Progress in Geo-based Data Integration (GDI) in the IAEA Department of Safeguards

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ABSTRACT

The International Atomic Energy Agency (IAEA) Department of Safeguards has deployed the Geo-based Data Integration (GDI) platform for information integration, analysis, and activity planning involving geospatially-related information used for nuclear safeguards verification. GDI provides interactive, layered maps in a secure, user-friendly collaborative environment for IAEA inspectors, analysts and managers to access, utilize and share geospatially-referenced information regarding nuclear facilities, sites and other locations and activities relevant to the implementation of States' safeguards agreements. GDI operates in the secure Integrated Safeguards Environment (ISE), and access to information in GDI is limited and controlled via the Safeguards Authorization Management (AM) system.

As nuclear safeguards implementation involves on-site inspection to verify that nuclear materials and activities in physical locations are as declared by States in accordance with their safeguards agreements, nearly all safeguards-relevant information has geospatial attributes. This includes State-declared information; information collected by IAEA inspectors and instruments; and open-source (OS) information, including commercial satellite imagery.

This paper updates on progress achieved in the IAEA Department of Safeguards since the original presentation of GDI in 2018. The paper, as presented in the IAEA Safeguards Symposium in 2022, describes enhanced functionalities; automated data integration with the Additional Protocol System (APS); and planning and reporting integration with the Integrated Scheduler and Planner (ISP) and Safeguards Field Reporting and Evaluation (SAFIRE). The paper also reports on gains in effectiveness and efficiency observed in user experiences with GDI for management; inspection briefings and practical knowledge transfer; structuring historical information; profiling facilities and buildings; and applying GDI analytical methodology to complex facilities and nuclear fuel cycle locations. The paper outlines future plans for GDI development and integration with other information technology applications, Agency datasets, and departmental workflows to further advance the utility of GDI for nuclear safeguards verification.

INTRODUCTION

This paper reports on progress in development and application of Geo-based Data Integration (GDI) in the IAEA Department of Safeguards, since its introduction at the IAEA Safeguards Symposium in 2018 [1]. GDI is designed to improve the efficiency and effectiveness of Design Information Verification (DIV) and Complementary Access (CA) activities in relation to States' Comprehensive Safeguards Agreements (CSAs) and Additional Protocols (APs), respectively. The GDI environment also offers enhanced abilities for Design Information Examination (DIE); AP declaration review; Safeguards Approach design; Acquisition Path Analysis (APA); and other facility-, location- and State-level analyses.

GDI provides a map-centric interface for location-based analysis using enterprise-wide commercial off-the-shelf (COTS) Geographic Information System (GIS) technology to access, search, query and analyse geospatially referenced data. GDI offers a working platform for accessing IAEA and Open Source (OS) multimedia information, such as photographs, video footage, site maps, floorplans, equipment schematics and process flowsheets related to nuclear

fuel cycle (NFC) activities [2]. The GDI platform allows integration of information from multiple sources to better leverage analysis, evaluation, and activity planning in IAEA headquarters to support the in-field activities of IAEA inspectors around the world.

Since 2018, GDI has met expectations in:

- continuing deployment of new functionalities and integrations with IT applications and datasets;
- applications for DIE/DIV and AP Review/CA planning; and
- contributing to development of facility safeguards approaches; APA, and State evaluation.

Due to resource constraints and challenges related to the COVID-19 pandemic, GDI fell short of meeting some goals envisioned in 2018 for deployment of enhanced functionalities.

IAEA experience with GDI has also included unexpected positive utility and gains:

- as a supporting tool for management real-time situational awareness and decision making;
- improved efficiency in inspection training/briefing for complex safeguards procedures in sensitive facilities; and
- development of a GDI working methodology providing more effective use of heterogenous IAEA information collections, including to enhance inspector and analyst cognition in analysing large and diverse datasets.

The body of this paper is organized in two main sections. The first reviews IT hardware, software and interface enhancements in GDI, and GDI integrations with other IAEA datasets and IT applications. The second reviews five areas of IAEA experience using GDI.

