2022

NuDiVe

Nuclear Disarmament Verification

Documentation of the NuDiVe 2022 exercise

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Contents

Preface

The »NuDiVe 2022 Documentation« details adaptions and changes with respect to the 2019 exercise and summarizes the course and the evaluation of the 2022 exercise. A reader interested in a more profound and detailed description of the general NuDiVe exercise-logic is encouraged to look into the »NuDiVe Documentation[1]« which provides more details, sources, in-game documents and exhaustive information on all technical and organizational aspects.

This document will not provide a thorough introduction to the background and general principles of nuclear disarmament and dismantlement exercises. For such an overview, please refer to the vast set of publications offered by IPNDV[2].

Extracts of the Step Guide as a new exercise documents are provided in the appendix. Within this document it will be put into context and explanations will be given to understand its function and the rationale behind its design. The Evaluation team's Final Assessment, preliminary inspection reports given by Hosts and Inspectors, the full Step guide, the adapted and extended »Procedure descriptions« and further exercise related documents are published in a supplementary document[3]. These documents will be summarized and referred to throughout this document.

NuDiVe 2022 has been a challenging undertaking, requiring thousands of working hours from organizers and participants to reach its successful conclusion. The organizers hope that by aiming for transparency and publishing the methods and findings in the most complete manner, the impact of their efforts will be maximized by providing a fruitful basis for IPNDV authorities and the scientific community to develop and test verification methods and technologies fit for inspection regimes truly enabling verified, multilateral irreversible nuclear disarmament.

1 https://www.ipndv.org/reports-analysis/nudive-exercise-full-documentation/
2 https://www.ipndv.org/reports-analysis/
3 https://www.znf.uni-hamburg.de/media/documents/forschung/nudive2022-supplement.pdf

1. Overview of the exercise

The »Nuclear Disarmament Verification« (NuDiVe) exercise held from 4th to 8th of April 2022 at Forschungszentrum Jülich, Germany, was the second comprehensive nuclear dismantlement exercise within the framework of the »International Partnership for Nuclear Disarmament Verification« (IPNDV). It was again jointly organized by the Federal Republic of Germany and the French Republic. After putting a particular focus on the inspection procedures and participant interactions in the first NuDiVe exercise, in 2022 the scope was extended to include more high-level verification technologies. Recommendations from the 2019 evaluation report were included as well.

Experts from 11 countries took the roles of personnel from a fictional nuclear weapon state (the »Host«) who declared to dismantle one of its nuclear warheads, and of members of a team of Inspectors, to verify that the simulated dismantlement took place according to the standards of a fictional treaty. The balance between the Inspectors' goal of collecting sufficient information to rule out any treaty violation, particularly the diversion of fissile material, and the inspected state's requirement to ensure the security and integrity of its confidential information and proliferation sensitive data, was the center point of the exercise.

1.1 Inspection logic and tools

The Host team was tasked with conducting the simulated dismantlement operation and carrying out the required inspection procedures at the behest of the Inspectors. The Inspectors were tasked to help enact the inspection regime so they could collect sufficient evidence. For security reasons, they could not do these tasks themselves.

Common goal was the verification of chain of custody, meaning the continuous documentation of the state and whereabouts of the warhead and its components until their final disposition. This required technologies for sealing and tagging the warheads in dedicated containers and confirming the absence of radioactive material in any other places including Host staff members leaving the area to ensure that no fissile material could have been diverted.

Portal monitor screening, radiation imaging, handheld radiation measurements, radiation template measurements together with a electronic optical sealing system, CCTV surveillance and sealing of potential diversion pathways were tools available for this. To get actual signals from the detectors, a surrogate radiation source containing a Cf-252 and a Ba-133 solution mimicking roughly 50g of plutonium was used[4].

Within the dismantlement facility, the Inspectors were closely guarded at all times and required to wear protective suits preventing the accidental, or intentional, collection of radioactive particles.

Excluding the first day of training, both teams were operating within the scenario for the entrire exercise, and private contact was restricted in order to obtain a professional and adversarial setting that could be realistically expected within a military installation.

4 The same surrogate source was used as for the NuDiVe exercise in 2019. Hence intensity decreased slightly due to radioactive decay.

1.2 Location and participants

Due to the COVID-19 pandemic, the NuDiVe 2022 exercise saw postponement, had to be arranged with a smaller number of participants then initially planned and could not provide in-person team meetings in advance. Finally, NuDiVe 2022 took place at the Forschungszentrum Jülich in the same building as in 2019 (Institute of Energy and Climate Research, IEK-6: Nuclear Waste Management) with the major inspection activities conducted in a radiation protection area (where the surrogate and test sources could be handled) and negotiations in conference rooms and offices. Inspectors were kept apart from Hosts and organizers in order to minimize accidental spread of information.

