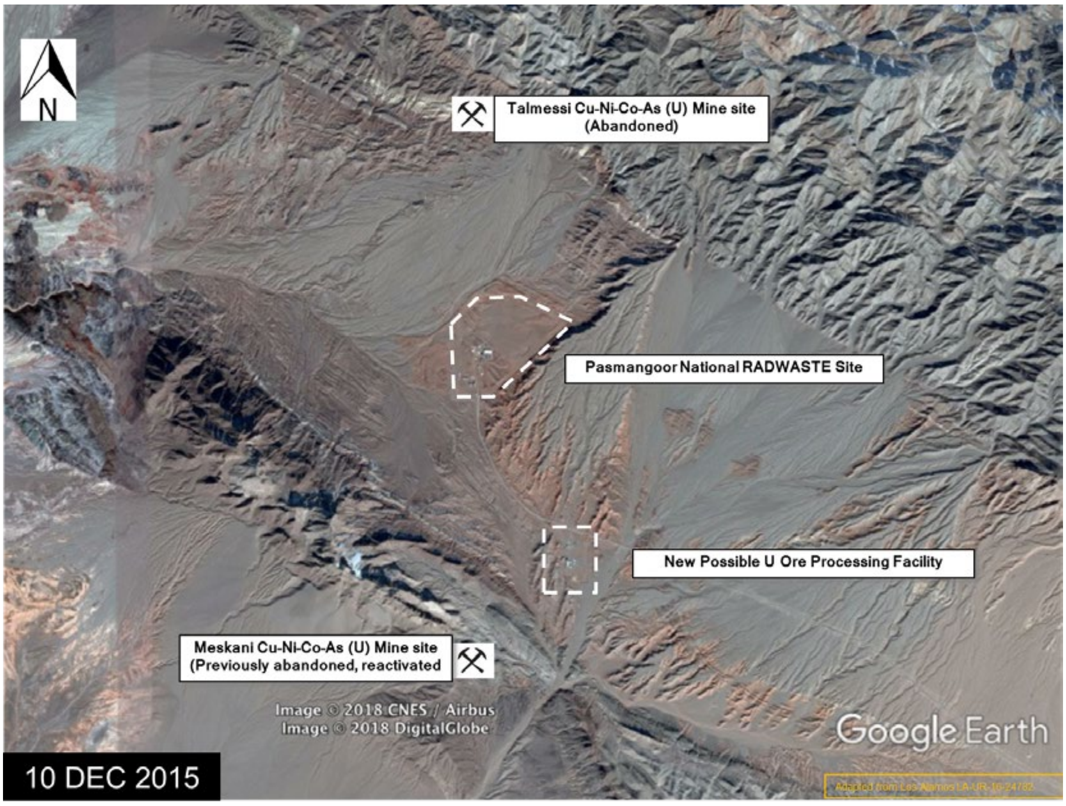

Figure 1: The Pasmangoor Nuclear Waste Stabilization and Storage Facility and the adjacent new possible uranium ore processing facility in relation to two known and previously abandoned uranium mines near Anarak, Iran. Given the proximity to two well-known uranium-mining areas, it would not be unreasonable to assume that this entire area is now under the authority the Atomic Energy Organization of Iran (AEOI).