In this paper, GDI is used both to refer to the collaborative map-based platform in ISE, and as described below, to the visual-analytic, multi-disciplinary, working methodology under development in the Department of Safeguards. The platform and methodology are grounded in the same fundamental context: for use by an on-site inspection agency verifying materials and activities in physical locations in States under respective safeguards agreements, nearly all safeguards-relevant information has geospatial attributes. Geospatial integration makes information practically useful for inspectors who are planning to conduct verification activities in specific locations in the field; for evaluation of the results of those activities; and for providing the most efficient and comprehensive basis for organizing information for consistency and completeness analysis in IAEA headquarters.

GDI IMPROVEMENTS IN IT INTEGRATIONS AND USER INTERFACE

This section reviews selected developments in the integration of GDI with other IT applications and datasets in the Department of Safeguards as illustrated in Fig. 1 below, and improved user interface and functionalities.

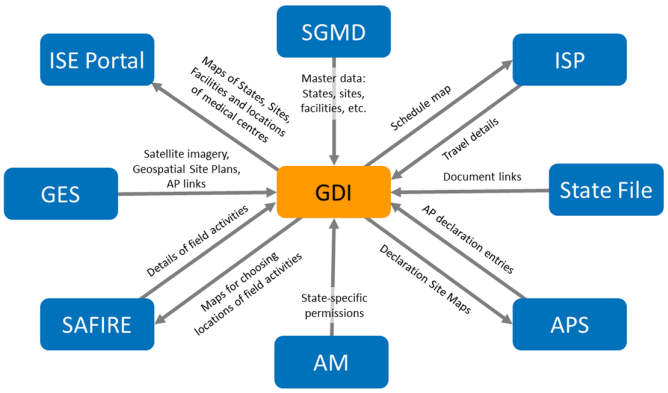

FIG. 1: GDI integrations with other IT systems and datasets in the IAEA Department of Safeguards

Background and context

From the onset of the GDI project in 2017, the project aimed at general users in Department of Safeguards Divisions of Operations and State Evaluation Groups (SEGs), rather than satellite imagery and geospatial analysts who use the specialized Geospatial Exploitation System (GES). Its main goals were – and remain – to assist safeguards inspectors and other users in planning and reporting of in-field activities as well as preservation, sharing and analysis of information to deliver credible safeguards conclusions. Deployed in the IAEA's secure Integrated Safeguards Environment (ISE), GDI provides up-to-date maps without requiring access to the internet. As an integration platform, GDI provides map-based access to safeguards information stored in different systems, and complements those systems when geospatial aspects are important. GDI fully integrates with the Department's Authorization Management (AM) system that ensures that users only see information about the States that they have authorized access to based on their roles and organizational units; this access is subject to approval by data owners and managers.

GDI automated data integration with structured databases in ISE

GDI is integrated with the complementary GES, providing authorized GDI users with access to the IAEA's extensive library of Commercial Satellite Imagery (CSI) and imagery-derived authoritative site plans. [3]

GDI is also integrated with the Safeguards Portal interface in ISE, which provides inspectors and other users access to applications and datasets, including the Electronic State File (ESF). A key integration for inspectors is the GDI interface with the State and Facility pages in the Portal, by which users can easily toggle between structured folder browsing and file search, and interactive maps, for States and Facilities for which users have access rights via the AM system. The standardized Facility page in the Portal provides practical access for inspectors and other users to the IAEA's diverse and extensive information collections, including Design Information Questionnaires (DIQs); inspection and DIV reports; destructive analysis (DA) reports; environmental sampling (ES) reports; equipment inventory; nuclear material accounting (NMA) data including Inventory Change Reports (ICRs), Physical Inventory Listings (PILs), and Material Balance Reports (MBRs); seals; procedures; and Facility Attachments (FAs).

Since 2018, another major advance has been GDI integration with the APS, which enabled GDI users to access buildings on the map together with entries of the AP declarations that describe the status and purpose of the buildings. GDI maps have also been embedded in APS. An important part of the review of AP Article 2.a.(iii) AP declarations (regarding 'buildings on a site') is to assess the completeness and correctness of State-supplied site maps. With this integration, while examining such declarations in APS, users can open the GDI map in a pop-up window, and efficiently compare the declared site map with IAEA site plans based on CSI and other sources. Users can also see the locations of specific buildings described in declaration entries, and access information regarding these buildings in GDI.

GDI has also been integrated with the IAEA DIrectory of RAdiotherapy Centres (DIRAC). That information is especially relevant for States that possess small quantities of nuclear materials primarily used for medical purposes. GDI displays the locations of these centres, and thus provides user-friendly access to the DIRAC information in the offline ISE environment.

