Containment and Surveillance Systems - reflections on future technologies

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Abstract:

Euratom Safeguards is busy implementing the Next Generation Surveillance System (NGSS) in the field currently, close to 700 units are to be installed in the next years.

This paper deals with the time after NGSS. It is time to design the technology that follows, to discuss the requirements for containment and surveillance systems in a broader sense, to study the very volatile general technical environment and select options for further development.

With the growth of the security markets, with the advent of autonomously driving cars, with increasing threats in cybersecurity, with the appearance of more intelligent, smart sensors using various physical technologies beyond optical vision, opportunities can be envisaged and analysed for applicability. This may allow more efficient and effective safeguards implementation, and ideally, could contribute to an opening of the market and help reducing cost.

At the same time, a growing number of facilities particularly at the back end of the fuel cycle turn static and new facility types appear. These pose their own challenges and may call for revised inspection approaches utilizing non image based sensors.

Keywords: publication; guidance; editing; standardisation

1. Introduction

Inspectorates are constantly being challenged with decreasing funding, amount of personnel, inspection days and mission budget. The efficiency and effectiveness of safeguards activities are debated. At the same time, new equipment must be developed to exchange old one's which has come close to the end of life cycle.

In order to fulfil the desired wish that inspectors are both more effective and efficient, we would need to see an increase in the number of sensors connected together with a clever automated decision-analysis and event-extraction. A current emerging system existing with a constantly increasing functionalities is "integrated Review and Analysis Program" (iRAP) which is a joint development project by IAEA and DG-ENER [1]. Adding the automated data transfer using techniques such as RADAR and Rainstorm is currently building a very cost-optimized solution.

Could we not in the (near) future have even more unattended equipment in place, which observes the processes transmitting relevant data to a local storage. Automated processes would identify events and assist the Nuclear Inspectors to confirm declared operations and to analyse potential situations where further analysis is needed. The unattended systems could be based on a combination of dedicated components and OEM modules.

The above scenario would require a larger amount of unattended sensors that has the capacity to transmit remotely its content to a central store. In Nuclear Safeguards of today we have an increasing amount of unattended systems, primarily Surveillance cameras and a few other connected devices for enrichment and reprocessing facilities [2].

This system, correctly configured and where relevant data is provided, is able to extract a list of relevant events and provide, if necessary and available a limited sized video-sequence over the time of the events. The strength of such a system setup is the efficiency with which the inspector would work, i.e. the time spent is focused on the events and not on all the time in between events.

With a constantly increasing threat from cyber-attacks, the new safeguards tools must be able to seamlessly follow the latest advancement in cybersecurity to ensure the authenticity of all safeguards relevant data and be able to handle future cyber-attacks.

2. New Safeguards tools

The valid lifetime for a safeguards equipment is very long. It is long not just because it is the perfect tool. The development-time and validation process is both long and expensive. Sometimes, the development of new equipment from idea to final fully functional system takes 5-10 years, sometimes even longer.

If the inspectors working with safeguards equipment would chose, quite some equipment would have been updated, changed or trashed. This cannot be done for the simple reasons that other comparable or better equipment neither exists nor can be developed in a reasonable amount of time.

Whenever new safeguards equipment is designed, the common sense would be to think about the long-term future trends. Not just the near future but also potentially considering relations to sensor-technologies from other industrial branches. By thinking out of the box, one could potentially gain strengthened detection capacities or effectiveness.

Where allowed by the operator and agreed with local state, the devices would without interaction from Inspectors or Technicians send its data to headquarters or local site-offices. The data can be processed automatically and large benefits can be identified both for Inspectors but also for Operators and State Inspectorates. With this in mind, the future safeguards tools must enable secure remote data transmission and centralized control.