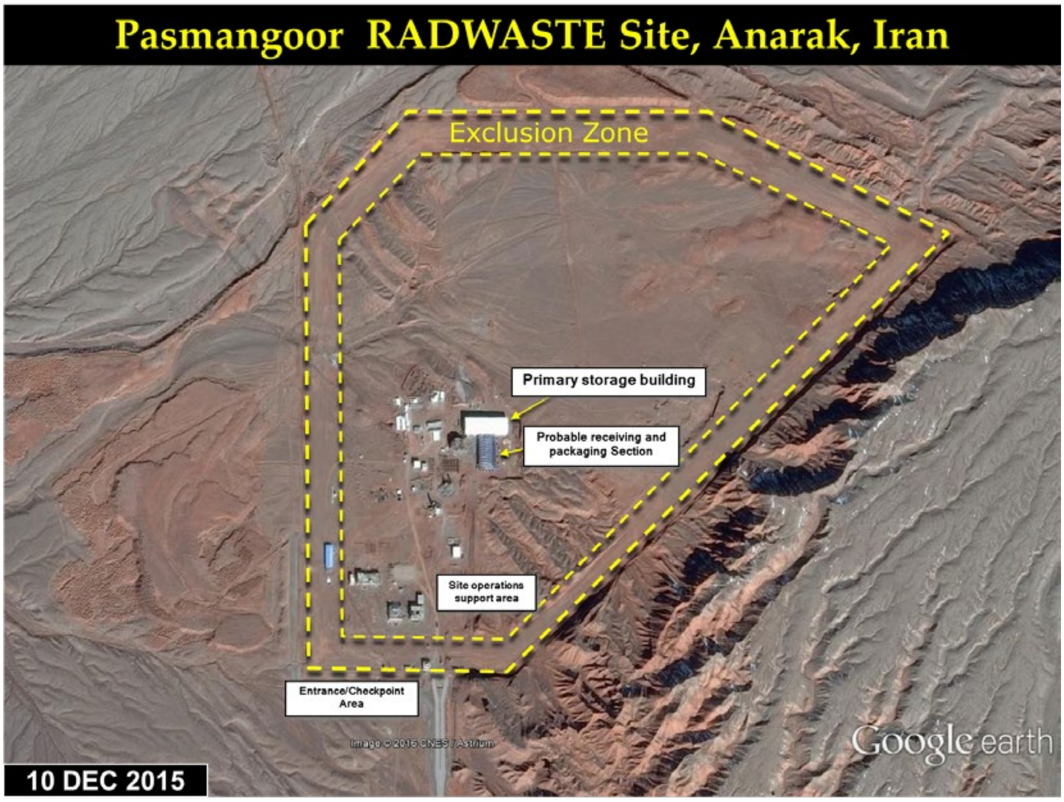

Figure 2: Overview of the new Pasmangoor Nuclear Waste Stabilization and Storage Facility near Anarak, Iran, as viewed on Google Earth. Note that the facility is double-perimeter-secured with a graded exclusion zone in between.