To ensure the proper handling of high-level verification technology, the Host team received support from Host technical personnel from Sandia National Laboratory, the Japanese Atomic Energy Agency (JAEA) and the German Federal Office for Radiation Protection (BfS) with two people from each institution. As in 2019, the whole exercise was accompanied by an independent Evaluation team whose report will be discussed later in this documentation. In addition to that, in 2022 the exercise welcomed two observers from UNIDIR and IPNDV who also shared valuable insights with the Evaluators and organizers.

1.3 Scenario

The fictional state around which the NuDiVe 2022 exercise was centered was called »Ipindovia«. It was designed to represent a nuclear weapon state and member of the Nuclear Non-Proliferation Treaty without mirroring any actual country.

Ipindovia’s nuclear arsenal includes 1000 warheads in total of which 900 are deployed: 200 warheads are present in gravity bombs or mounted on ALCMs, 300 on SLBMs and 400 on ICBMs (both in silos and road-mobile). Additional 100 warheads are located at Ipindovia’s Primary Nuclear Weapons Site, a military campus used for multipurpose activities related to the monitoring of its nuclear arsenal.

As a signatory state of the fictional Nuclear Weapons Reduction Treaty, Ipindovia is under an obligation to reduce its arsenal from 1000 to an agreed limit of 500 warheads. Both its reduction to that agreed limit and the absence of undeclared warheads above the limit of 500 are to be verified.

The agreement involves other nuclear weapon states reducing their arsenals to the 500-warhead limit, beginning with another country that is the same as Ipindovia in terms of numbers, posture, etc. Verification is carried out by an inspection body consisting of nationals form both nuclear weapon states and non-nuclear weapon states. The verification protocol foresees baseline inspections, inventory inspections and dismantlement inspections to verify the whole dismantlement process. The NuDiVe 2022 exercise simulated a dismantlement inspection taking place at Ipindovia’s Primary Nuclear Weapons Site, the Lead Assembly/Disassembly Unit (LADDU).