GDI integration with the inspection reporting system SAFIRE

The first major feature implemented was to integrate GDI with SAFIRE, allowing users to link site and building objects in GDI to CA reports maintained in SAFIRE. For the first time, as shown in Fig. 2 below, inspectors could use a map-based user interface to visualize the buildings

that had been visited during past CAs, and with a single click access more detailed information on those CAs provided by SAFIRE.

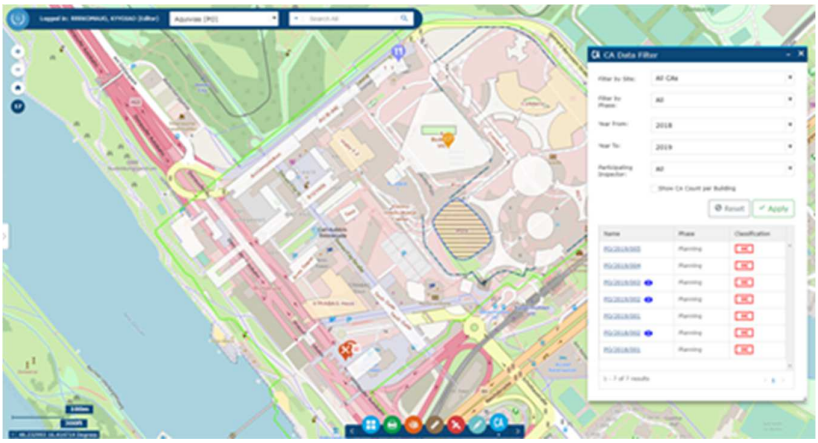

FIG. 2: GDI map with access to information on past CAs (mock data at Vienna International Centre-VIC)

To make geotagging routine in inspection reporting, as shown below in Fig. 3, GDI provided an embedded mini-application integrated into SAFIRE. When SAFIRE users plan in-field activities for a CA (in a State with an AP), SAFIRE presents users with an embedded map powered by GDI. With that map, users can indicate buildings to be visited during the CA and points and areas where tasks are to be performed. The use of maps during the CA planning process enables users to review site layouts before travel, and facilitates data geotagging in the course of inspection reporting. This is an important advance in making past CA data practically useful for planning future CAs, and for assessing the results of CAs.

Another major GDI advance integrates GDI with DIV and inspection planning and reporting in SAFIRE. As of 2023 this has been partially deployed: facilities visualized in GDI now provide access to recent DIV reports and inspection packages.

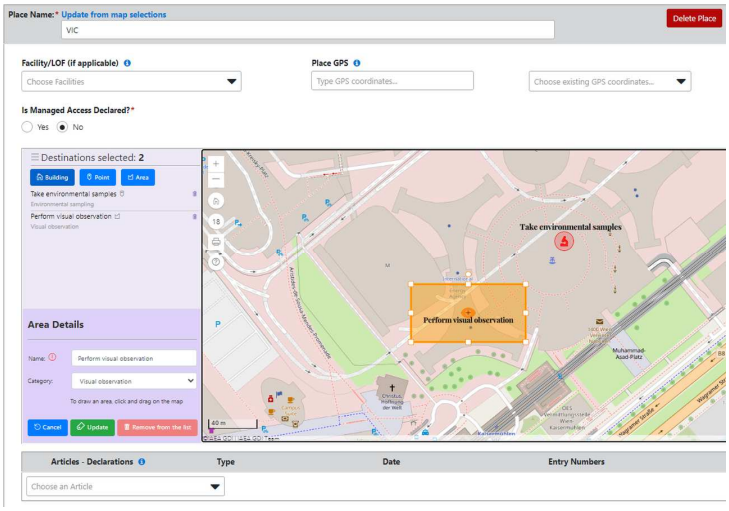

FIG. 3: GDI map in SAFIRE for activity planning during future CA (mock data at VIC)

GDI integration with the IAEA inspection planning system ISP

In 2020, GDI maps were incorporated in the Department of Safeguards' Integrated Scheduler and Planner (ISP), which covers all stages of planning, scheduling and reporting safeguards-related travel. In the first iteration for authorized users, GDI map embedded in ISP

displayed the countries in which safeguards inspectors and other safeguards staff were located during any time period and displayed their names and organizational units. This feature was later enhanced to show precise locations (cities, nuclear sites and facilities). In 2022, the map integrated in ISP was further enhanced to show locations of all sites and facilities with links to more information. This facilitates the work of schedulers and other staff supporting travel-related activities and, as described below, is a useful tool for managers.