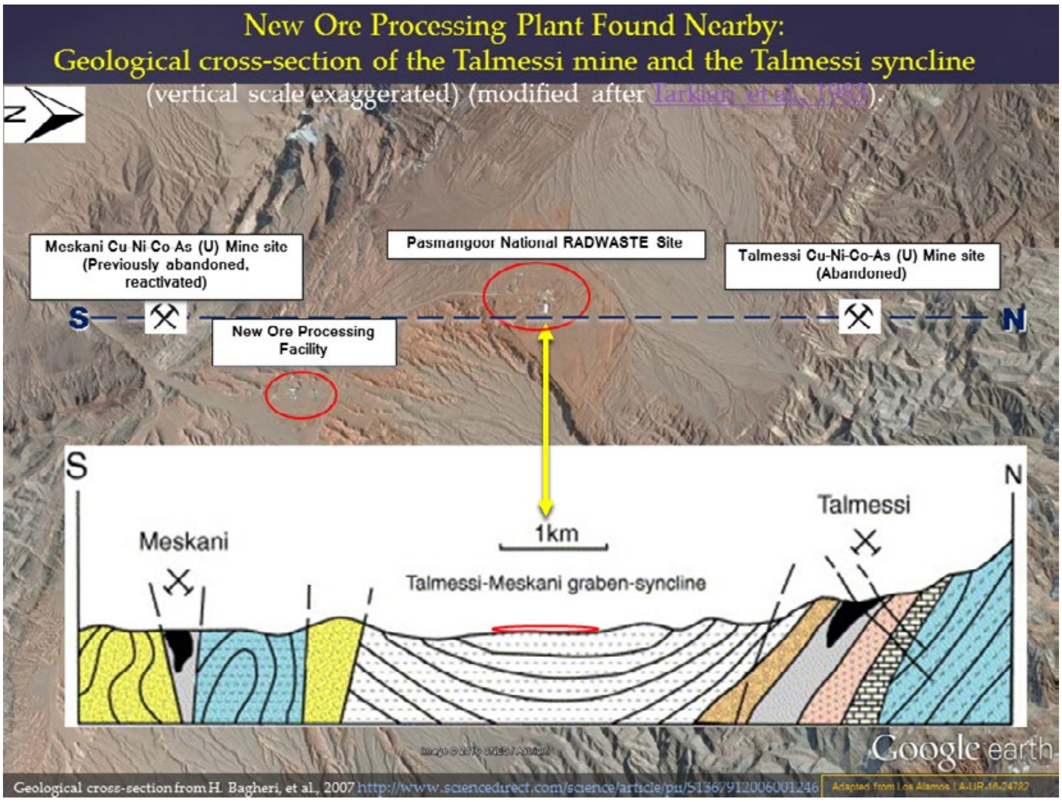

Figure 3: Geological cross-section running south to north (left to right) through the two former uranium mines and the new Pasmangoor national nuclear waste stabilization and storage facility. The vertical scale is exaggerated and this figure is modified after [48] as reported with the geological cross-section from [47].

Figure 4: The Pasmangoor Nuclear Waste Stabilization and Storage Facility near Anarak, Iran. The white-roofed building is the concrete vault radwaste storage building. See: https://www.youtube.com/watch?v=YbzzVeXlVOA

Figure 5: Interior views of the main concrete vault storage building as seen on an Iranian publicly posted video.
See: https://www.youtube.com/watch?v=_bQTYpz3ylg

5.3 The New Meskani Ore Processing Facility

The Pasmangoor Nuclear Waste Stabilization and Storage Facility identification started from a news media report, continued on high-resolution imagery and was corroborated by audiovisual posted on the web. The following example originated from the analysis of the high-resolution satellite images of the Pasmangoor Facility, continued with the search of scientific literature about the geology of the area and finally obtained additional corroboration over time by monitoring the evolution of the site's activities on high-resolution satellite imagery and researching of the site with open source tools.

In July 2018, Google Earth provided more current (July 4, 2018) commercial satellite imagery of higher resolution of both the Pashmangoor radwaste facility and a second facility (which during initial construction appeared as some type of "Entrance Facility" for the new radwaste site – Action 2). That second facility could be identified remotely on satellite imagery as a small "ore processing facility", and exhibited sufficient features to be assessed as a small (e.g., pilot-scale) "possible uranium ore processing facility" (See Figure 6). Among the noteworthy features of that facility which compared favorably with those found at the known Yellowcake Production Plant (YPP) located near Ardakan, Iran, include: truck scales and possible radiometry station on the road from the mine site (see Figure 7, top); and a segregated ore pile storage area (see Figure 7, bottom). Other identified features include: an ore receiving, crushing, grinding and conveyor circuit; five probable fine ore storage silos; a probable leaching building; a probable mixer-settler solvent extraction shed; reagent storage tanks; and a small concrete lined possible water-holding tank. More recent imagery from mid-2018 shows that an 11-meter diameter clarifier/settler tank had been added, along with what might be a growing processing waste pile (See Figure 8). Figure 9 provides another comparison of the ore processing related infrastructure observed at the Yellowcake Production Plant (YPP), Ardakan, Iran with that observed at the new ore processing facility associated with the Meskani copper-nickel-cobalt-uranium mine near Anarak, Iran.

Physical site security includes an entrance/exit checkpoint near the main road, and makeshift earthern barrier walls, which might also serve as visual obscuration berms for perimeter security along the road to the Pasmangoor nuclear waste stabilization and storage facility (see Figure 10**)**. Imagery from late May 2016 indicated that the ore processing facility could have become operational, as the ore piles had changed and liquid was visible in the formerly clean concrete lined holding tank (action 6). The nearby Meskani copper-nickel-cobalt-uranium mine site, which had been abandoned for decades, had evidently been reactivated (Action 6), and one large operations support building (with a blue roof) was constructed during February 2014 (See Figure 11). The mine and ore processing facility are serviced by a newly paved access road, which had just been built to support the Pasmangoor radwaste site.