3. Next generations Nuclear Safeguards camera (NGSS)

The NGSS is currently deployed in large scale substituting old DCM-14 cameras and other commercially available systems such as FAST/NICE. The camera, despite initial engineering difficulties, is a success. Currently, the output video stream files from the camera can be handled by both the Safeguards review station GARS, by iRAP but also by new emerging video-review tools such as Video-Zoom [3] or in its most basic form, any MPEG enabled video-application. The NGSS has important features such as multiple asymmetric crypto-keys for authentication, enabling dual-use and third party installation and maintenance.

The primary components, i.e. the imaging sensor and the processing DSP, acquire the images and implements scene-change detection. This detection capacity means that the camera can by itself react to scene changes and when these occur, tag the event and change the image storage frequency. The camera can also be triggered by external sources via a few electrical interfaces.

The subsequent video review tool, then can list all the events that have been detected both by the scene-change detection but also from other events that has been connected via electrical or network-based connections.

Still, the camera, having all the advanced capacities in some cases returns large amounts and long sequences of video data. Generally, it is a very time-consuming task for the inspectors to perform an efficient and effective analysis of long video-streams.

When considering a future generation of Surveillance Cameras, what kind of additional tools and sensors can be added? Remember that to go from an idea to final deployable product is very long, maybe now it is time to start thinking of a successor. Currently, the commercial market is designing new generations of advanced sensors that did not exist some years ago. To be more visionary, some sensors, which may be essential for safeguards in 10 years from now, has potentially not even been launched commercially?

We should probably consider the fact that commercially available or open modules may fit into new systems and form its central parts. Of course, the global aim of a robust system with long term guaranteed operational lifespan must be kept in mind. Still, new emerging tools, sensors and OEM platforms could be part of a new generation of safeguards tools.

Apart from the basic CMOS/CCD light sensitive sensor, what additional components could be of interest to design the future system? A list drawn today cannot be fully comprehensive, since future intelligent sensors are not known. Trying to answer the question, we can start with a few components that appear in existing Nuclear Safeguards equipment, which could also be of interest in a compound sensor-system.

3.1 LIDAR sensors

A Lidar is by the name; Light Detection and Ranging, is a sensor which uses electromagnetic waves in the near- or visible spectra to measure distances. These sensors have the capacity to measure the near surrounding in 3 dimensions. Already now, they have entered into the consumer market and the first smart-phones equipped with solid-state sensors with active light enabled 3D capacity are commercially available [4].

How would this help future surveillance systems? In the area of design information verification/Building Technical characterization (DIV/BTC) or containment verification, this technique is already a key-player. Several nuclear safeguards systems use these sensors to draw conclusions; Static 3D scanners used in 3DLVS/3DLR for accurate change detection [5] and a mobile scanning equipment for large scale mapping and indoor-localization[6].

But what can they do for a Surveillance system? As previously mentioned, video-review is a crucial but fairly time-consuming activity. Intrinsically, a large amount of image sequences may be visualized to identify declared activities. Furthermore, an inspector must maintain focus to potentially also find what not searched for, i.e. potential non-declared activates.

A Lidar amended Safeguards Surveillance Camera could be designed in such a way that a triggered event occurs whenever something in the scene physically happens. One could neglect changes in the image-scene such as shadows, light changes etc. and concentrate on actual movements.

Figure 1 shows an image and a schematic drawing of a spent fuel pond. The surveillance camera is placed to