GDI user interface and functionalities

In 2018, GDI provided users with web-based tools to draw various types of objects (sites, facilities, buildings, material balance areas, etc.) and link the objects to entities in the safeguards "master data" so that information about them could be displayed when users click on objects on the map. Users could add markers, which used different symbols depending on the user-selectable category (e.g. site entrance, location of ES, office, hotels and so on), and link them, like other objects, with one or more documents or folders in the ESF, such as the photograph shown in Fig. 4 below. Basic geolocating search capabilities were provided, with other GIS tools such as distance, area and geospatial coordinate measurement.

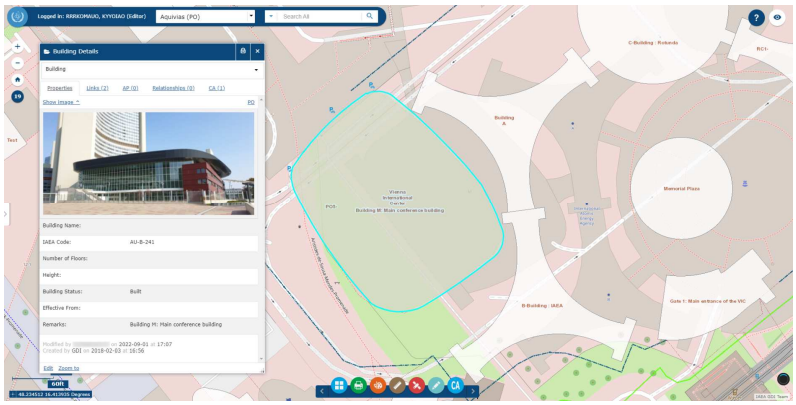

FIG. 4: GDI map showing image associated with a building on a site (mock data at VIC)

Subsequently, other functionalities were deployed. Users were given the ability to link documents from the ESF to GDI objects via drag-and-drop. Lists of linked documents could be grouped by category (OS, ES, satellite imagery analysis (SIA), etc.), or sorted alphabetically. Buildings with links to documents were indicated by colour differences, to help users to quickly see buildings that have associated information, and those that may require attention to identify and link relevant documents.

In 2021, a major improvement in the GDI user interface was deployed, providing an access panel on the left side of the screen that allows users to quickly navigate to sites, locations and facilities on maps, and improving user control over visibility and behaviour of data layers.

In 2022, an option was deployed to indicate the operational status of buildings (i.e., in construction; built; demolished). This feature addresses the reality of changes over time in the status of buildings, including their physical removal from sites and locations, and allows users to toggle the visibility of buildings based on operational status.

Since the status of GDI was reported in late 2022 [4], further deployments enable:

- customized integrations for semi-structured datasets, including for one SEG the locations, status and nuclear material declarations of hundreds of geographically dispersed LOFs, facilitating monitoring of transfers and planning logistics for efficient in-field verification;
- customized layer-based filtering visualizations for document datasets, including for one SEG several thousand historical documents reporting on in-field verification activities;

- enhanced geolocator search to find locations by coordinates, and find locations based on building names; and
- improved drag-and-drop linking of AP declaration text entries to buildings shown as objects in GDI, including (for authorized staff based on AM access permissions), the ability to link GDI objects of one State to AP declaration entries of a different (supplier or partner) State.

USER EXPERIENCES

Management

The COVID-19 pandemic led to rapidly changing health conditions and travel restrictions. To sustain the implementation of nuclear safeguards agreements, the Department of Safeguards management needed to know the location of inspectors and other staff traveling. Through integration of GDI with ISP, as described above, managers were able to access near-real-time information on the location of Safeguards staff on duty travel.

This use of GDI was not anticipated when the system was created, but proved important in assisting the IAEA to continue fulfilling its responsibilities for implementation of nuclear safeguards, while also aiding in measures to protect the health and safety of inspectors and other safeguards staff. This visualization and data access capability provided via GDI is now used on a routine basis for scheduling, and can support management decision-making in crisis situations such planning and monitoring inspector travel to areas experiencing conflict or natural disasters.