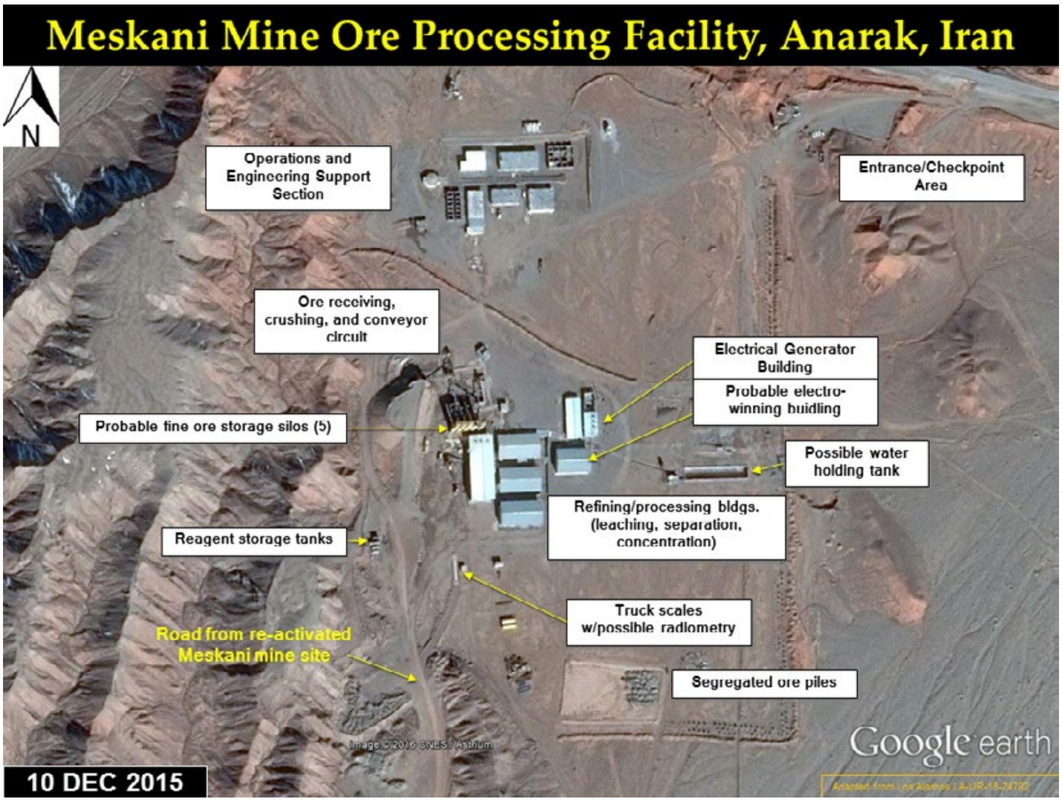

Figure 6: Late-2015 overview of the new small ore processing facility serving the newly re-activated, adjacent, Meskani mine. Labels identify the more likely roles of each part of the facility for illustrative purposes and are not meant to be definitive.

Figure 7: Comparison of features observed at the Yellowcake Production Plant (YPP), Ardakan, Iran with those observed at the new ore processing facility associated with the Meskani mine near Anarak, Iran. The top left shows an ore discrimination station with scales and radiometry for incoming ores from the Saghand uranium mine. The top right shows a similar appearing truck scale for the new small ore processing facility near the Meskani mine. The lower left shows the uranium ore on a storage pad near the ore crushing and grinding circuit at the YPP. The lower right shows mined ore piles on a storage pad at the new small ore processing facility near the Meskani mine.

Figure 8: Mid-2018 view of the new small ore processing facility serving the newly re-activated, adjacent, Meskani mine. Labels identify the more likely roles of each part of the facility and are not meant to be definitive.