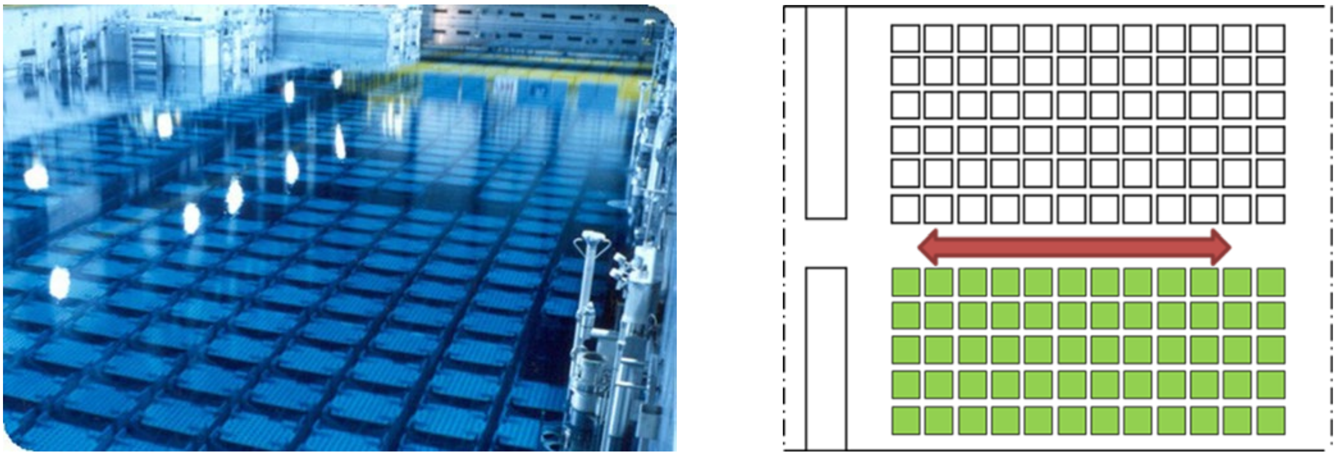

Figure 1: Left: Image of Interim storage pond in La Hague, France (image from Areva Webpage), Right: concept pond with green baskets under surveillance and red arrow indicating daily movement of equipment with traversal crane.

overlook the stored bins and no changes are to take place. The natural movement of traversal crane with a bin-carrier both introduce natural scene-changes in the observed scenario. The crane will also introduce small waves which makes the reflection of illumination to flicker in the water-surface. In such a situation, an image scene-change detection will have difficulties to perform well. By introducing a 2D or 3D based laser scanner we don't need to rely only on the image itself. The additional sensor will map in true dimensions a plane parallel to the water surface above the bins; and any interference with a device, rod or traversal crane can be detected and consequently an image sequence event can be stored.

There are several examples of where an added proximity sensor would assist and provide robustness, efficiency and effectiveness to a safeguards camera.

3.2 Radiation sensors

Both Neutron and gamma detectors are playing an important role for a safeguards camera to trigger when relevant scenarios occur. Most probably, future safeguards cameras would integrate such sensing capacities and, based on need, assist in the triggering of events.

3.3 Other sensors

Considering that we discuss future technologies, why not broaden the concept. Many commercial sensors; pressure gauges, noise sensors, scales, temperature and pyroelectric sensors and ID-readers could be of interest. And last but not least, the sensors which are not even commercially available yet.

4. Introducing the concept of a "Remote Safeguards Device"

When designing a new generation of surveillance cameras we should take the moment also to consider, as discussed above, the capacity to add extra sensors. The new design should be clever to handle future unknown sensors to some reasonable limit.

As the basic requirements reflect on any unattended safeguards equipment installed in a nuclear environment, some basic rules apply: a system must be able to withstand power-outages for days, store locally data and have tamper-proof enclosures. A new and future system also needs remote transmission and control. This to summarize, means that the main system must be designed with a certain number of basic capabilities.

Identifying what components that would be mandatory to implement these basic capabilities, we would have a basic box and any sensor connected could as well be 'extra sensors', even the imaging sensor.

The thing remaining without the extra sensors is a very competent base system, then "Remote Safeguards Device", which can be placed in nuclear installations which intrinsically carries all the necessary mandatory features.