Inspection briefings and practical knowledge transfer

Since 2018, inspectors assigned as Facility Officers (FOs) used GDI to achieve unprecedented efficiency in planning, training and briefing for complex inspection procedures in facilities with sensitive technologies. Such cases present special challenges in that inspectors who have not previously conducted the specific inspection procedures for those facilities need to be fully prepared to implement them correctly the first time with limited or no in-field supervision and within the time allocated to avoid unnecessary impact on facility operations.

Inspectors used GDI to geospatially display floor plans and layouts of locations and process flows of nuclear materials; key measurement points for verification; locations of IAEA assets such as storage of hand-held and installed instruments, unattended monitoring systems, seals, and surveillance cameras; precise locations for ES; and geolocated photographs of key equipment and locations with instructions on specific measurements to be conducted, including to avoid inconclusive measurements .

By using GDI to integrate information and visualize the context and facility features for the safeguards approach as a whole, FOs reduced the time required for planning and training inspectors to be able to work quickly when in the field. Also, integration of practical information with detailed instructions in GDI positioned the IAEA to realize comparable efficiency gains in future inspections. Other benefits include facilitating safeguards asset management, and transfer of practical knowledge from experienced inspectors scheduled to retire or move internally.

Structuring historical information

An ongoing GDI initiative is to systematically structure and georeference unstructured historical information on facilities, sites and locations outside facilities in a State with advanced NFC capabilities and an AP. The resulting geospatial information is integrated with existing authoritative geospatial and CSI datasets and visualized in GDI, for analysis and to support planning and evaluation of verification activities.

By systematically creating structured datasets derived from unstructured safeguards-relevant information, users can access and analyse information from multiple sources and information types through one interface – GDI. Creating these new digital datasets from

information compiled over many years or even decades, and developing new intuitive GDI tools and functionalities to visualize and disseminate information to authorized users is challenging, but early experience indicates that it bears significant promise.

While a very large volume of unstructured information held by the IAEA is stored in various proprietary file formats, structured data have clearly pre-defined data types, models, standardized definitions, and well-established validation and quality control procedures. The new structured data approach in GDI effectively addresses a key information management challenge – how to more efficiently discover and disseminate all relevant information within a complex, information-rich but largely unstructured historical information environment and streamline analysis and evaluation of safeguards-relevant information.

A predefined, standard geospatial data schema was created for compilation of ES, CA and SIA information using COTS database software. A COTS solution is advantageous as it is already widely used across the IAEA; is stable, robust and does not require significant internal training or development costs; and has functionalities to assist standard data entry and validate and 'clean' data. The COTS solution will also facilitate future interoperability of GDI with SAFIRE and other applications.

The new datasets were prepared manually by extracting relevant information from mostly unstructured textual documentation such as internal reports and briefing presentations, and systematically populating all of the data records in the schema. The datasets contain attributes for each data entry to be displayed via a pop-up, as well as geospatial coordinates to enable data visualisation in GDI. These coordinates can represent a building or any infrastructure within a NFC location. Other key attributes captured for data points include State-declared or IAEA-assigned building numbers, ES or CA information, and links to original documents or other references stored in ISE.

As data is tabulated, new content is updated and harmonized; terms and definitions standardized; and data quality maintained to ensure accuracy and comprehensiveness. Information is cross-checked with other internal databases. Missing information from legacy hardcopy documents, is identified and clarified; duplicate data minimized; and incorrect information amended. Structured, tabulated datasets effectively centralize safeguards-relevant information and make the data 'fit for use' by GDI and other software applications in ISE.

New tools and functionalities have been developed for the GDI platform to visualize the structured information superimposed on CSI or GDI maps. A key challenge is how to effectively visualize all of this data without overwhelming users. To trial possible solutions, through the pre-defined configuration table attached to the main datasets, authorized staff can modify cartographic symbols, map legends and the general appearance of data, and the modifications are reflected immediately in GDI. This type of agile development enables testing and evaluating alternative visualizations of data, which is very useful when designing new functionalities.

