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# HEY INSPECTA!

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## ABSTRACT

Artificial intelligence (AI) and its underlying algorithms are increasingly responsible for how we perform our daily lives – from cars with automated driver-assistance, to online vendors suggesting future purchases, to voice-assisted smart home controls. International safeguards inspectors of nuclear facilities are inundated with information and activities and must process the information and perform the activities effectively and efficiently as they have limited time in a facility. Inspectors review reports, physically inspect equipment, take measurements and samples, review information from and maintain on-site sensors, understand context, look for anomalies in a facility, and use facts obtained to draw overall conclusions. Use of AI could allow inspectors to complete their in-field activities more quickly and can identify patterns and their deviances among myriad data inputs at once in a way human inspectors and analysts cannot. This paper will provide research from a project titled "Hey Inspecta" that defines requirements for an international nuclear safeguards smart-assistant, determines technical capabilities needed to implement an Inspecta prototype, and identifies limitations in current technologies or safeguards-specific issues that may delay or hinder near-term Inspecta technical adaptation.

## INTRODUCTION

The International Atomic Energy Agency (IAEA) Department of Safeguards is responsible for verifying international nuclear safeguards treaties. The mission of international safeguards is "to deter the spread of nuclear weapons by the early detection of the misuse of nuclear material or technology. This provides credible assurances that States are honouring their legal obligations that nuclear material is being used only for peaceful purposes" [1]. The implementation of international safeguards is unique for different states, as they are based on sovereign agreements between a state and the IAEA, as well as from facility-to-facility as determined through a safeguards agreement's facility attachment. The realization of safeguards activities at a nuclear facility are also defined by state factors and the IAEA's technical objectives as defined in the Annual Implementation Plan. Despite these variations, there are common inspection activities performed by inspectors such as reviewing facility bookkeeping, physically inspecting and maintaining safeguards equipment, taking measurements and samples, verifying seals, item counting, reviewing surveillance images, and generally observing their environment for anomalies. These activities are often mentally and physically challenging, thus may be susceptible to human error. Additionally, there is an upwards trend in the responsibilities of international safeguards inspectors. This increase in responsibilities is a direct result of 1) an increase in the types of nuclear facilities under safeguards related to the development of novel nuclear fuel cycles; 2) an increase in the global number of significant

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quantities of special nuclear materials due to the longevity of safeguards over waste products and spent fuel; and 3) a push for inspectors to move from a traditional role of "auditors" in the field to more investigative roles in which activities are defined via technical objectives in pre-defined safeguards criteria. Even with these increased responsibilities, inspectors still have limited time in facilities and must work as efficiently and effectively as possible.

Artificial intelligence (AI) and its underlying algorithms are prominent and increasingly present in our everyday lives, i.e. cars with automated driver-assistance, online vendors suggesting future purchases, voice-assisted smart home controls, AI/robotic vacuum cleaners, and smart-digital assistants like Amazon's Alexa. Sandia National Laboratories (SNL) is developing a conceptual design for an AI-enabled smart digital assistant for safeguards inspectors to support their increasingly challenging task requirements, named Inspecta (for "International nuclear safeguards personal examination and containment tracking assistant").

In this paper, we present the technical requirements for Inspecta based on a series of safeguards tasks and introduce the state-of-the-art of technologies that support the development of a prototype Inspecta.

## METHODOLOGY

To evaluate the requirements for Inspecta capabilities, we completed a three-step process:

1. Safeguards task analysis. We began by collecting a list of tasks that inspectors complete in the field, based on the IAEA Safeguards Manual. The task list is at a relatively high level (e.g., "perform maintenance on safeguards surveillance equipment," rather than detailing every step). For the task analysis, the only new technologies that we considered were part of the potential immediate implementation of Inspecta. We intentionally focused on current safeguards practices and ways to improve the practices using AI. While some of the technologies and their use might be new to safeguards, the implementation of technology is closely aligned with the current safeguards methodologies.
2. Review of IAEA publications of safeguards challenges. The team reviewed several IAEA safeguards publications to identify challenges that inspectors currently face or expect to face in the future. As the team reviewed the documents, we made notes according to the task analysis described in step 1 regarding where the publications were identifying challenges, or opportunities for AI, robotics, automation, etc. The documents we reviewed for this step include:
    a. "Emerging Technologies Workshop: Trends and Implications for Safeguards Workshop Report." [2]
    b. "Emerging Technologies Workshop: Insights and Actionable Ideas for Key Safeguards Challenges Workshop Report." [3]
    c. "Research and Development Plan: Enhancing Capabilities for Nuclear Verification." [4]

    d. "Development and Implementation Support Programme for Nuclear Verification 2020-2021." [5]
3. Former inspector challenges elicitation. Finally, we identified former IAEA safeguards inspectors, and individuals with highly relevant experience in facility operations and nuclear materials control. We interviewed eight experts, and documented their anonymized input regarding:
    a. The most difficult or most tedious tasks performed as an inspector.
    b. The inspection tasks most subject to human errors.
    c. The inspection tasks/activities that other inspectors might most trust to automated systems and the level of human-in-the-loop that would be needed.
    d. Perceived challenges of facility operators to meet their international safeguards obligations.