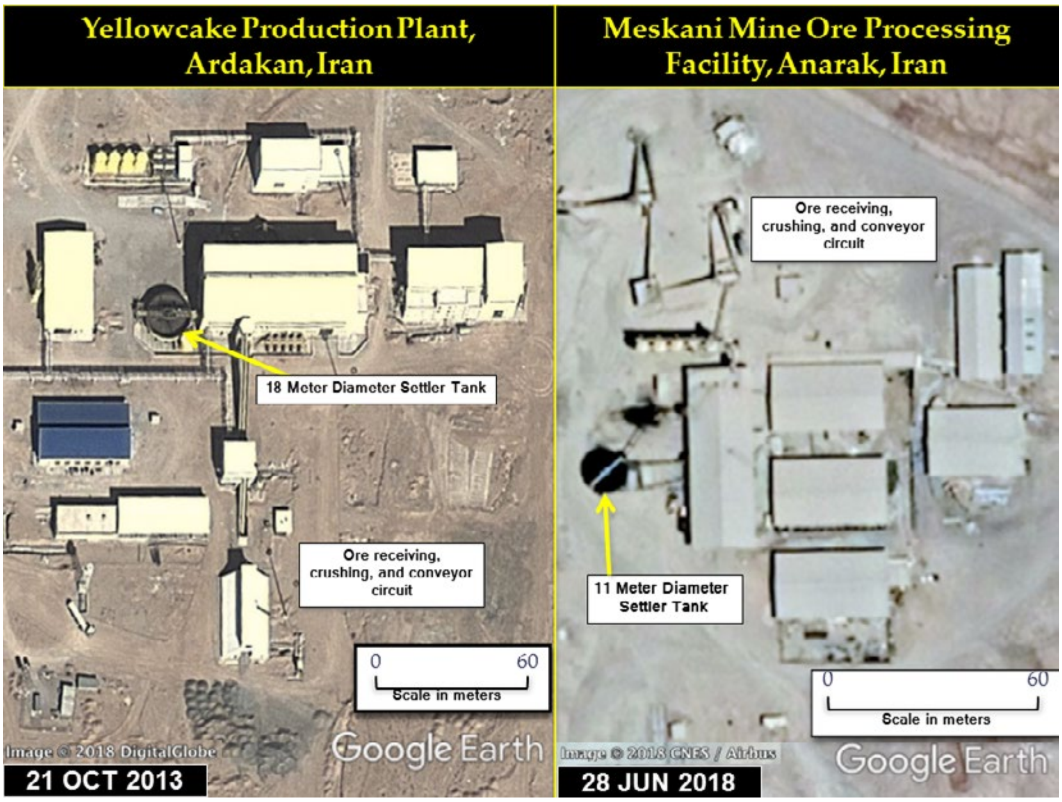

Figure 9: Comparison of ore processing related infrastructure observed at the Yellowcake Production Plant (YPP), Ardakan, Iran with that observed at the new ore processing facility associated with the Meskani mine near Anarak, Iran. An 11-meter diameter clarifier/settler tank was added to the processing circuit of the ore processing facility near Anarak post-2015 (right), smaller than the 18-meter diameter clarifier/setter tank located at Ardakan (left).

Figure 10: Operations and Engineering Section of the new ore processing facility showing the physical security as exemplified by an entrance/checkpoint area and visual obscuration berms that also serve as perimeter security barriers. Tree plantings (three rows of dot-like features) inside the berms are also evident, which will help with berm stabilization as well as providing additional future visual obscuration.

Figure 11: Close-up of the mining operations support area of the recently re-activated Meskani mine.