Several structured datasets now available in GDI are displayed as geospatial 'point data' - each coloured symbol corresponds to at least one data record in the dataset. Users can search and query attributed geospatial data using the map interface or the access panel. Retrieved results - content from the structured database - are displayed in the pop-up window with links to original reports, presentations and models. Additionally, using an interactive map legend, users can filter to display only a selection of data, e.g. all ES data collected during one calendar year, or all SIA products of a certain type for a site or a building.

The pilot structured datasets with the new GDI functionalities have demonstrated the potential of GDI as a one-stop platform for accessing and disseminating the vast information resources of the Department of Safeguards to authorized users. This approach to systematically georeferencing and structuring historical data requires investment in staff resources, including to sustain quality in data comprehensiveness and accuracy. Once data is structured, it becomes more efficiently accessible to all current and future users.. Based on this pilot experience, a

comparable effort is underway to apply this GDI approach to structuring historical AP, CA and ES information in another State with a complex NFC and AP. Furthermore, a number of other SG-relevant structured datasets have been compiled for visualization in GDI, where feasible through automation, interoperable integration, and improved search capabilities to access other existing databases.

Facility and building profiles

Since 2018, GDI has been used to geospatially integrate and analyse complex locations with multiple NFC facilities in States with CSAs. For these efforts, declared, verification and OS information was geolocated and visually mapped building-by-building, floor-by-floor, room-by-room, using COTS software to integrate and contextualize information on all safeguards-relevant locations storing or processing nuclear material and all essential equipment related to the use of nuclear material. The facility profiles were based on comprehensive DIE and used to plan DIV, and to engage the expertise ofsatellite imagery, ES, nuclear technology, OS and trade information analysts. This improved SEG understanding of flows and functional connections among NFC-relevant facilities on the complex sites, and enabled identification of possibly safeguards-relevant buildings and installations at the locations.

This kind of analysis is also essential to review AP site declarations for correctness and completeness. Especially for complex sites, GDI enables efficient cross checking and identification of any inconsistencies between AP text declarations and State-provided site maps.

In one case applying GDI, possible omissions and inconsistencies were identified in facility DIQs, and clarifications were sought via DIVs and inquires with the State. Through disciplined geospatial attribution and comprehensive assessment of information, in one case the SEG gained increased confidence that in the building complexes analysed, there were no indications of undeclared nuclear material or activities required to be declared under the relevant safeguards agreement.

In these experiences, it was found that the IAEA could achieve considerable visibility into NFC activities through expert collection, geospatial attribution, and multidisciplinary use of OS information including CSI. Systematic georeferencing of OS photographs and video images provided complementary information for analysis and activity planning in relation to declared facilities, and a workflow basis to identify any possible indications of materials, activities or buildings that should have been but had not yet been declared to the IAEA.

It was also found in these cases that after decades of implementation of safeguards agreements, the IAEA holds extensive and richly detailed collections of all available types of safeguards-relevant information. Until the collaborative environment provided by GDI became available to inspectors and analysts working in SEGs, this information had never been fully integrated and the SEGs were not enabled to utilize the full breadth, depth and level of practical and safeguards-relevant detail of the historical information collections held by the IAEA.

In one case, it took time for the SEG to recognize the significance of several pieces of information because the information had not been integrated and assessed in geospatial context. After extensive analysis and review, clarification was requested from the State. In another case, historical information held by the IAEA provided increased confidence that the purposes of nuclear facilities were as declared by the State in DIQs.

In these experiences, the GDI platform was found to be the best available collaborative environment for integrated multi-disciplinary analysis; integration of headquarters evaluation and planning with in-field verification activities; and long-term knowledge management of OS and all other safeguards-relevant information.

Like the data structuring approach described above, the facility and building profile approach is labour-intensive. Both efforts require investing staff resources today, to achieve

gains in efficiency and effectiveness in future use of the IAEA's extensive but heterogeneous information collections. Hence both approaches are implemented on a prioritized basis.

GDI methodology

Based on the experience recounted above, it became evident that in some respects GDI can be considered as offering a new methodology for integrated analysis and activity planning in safeguards. By integrating and analysing all available types of safeguards-relevant information and documenting practical knowledge building-by-building, floor-by-floor, and room-by-room, IAEA staff can better leverage all of the diverse and complementary types of safeguards-relevant data. This is especially true of State-declared, inspector-collected, and OS visual multimedia like maps, floorplans, flowsheets, photographs, and video footage.