Once we completed data collection from the sources described above, we documented the potential capabilities for Inspecta and identified the technical capabilities required for each of those. While this was done for all inspection tasks to some degree, only a subset of the tasks with their mapped Inspecta skills and technical capabilities were further examined.

## INTERNATIONAL NUCLEAR SAFEGUARDS INSPECTION TASKS

The list of tasks performed by inspectors and mapped to potential Inspecta skills and technical capabilities included tasks for Physical Inventory Verification (PIV), Design Information Verification (DIV), Complementary Access (CA), and a category called "other" that included tasks such as inspector preparation that would occur at IAEA headquarters (HQ). As an example, entries under PIV included comparison of declaration to physical inventory, NDA/spent fuel verification, containment/surveillance (CS) in-situ verification of seals, and CS/review surveillance data. Table 1 gives an example entry showing the task name, the potential Inspecta skill, and technical requirements to perform that skill.

**Table 1: Sample high-level international nuclear safeguards inspection tasks with corresponding Inspecta skills and technical requirements needed for implementation.**

| SG Task | Inspecta Would… | Technical Requirements |
|---|---|---|
| Containment/Surveillance (CS)/In-situ Verification of Seals[1] | Map container and seal locations and corresponding information (i.e., identifiers (IDs), attachment date)<br><br>Inspect seals<br>- (Cobra) Physically attach reader, acquire an image, | Digitize facility map or infer/create map based on inspector movements<br><br>Wayfinding/indoor navigation |

[1] From D&IS [5]: spent fuel in dry storage could triple in next one to two decades – this will result in increased verification burden and exposes inspectors to environmental risks (radiation exposure).

<table>
<tr><td></td><td>save image, retrieve reference image, compare to current seal image, note seal ID and compare to expected seal location, log results.<br>- (EOSS) Connect using physical reader, download and analyze state-of-health (SOH), log of fiber open/close, etc. Log results.<br>- (Metal cup) Acquire an image of the seal and wire, compare seal ID with expected seal location, log results.<br>- For all seals, pull on wire to confirm attachment.<br><br>Collect and log data from active seals<br><br>Record all seals that were seen/verified in the field and highlight any issues (i.e., wrong location, images do not match, tamper event)</td><td>Display facility information, such as item location, location of other inspection team members, location of seals, etc., based on current and historical data.<br><br>Image processing (comparing images, anomaly detection, classification)<br><br>Robotics (line up for image capture, physically connecting reader if needed, pulling on wire)<br><br>Optical character recognition (OCR) of seal ID and container/item ID</td></tr>
</table>

The team noted after completing the table that many of the technical requirements mapped to several inspection tasks, e.g. OCR could be used for many different tasks (e.g. reading seal characters during seal verification tasks, reading container information and ingesting operator records).

To prioritize initial Inspecta capabilities, we used the following criteria: (1) task identified by interviews or IAEA documents as high-impact, meaning the task would be helpful to inspectors in terms of completing an activity in less time, with less error, or more effectively; and (2) the technology needed to perform the activity is relatively mature, with minimal modifications or R&D required.

## SAFEGUARDS CHALLENGES

The team reviewed several IAEA safeguards publications to identify challenges that inspectors currently face or expect to face in the future and noted where the publications were identifying challenges, or opportunities for AI, robotics, automation, etc. This section highlights a subset of our findings. From the R&D plan [4] the following objectives were identified that may relate to Inspecta:

- T.1.R1 Develop and introduce an integrated system of instrumentation data processing and review, with high level of automation and with unified user interface.
- T.1.R2 Develop the Next Generation Surveillance Review software (NGSR).
- T.5.R1 Identify, evaluate and test promising applications of robotics and machine learning/artificial intelligence (ML/AI) to improve the effectiveness and efficiency of safeguards.

From the 2017 Emerging Technology Workshop Report [2], a select finding was that AI/ML could help achieve further efficiencies and enable inspectors to focus on value added tasks, through automation and by reducing repetitive tasks. It was also noted that such technologies will not replace inspectors.