4.1 Basic concept design

In figure 2, the blue box lists components and capabilities forming a fundamental Remote Safeguards device. As seen, the system module has all the capabilities to be installed in a nuclear site. All the components for command and control exists; a modular CPU for decision making and logics, exchangeable memory module, battery-backup, remote communication for control and data-extraction which makes it a modular smart sensor. The basic system must be equipped with a state-of-the-art protection for cyber-attacks as well as configurable encryption logics for digital encryption and data-authentication. Other components needed for the execution, i.e. the 'extra sensors', are added as needed via a pre-defined electrical, logical and physical interface. This enables a concept where several sensors can interact within the same tamper-proof enclosure as a single smart sensor.

From a maintenance point of view, the system concept should allow an external actor to perform on-site activities. An installation of a pre-configured device and basic maintenance such as battery-change and memory-card substitution should be allowed by design. This would mean that safeguards organizations significantly could reduce mission costs and manpower. We could also identify a clear benefit for the operator, which would not need to plan, organize and host visits on the site.

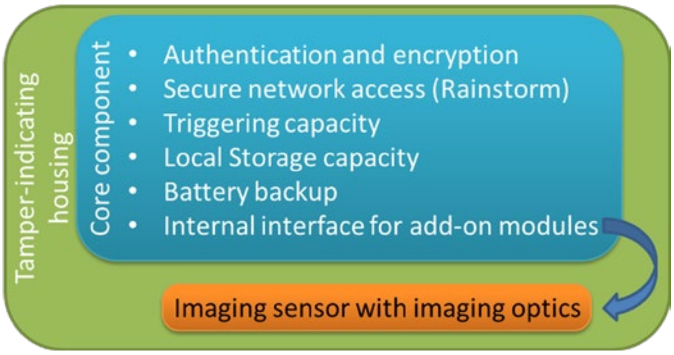

Figure 2: Schematic design of a new base unattended system with capacity to attach sensors using an internal interface

For sure, the imaging sensor will in most cases be used to enable an 'inspectors eye' in case of events. But the sensor base could also be used as a future remote data acquisition module in an extended RADAR architecture.

Ideally, the design of the system is based on existing subcomponents that are offered openly by the electronics industry or where intellectual property rights (IPR) can be guaranteed for Nuclear Safeguards. A realistic scenario would probably be to use a dedicated and optimized inner core-module together with added outer OEM or semi-commercial components. By using an existing open operating system and maintaining an open architecture, we would meet the Nuclear Safeguards community concerns and requests regarding IPR and cost-optimizations. This of course is easy said but would demand a high level of cooperation and openness between a few major players in the design and potential development phase. After all, this is a conceptual discussion where we do not need to address major hurdles but instead can focus on the functional aspects.

4.2 How concept fits into current and future remote data transmission paradigm

The ever-increasing need and request for remotely connected devices lead to the concept for unified approaches. Both remote transmission of data from device to headquarters or local servers can be implemented with this modular architecture. Streamlining the remote transfer enabling a Rainstorm [7] connection as a core component would immediately enable the strength of a compressed and adaptive network connection to a large amount of devices.

Once implementing the remote connection capacity with the core component, all systems will inherit the same communication interface and thereby unify both data-transfer and control logics.

Figure 3 shows the data-transfer scheme for a site that has several connected systems based on the concept device. As seen, different sensors can connect to remote transmission software with standardized means for data-transfer or connected to data-consolidators like RADAR. In cases where there is no remote-transmission available, data can be hand-carried using digital memories.

The same concept for unification goes for control and command. An established unified way to communicate state of health and to read/update configuration can be implemented for the common system cores which greatly simplifies control software.