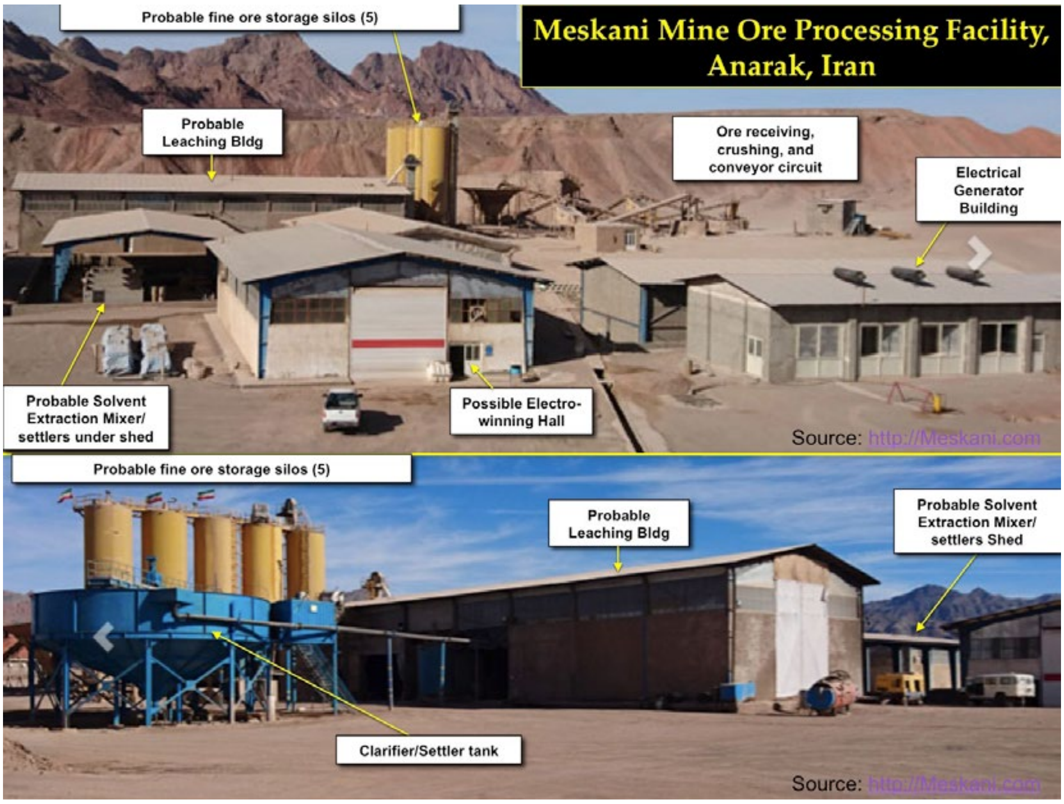

Figure 12: Ground Photos of the Meskani Ore Processing Facility. Labels identify the more likely roles of each part of the facility and are not meant to be definitive. The original images can be found at http://Meskani.com

5.4 Dependability of the Identifications

The identification of the radwaste facility is now certain, as it has been corroborated by official videos released by Atomic Energy Organization of Iran.

The identification of the processing facility as an "ore processing facility" has a very high degree of dependability, as the high-resolution satellite images provided by Google Earth over time allow a clear identification of the function of the installed infrastructure. Visual comparison with another well-known ore processing facility in the same country do not leave reasonable doubts on the correctness of the identification. Upon further open-source investigation, that included finding a Farsi labeled ground photo of the facility on the Google Earth "Photos" layer[8], it was possible to determine that the facility is indeed a facility for the processing ores from the Meskani mine. The identified operating company, Meskani, has a web site[9] providing a detailed history of the site, a discussion of ore process flow, an equipment list, along with two ground photos of the facility (actions 1, 4, 5). Figure 12 provides those two ground perspectives of the facility, with one showing the clarifier/settler tank, indicating that the images were acquired post-2015. All available information indicates that the ore processing facility is for the sole purpose of refining copper from those ores.

The Safeguards relevance of the ore processing facility cannot be ascertained easily from the high-resolution satellite images alone. While the area is known to contain uranium [47], the reporting found on the Meskani mine website claimed that the first cathode copper production of 99.99% was manufactured in February 2015. With respect to possible uranium extraction, the website specifically states that the AEOI (The Atomic Energy Organization of Iran) had, after 2005, "*begun extensive studies aimed at solidifying radioactive elements in the mine. Based on exploratory studies, the presence of radioactive elements in this mine was not proved, therefore, the organization returned the mine to the Industrial, Mine and Trade Organization of Iran in 2007.*" That information expands upon other available reporting that the AEOI had renewed uranium exploratory efforts in the Meskani area prior to 2007 [47]. The ability to remotely differentiate and characterize an ore processing facility that extracts copper vs uranium has been shown by other researchers [49, 50] to be somewhat difficult apart from the identification of a building housing the "Electro-winning" process step for copper extraction, which would not be part of any uranium processing flowsheet. The Meskani Mine website states that the facility includes such an electro-winning step, and the ground photos appear to provide support to that claim. What could be the electro-winning hall is located immediately adjacent to a building that can be clearly identified as an electrical power generator building (see Figure 8 and Figure 12). According to the research described above regarding differentiation between a typical copper ore processing facility and a typical uranium ore processing facility, "*[o]ne*