This GDI approach provides methodological discipline in use of diverse information types to analyse the consistency and completeness of declared information, and to identify any information gaps or possible inconsistencies for which further information collection, analysis, verification activity, or eventual inquiry with the State may be required. This methodology continues to be refined through user trials, to identify workflow and analytical 'best practices.'

An unexpected benefit of this GDI methodology was the experience of some inspectors and analysts of improved cognition, especially in comprehending large and heterogenous datasets (including photographs, satellite imagery, flow and process drawings, measurement data, quantitative nuclear material accounting information, and textual descriptions in declared, verification and OS information). This experience is apparently rooted in universal human capacities for spatial perception and reasoning. [5]

Positive IAEA experiences with GDI methodology and their apparent roots in human capacities for spatial understanding has two important implications for the quality and organization of work in the Department of Safeguards. First, by working and documenting knowledge geospatially, analysts and inspectors may produce better products, such as more efficient inspection plans or more comprehensive or incisive analyses. Second, many staff who are not experts in specific nuclear technologies may be able to contribute to the geospatial organization of historical unstructured data, to enable comprehensive technical assessments by analysts and verification by IAEA inspectors.

Plans for GDI development

The development of GDI, like other Department of Safeguards software applications, proceeds according to regularly updated roadmaps monitored by IT staff and managers and reviewed quarterly with user representatives from all of the Department of Safeguards Divisions.

Moving forward, one user-specified need is to facilitate access in GDI to sub-elements of text documents containing images, such as DIQs that include text and also maps, diagrams, photographs, tables, and other non-text data. Unlike AP declaration data, which is provided or uploaded into a fully structured database, DIQ information is in lengthy unstructured documents.

Safeguards staff also need GDI visualizations for facilities and other objects that consist of multiple parts, and their associated information assets, such as floor plans or maps. For example, a facility may occupy two buildings and one wing or one floor of a third building. A declared site may consist of two distinct geospatial areas separated by an area that is not part of the site. Readily comprehensible multi-part visualizations may be facilitated as products of three-dimensional (3D) modelling and virtual reality (VR) tools are made accessible via GDI.

Safeguards users also need visualizations and access functionalities in GDI to compare information over time. This change detection capability may be implemented through layers, pop-ups, or a "slider" option by which different parts of a diagram or other visual image can be compared over the history of a facility or location. Whether updated through automated data

integrations, or through recurring evaluation processes (such as annual AP site declaration reviews), it will be important to preserve and provide access to the history of previous entries.

It is planned to enable GDI to integrate and display reports and data produced by the Instrument Record Integrator for Safeguards (IRIS) system, including geospatial display of inspector footpaths during the temporal sequence of CA and DIV. IRIS integrates geospatially and temporally all of the measurements and recordings taken during a verification activity, so inspectors can subsequently review a radiation measurement and photograph of equipment taken at the same time and room, on a footpath superimposed on a building floorplan.

A promising inspector-identified area for data integration currently under examination is considering how GDI could be used to visualize and provide geospatially-referenced access to information on safeguards equipment assets installed or stored in locations in the field.

CONCLUSION

GDI deployment and its further development since 2018 has delivered significant advances for IAEA safeguards. As expected, GDI has been integrated with IAEA data sets and IT applications; its functionalities enhanced; and it has been used in planning and evaluating the results of CAs and DIVs in the field and in conducting analyses in IAEA headquarters. Some development goals have been slower to be realized than originally hoped. However, IAEA experiences with GDI since 2018 have also included unexpected positive benefits, notably in supporting management awareness and decision making; preparing inspectors for complex verification activities; and development of a working GDI methodology.

Nuclear safeguards implementation is a multidisciplinary enterprise, in which a diverse range of information, expertise and activities have geospatial dimensions. GDI offers user-friendly geospatial maps and visualizations to engage the wide range of expertise required to analyse diverse information streams, and prepare for and assess information collected by inspectors and instruments during in-field verification activities. This shared and secure geospatial working environment facilitates collaboration, and better integration of work in IAEA headquarters with in-field verification. GDI also supports long-term, contextualized knowledge management for safeguards verification over the lifetimes of nuclear facilities, sites and LOFs. GDI thus enables inspectors and analysts to consolidate their collective knowledge, and thereby prepare their successors to implement IAEA safeguards in coming decades.

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