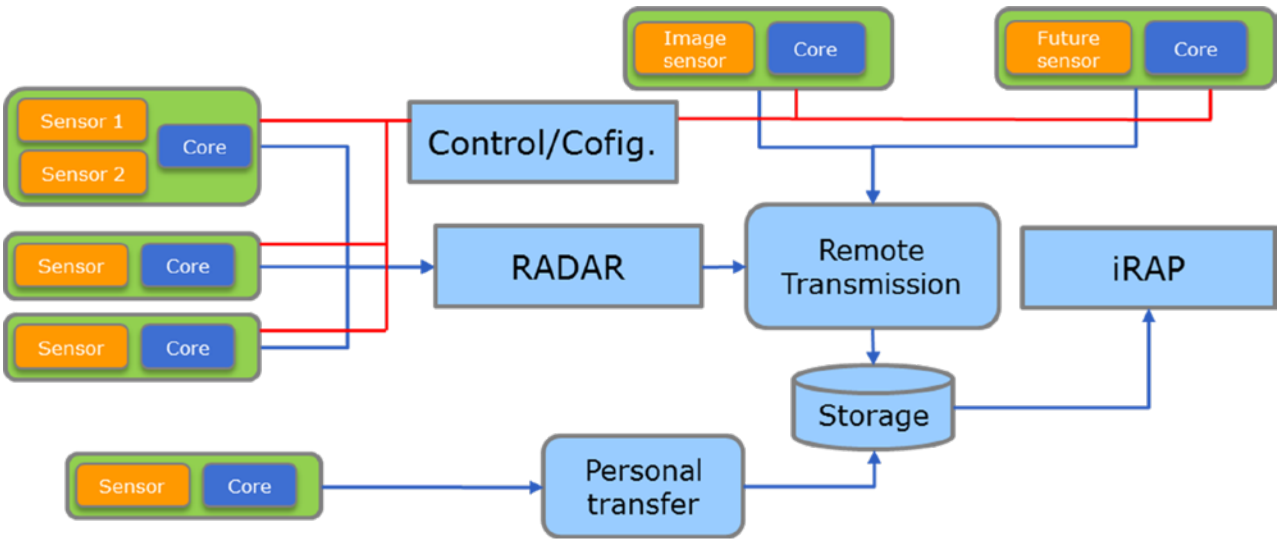

Figure 3: The concept safeguards platform in a future remote data transmission scenario. The blue arrows show the direction of data-transfer. The red lines indicate flow of command and control.

4.3 Concept usage

Future safeguards will require future technologies and new ideas. Currently, the safeguards community is facing new challenges such as an increase in dry storages and commissioned geological repositories are around the corner. New sensors and systems are entering the arena that needs to be managed regarding both installation and configuration but also related to remote data and status transmission.

This happens at the same time as efficient work-procedures are discussed. Remote sensing with less mission days as well as more effective inspections is requested.

The remote devices installed should generate a minimal footprint in volatile memory for normal situations, but when an event can be identified; higher framerates, more information and extended datasets can be accepted. The only issue is, who is deciding what is an event and when does it happen?

Sample case 1:
If we can detect an object physically entering an area of safeguards interest, we would robustly be able to consider this as a safeguards relevant event. For a Safeguards camera, adding a 2D/3D laser-based proximity sensor, we would achieve a more effective analysis following an efficient posterior review. Such system in the new concept would be based on a combination of an imaging sensor and a 2D/3D sensor.

Sample case 2:
In a transfer hall or loading cell, observation of loading events is requested. The presence of nuclear material would be detectable with either a small gamma or neutron detector. By coupling the presence of nuclear material to the imaging sensor, we would achieve a very competent surveillance system within a single tamper-proof case enabling effective and efficient posterior image review where events would reveal relevant movements.

Sample case 3:
Monitoring dry-storage casks in a storage is a fairly static operation. Very few or no movements occur over long periods. In this case, potentially no imaging capacity would be needed. Why would we need to generate video-files that show a static scenario? Instead, here a 2D laser would be able to monitor the casks and in case movements occur; an item tracking file could be extracted. An optional still image could also be acquired to document the event. Furthermore, adding also a radiation sensor could potentially add essential information to an event-data set.

Sample case 4:
Pressure, temperature, light, pyroelectric, weight, position, item counters, ID readers or other sensors already applied to a material-process by an operator could be used to confirm a normal operation. The sensor data could be bypassed in a base-system with copy functionality as described by Thomas et. Al [8], where the data transmission is read but not logically interfering with the data flow. The data copied would then be authenticated and transmitted accordingly.