8 The photo, dated December 10, 2015, provides a panoramic view of the ore processing facility with a label naming it as the "Meskani Copper Mine" https://plus.google.com/photos/photo/108081858346305578393/6365120356766431170
9 http://meskani.com/

major difference between a dedicated Uranium Mill and a dedicated Copper mill has to do with the scale of operation. For economic viability Copper mills have to produce much larger outputs than Uranium mills. Thus invariably a Copper mill is at least 2 to 3 times larger than a Uranium mill" [50]. From an economic viability point of view, the size of the Meskani Ore processing facility seems to err on the small side for a copper processing facility.

No.	Criterion Description	H1 (copper mill)	H2 (uranium mill)
1	The area contains the material in object and is compatible with mining exploitation	The area is well known for containing copper [47, 48]. The quality of the copper ore in the area is reportedly sufficient for the operation of a copper mine	The area is known for containing uranium, but open literature reports the presence of U as a trace element with an abundance of ca. 10 ppm [47, 48], well below the inferior limit considered for commercial viability (ca. 1000 ppm[1,2]). One source mentions a literature study reporting the presence of "*[a] ggregate accumulations and single isolations of uranium-bearing (7-30%) hard bitumen*" [53]. According to another source the mine is among the oldest exploited uranium deposits in Iran with up to 200 tons of uranium potentially available [54] AEOI performed U explorations over the years that reportedly did not prove the presence of exploitable radioactive material[9].
2	The site hosts all the needed infrastructure	Most of the site infrastructure is compatible with a copper processing facility. The most important facility for discriminating between a copper and a uranium mill (the electro-winning facility) could not be identified dependably as the potential building hosting it is substantially different from the usual shape and characteristics [49, 50]	Most of the site infrastructure is compatible with a uranium processing facility. The most important facility for discriminating between a copper and a uranium mill (the precipitation facility) could not be identified dependably [49, 50]. The presence of a radiological portal at the weighing station cannot be corroborated by the available images (Figure 7).
3	The facility is consistent with other similar installations	The processing facility is erring on the small side for a copper mill to be considered as commercially viable [50]. The size of the CCD[3] seems however compatible with the throughput declared on one website dedicated to the facility[9]. The area has historically been of interest for Cu extraction.	The visual similarity with the Ardakan uranium ore concentrate processing facility is striking (Figure 9). The size of the Meskani facility is compatible with a small pilot scale uranium processing facility. Average U abundance in the Saghand ore (processed in Ardakan) is however two orders of magnitude higher than the one reportedly available at Meskani[4].
4	Collateral sources corroborate the end use	The processing facility has a dedicated website[9] identifying it as a copper mill, giving details about the company, the site, the type of infrastructure and processes. The site contains also a small history of the site and a couple of ground pictures (see Figure 12). The pictures available on the site do not provide conclusive evidence of the existence of an electro-winning facility.	There is no collateral reporting of uranium ore processing having occurred at this facility (but uranium has been reported to be one of the elements, in addition to copper, occurring in the ore that is being processed) One website[9] clearly identifies the site as a copper mill and explicitly states that the site was subject to AEOI explorations that reportedly did not find prove of radioactive material and therefore the site was released. The facility is close to an AEOI radiological waste disposal and storage site, but there is no evidence that the ore processing facility is under the purview of AEOI. The facility does not appear in the list of those declared to the IAEA. Its close proximity to a declared nuclear-related site makes the facility – easily revealed by satellite imagery - highly unsuitable for a covert, undeclared nuclear activity meant to remain secret, and a strong candidate for complementary accesses.

Table 4: Analysis of Competing Hypotheses (ACH) for the Safeguards significance of the Meskani mine. The two hypotheses against identified criteria. The analysis has the sole purpose of illustrating the method and should not be considered as a dependable analysis of the site.