From the 2020 Emerging Technology Workshop Report [3], the following subset was highlighted:

- There are challenges in surveillance in how algorithms deal with anomalies vs. novelties
- Efficient surveillance review is desired so inspectors can focus on other tasks
- Robotics could be a consideration for use with spent nuclear fuel verification

## INSPECTOR ELICITATION

The research team conducted scripted interviews with eight former IAEA safeguards inspectors and individuals with highly relevant experience in facility operations and nuclear materials control. The interview questions were designed to elicit the identification of high-impact inspection tasks that Inspecta could potentially assist with. The tasks with the most frequent identification from former inspectors and SMEs are shown in Table 2.

**Table 2: Inspection tasks identified during interviews as most challenging, tedious, prone to human error. Tasks listed in this table were those identified by more than one inspector.**

| Inspector-identified tedious, challenging tasks or those prone to human error | Mapping to task table | Technical capabilities identified for Inspecta |
|---|---|---|
| Spent fuel verification (one inspector hovers over pool on bridge with Cerenkov viewing device, uses visual inspection to determine if spent fuel is present, reads information out loud to second inspector, second inspector writes down information on a map. Potential issues include visual fatigue, repetitiveness, transcription errors.) | Non-Destructive Assay (NDA)/Spent fuel verification | • OCR<br>• Voice-to-text<br>• Speech synthesis<br>• Robotics<br>• Anomaly detection<br>• Information recall<br>• Indoor navigation<br>• Object identification |

| **Inspector-identified tedious, challenging tasks or those prone to human error** | **Mapping to task table** | **Technical capabilities identified for Inspecta** |
|---|---|---|
| Transcription (prone to error); tired eyes and redundant tasks contribute to errors; hard to write things down on paper in Personal Protective Equipment (PPE) or bent over spent fuel pool | Maps to many different tasks<br>Cross-cutting | • Voice-to-text<br>• Speech synthesis<br>• Information recall |
| Integrating disparate information from multiple inspection activities (especially during large PIVs) | Maps to many different tasks<br>Cross-cutting | • Data standardization and formatting<br>• Anomaly detection<br>• Understanding context and data relationships<br>• OCR<br>• Voice-to-text<br>• Speech synthesis<br>• Robotics<br>• Information recall<br>• Indoor navigation<br>• Object identification |
| PIVs in general<br>Confirming items and checking against serial numbers, physical activities (changing batteries, physically accessing various equipment)<br>Checking lists, book-keeping and records audit | Maps to many different tasks (may need to select several specific tasks under this umbrella)<br>Cross-cutting | • Data standardization and formatting<br>• Anomaly detection<br>• Understanding context and data relationships<br>• OCR<br>• Voice-to-text<br>• Speech synthesis<br>• Robotics<br>• Information recall<br>• Indoor navigation<br>• Object identification |

| Inspector-identified tedious, challenging tasks or those prone to human error | Mapping to task table | Technical capabilities identified for Inspecta |
|---|---|---|
| Surveillance review | CS/Review surveillance data | • Anomaly detection<br>• Object identification<br>• Understanding context and data relationships<br>• Machine-learning driven (ML techniques may be approach used for many tasks, but surveillance review specifically will use ML) |
| Applying and checking seals, comparing numbers, writing | CS/In-situ verification of seals<br>Comparison of Declaration of Physical Inventory<br>CS/Removal/application of seals for analysis at HQ | • OCR<br>• Indoor navigation<br>• Robotics<br>• Object identification<br>• Voice-to-text<br>• Speech synthesis<br>• Anomaly detection<br>• Information recall |

## CURRENT TECHNICAL CAPABILITY ANALYSIS

From the subset of tasks identified, we extracted the underlying technical capabilities needed for that task and are currently performing an evaluation of the current state-of-the-art (how mature is the technology, is it commercially available or available through open source, and what general or safeguards-specific modifications may be needed). The technical capabilities under evaluation are:

(1) Optical Character Recognition (OCR)
(2) Anomaly detection
(3) Object identification
(4) Voice-to-text
(5) Speech synthesis
(6) Information recall
(7) Robotics
(8) Indoor navigation

While this list of capabilities is not exhaustive, it provides focus for an initial Inspecta prototype with a defined set of skills and underlying technical capabilities. These technical capabilities will require some level of integration. This evaluation will be completed and documented by the end of September 2021.

## SUMMARY AND NEXT STEPS

An AI-enabled smart-digital assistant can be integrated into the process of international nuclear safeguards inspections to assist with mentally and physically challenging tasks and those prone to human error to increase the effectiveness and efficiency of inspections. In this work, we have identified safeguards tasks, down-selected tasks that are mentally/physically challenging and prone to error based on subject matter expert interviews and mapped these tasks to Inspecta skills and required technical capabilities to perform these skills. Next steps are to continue the analysis of current technical capabilities – what is the state-of-the-art, what would be required to adapt the capability to safeguards, can this capability be implemented in the near-term (1-3 years) and what are the limitations? We will use this information to inform the development of an initial Inspecta prototype beginning as early as October 2021.

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