Sample case 5:
Today we maybe won't care for sound, ambient temperature and light sensors or other currently not known sensors. In the future, there may be the need for a combination of such sensors. We cannot design and implement the future sensors but we can to as large degree as possible make space for them and allow a smooth integration into the future generations Remote Safeguards Device.

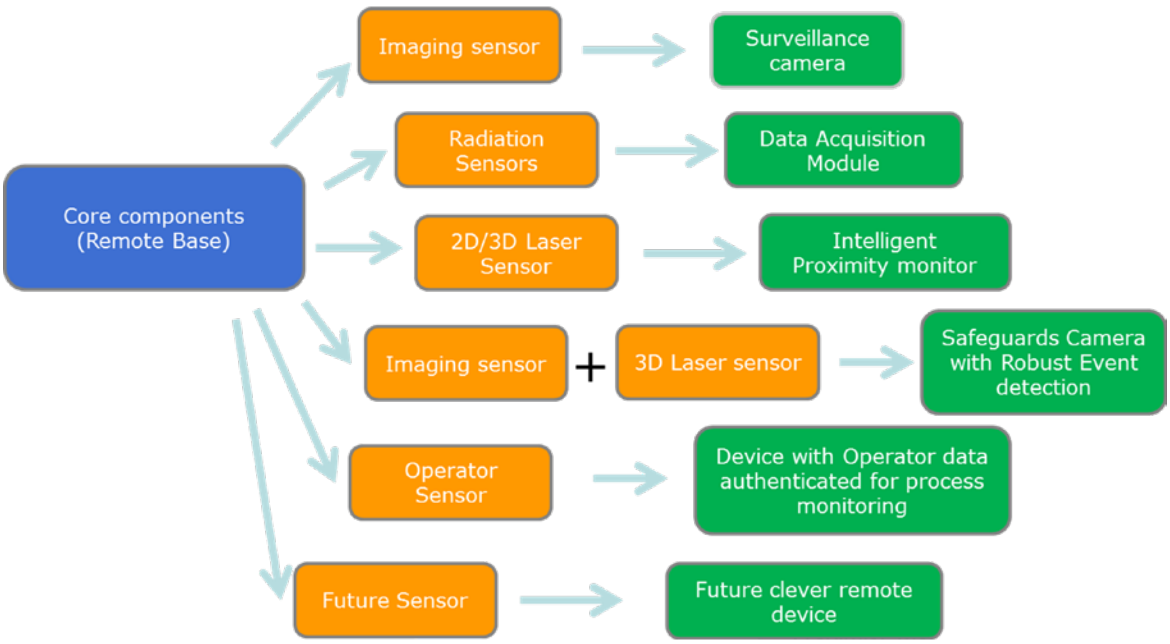

Figure 4: The base unattended system with a few conceptual sensors and there indicated use-cases.

Figure 4 describe in a single image a few realistic sensors and their indicative use which can be part of a future toolbox of devices ready to be deployed in the field when deemed necessary. The Orange boxes define a few sensor architectures which could be relevant. The green boxes briefly describe the potential use of such configurations.

5. Summary

The development of a new Safeguards instrument is a long process. There are currently a large number of different instruments in the portfolio. Not all, though, are optimized for the future. In this paper we have identified a few features that would be needed for a future device such as remote transmission, effective and clever decision making. By analyzing the prospect of a next generation of Surveillance camera, we introduce the concept of a Remote Safeguards Device which would be a modular device with the capacity to host different sensors in a tamper-proof case. Depending on the need, the basic sensor-platform and its connected sensors would enable a smart device which would be able to support the demanding requirement of an effective and efficient safeguards device. In order to sketch the requirement for a new safeguards camera a large amount of preparatory work is needed. This paper summarizes a rather visionary concept and certainly further analysis and discussions is needed.

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