[1] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/uranium-mining-overview.aspx

[2] https://www.nr.gov.nl.ca/nr/mines/prospector/matty_mitchell/pdf/prospecting_for_uranium.pdf

[3] "Counter Current Decantation" unit

[4] https://www.iranwatch.org/iranian-entities/saghand-uranium-mine

No.	Criterion Description	H1 (copper mill)	H2 (uranium mill)
1	The area contains the material in object	++	+
2	The site hosts all the needed infrastructure	+/-	+/-
3	The facility is consistent with other similar installations	+/-	+
4	Collateral sources corroborate the end use	++	--

Table 5: Evaluation of the two hypotheses on the basis of the evidence supporting/disproving the identified criteria. The evaluation has the sole purpose of illustrating the method and should not be considered as a dependable analysis of the site.

The presence of a (possible) radiological portal at the weighing stations would represent a non-conclusive indicator, as the potential presence of radioactive material in the ores might justify a radiation monitor characterizing the truck loads leaving the facility for health and safety reasons.

Methods for the analysis of competing hypotheses (ACH), developed in the domain of intelligence analysis [51], are of potential interest for open source analysts that need to be able to "*consider inconsistent and anomalous information, develop competing hypotheses (which can include deceptions), and test hypotheses in a manner that reduces susceptibility to cognitive limits and biases*" [52]. Table 4 and Table 5 present a partial illustrative analysis of competing Hypotheses for the Meskani ore processing facility. The two hypotheses considered are H1: "The Meskani facility is for copper processing" and H2: "The Meskani facility is for uranium processing". The objective is to illustrate a possible use of the ACH and not to perform a non-proliferation analysis of the site used in the example. The analysis is illustrated making use of a subset of available information on the topic.

With this ACH illustration, while acknowledging that it is being derived from a limited subset of information, we can arrive at one valuable insight: Given the available collateral sources, H1 ("The Meskani facility is for copper processing") is largely favored over H2 ("The Meskani facility is for uranium processing").

In the purely hypothetical case in which the collateral sources were to be considered part of an elaborate deception scheme, the advantage of H1 over H2 would decrease considerably, and conclusive identification of the facility's purpose would require either additional evidence gathering or onsite access. It is therefore particularly important, for any open source analysis, to characterize thoroughly the completeness, coherence and quality of the information upon which the analysis is based, and make such characterization an explicit part of the message passed to the evaluation team.

6. Conclusion

The revelation of Iraq's clandestine nuclear weapons program in the 1990s first made clear the necessity of bringing new tools to bear in the service of the IAEA and other international non-proliferation efforts. The adoption in 1997 of the Additional Protocol by the IAEA Board of Governors paved the way to the introduction of the State-Level Concept (SLC). Open source information can play an important role in supporting several aspects of the SLC, integrating and supplementing the information retrieved from States' declarations and infield verification activities. In particular, Open source information has the potential of being the main key source of information for identifying potentially undeclared nuclear activities in a State, an area that historically proved to be the most challenging of the entire non-proliferation regime.

While no verification activity is without issues, the detection of undeclared activities on undeclared sites faces formidable technical and epistemological challenges; and until such sites are thoroughly investigated it is likely that the dependability in excluding their existence cannot come close to that for declared activities on declared sites, and any new discovery of such undeclared activities will remain serendipitous. Nonetheless, open source analysis can provide insights on previously unknown aspects of a nuclear fuel cycle in a State, and the actions presented in this paper can potentially enhance the possibility of making new discoveries combining open source information including high-resolution satellite images.

The serendipitous discovery of a new ore processing facility near an AEOI operated radiological waste site located near a previously abandoned mine in an area containing copper, nickel, and uranium provides an excellent analytical case study exemplar, combining heterogeneous open source and geospatial information to derive significant, but otherwise at that time unknown, information for nuclear safeguards applications. While all currently available open source information indicates that uranium is not currently being extracted as a byproduct of copper ore processing at the Meskani mine, the site has attracted the interest of AEOI and, as recently as 2007, was under study by the organization as a potential source of "radioactive elements"[9]. As a consequence, this exemplar is an instructive case in the combined use of open source analysis to identify potentially relevant industrial activities and analyze their safeguards significance.

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