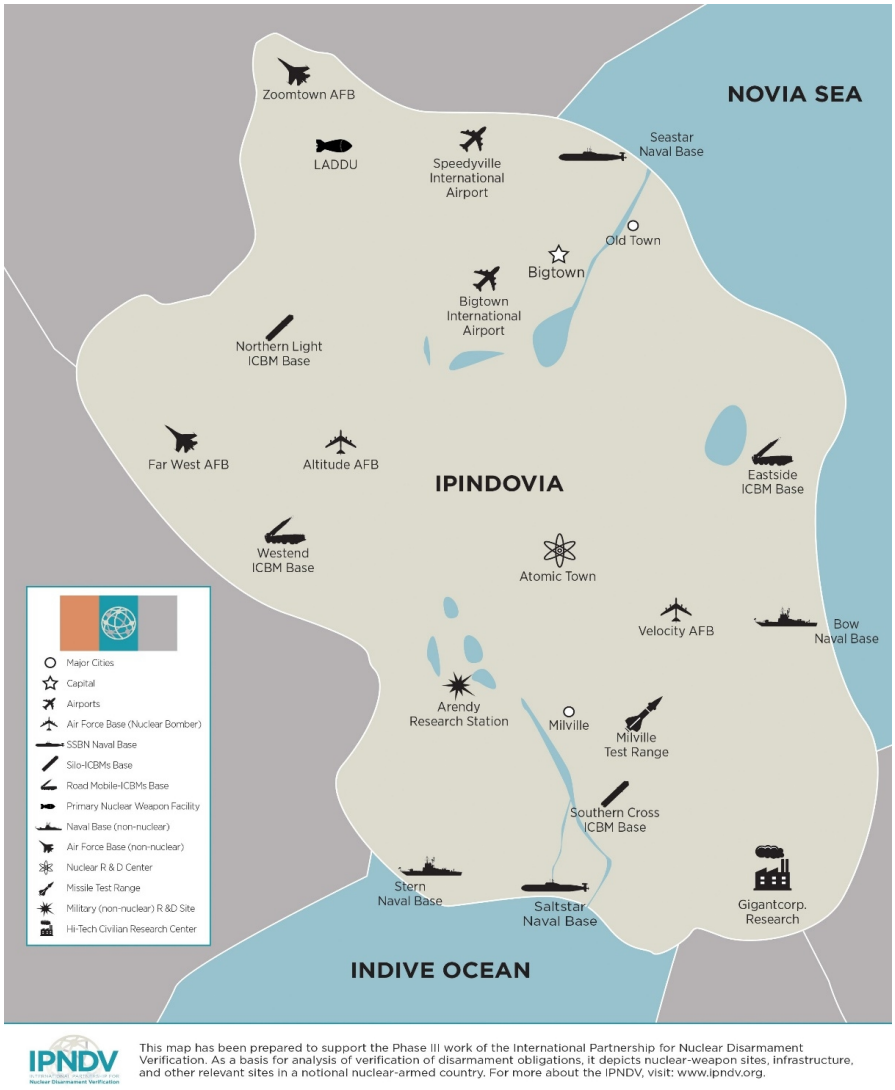


Figure 1: Map of Ipindovia. ©IPNDV

2. Adaptions and modifications

2.1 Technologies

While the NuDiVe exercise in 2019 had a strong focus on procedures, NuDiVe 2022 was intended to include more high-level verification technologies to increase the level of realism. Inspired by the 2019 IPNDV measurement campaign[5] at SCK CEN in Mol, Belgium, where a vast amount of detectors was applied, and supported by comments from the 2019 Evaluators, four additional verification technologies were included in the exercise. As already established in 2019, these special verification technologies were operated by personnel from the sending institution. The operators with the in-game denomination »Host technical support« were formally part of the Host team.

Gamma imaging: New to the NuDiVe 2022 exercise was the gamma imaging technology used for absence measurements in the dismantlement room. For the time of the exercise a Polaris-H[6] Compton camera was provided by the Japanese Atomic Energy Agency (JAEA) to verify the absence of gamma radiating material stored in potential hidden compartments in the room structure.

5 https://www.ipndv.org/reports-analysis/results-of-the-sck-cen-exercise-for-disarmament-verification-technologies/
6 https://h3dgamma.com/H100Specs.pdf?

After demonstrating the functionality with an authenticated test source, any other source should be observable in the image taken by the detector. The gamma imager facilitated the procedure significantly by replacing the handheld gamma measurement which in 2019 required a Host to sweep walls and the floor under an Inspector's instruction. The imaging method is less prone to human error and also more easily covers places which are hard to access by a handheld detector. To ensure agreed functionality, Inspectors could ask for a test measurement with an authenticated and sealed Ba-133 test source.

Radiation template: Sandia National Laboratories provided their »Trusted Radiation Identification System« (TRIS)[7] to support verification of the chain of custody. While initially developed to verify a treaty accountable item to be a nuclear warhead, in NuDiVe 2022 the system was used to ensure continuity of knowledge. By taking a radiation template of a treaty accountable item in a first stage, Inspectors can confirm the item to be still the same at a later point of the disarmament process – as long it has not been manipulated. The system is developed to meet non-proliferation and security interests while providing confidence to Inspectors. It is stored in a temper-proof casing and processes data in two separate processors. The exercise included a template confirmation of the warhead without high-explosives before the dismantlement and the generation of a new template of the containerized special nuclear material after the dismantlement.

Electronic optical sealing system: The »Electronic Optical Sealing System« (EOSS)[8] developed and provided by Neumann Elektronik GmbH is heavily used by the International Atomic Energy Agency (IAEA) in safeguards activities at nuclear facilities and was included in NuDiVe 2022 to contribute to the simulation of a consistent chain of custody. EOSS is an electronic seal with a fiber-optic loop which provides evidence of opening of the seal once applied on a cask. The reader is realized by a laser source that verifies the integrity of the fiber-optic loop over time. During NuDiVe 2022, EOSS was used to seal the container with the special nuclear material after dismantlement. The time, date and duration of any opening and closing of the fibre optic loop were recorded internally.

SHA256 hashing: To securely transfer inspection related data from the radiation protection area to the Inspectors' office, SHA256 hashing[9] was introduced. Photos and CCTV footage acquired during the inspection were compressed and hashed at the authenticated Inspector terminal with a verified algorithm. This operation was executed by a Host team member under the Inspectors' surveillance whenever the Inspectors deemed it necessary. The generated hash values were noted in a log sheet and verbally transmitted to the Inspectors' office. The integrity of data received from the Host could then be verified at any point by running the hashing algorithm again and confirming the resulting values.

These technologies were complemented by verification methods already used during the NuDiVe exercise in 2019:

7 https://www.sandia.gov/rnmm/_assets/documents/TRIS_Factsheet.pdf

8 IAEA (2011): Safeguards Techniques and Equipment: 2011 Edition. International Nuclear Verification Series, No. 1 (Rev. 2). https://www-pub.iaea.org/MTCD/Publications/PDF/nvs1_web.pdf, page 74f. Developed under the German Member State Support Programme to the IAEA.

9 https://nvlpubs.nist.gov/nistpubs/FIPS/NIST.FIPS.180-4.pdf

- A **portal monitor** with two columns of neutron and gamma detectors capable of detecting at least 50 g of plutonium without significant shielding; provided and operated by the German federal radiation protection office (BfS);
- **Handheld neutron and gamma detectors** used to sweep rooms, personnel and containers;
- A **CCTV system** of five cameras watching each other and transmitting data to a secured Inspector terminal which transmits the data to a Host terminal for the Host's revision;
- **Adhesive seals** to seal equipment, doors, containers and potential diversion pathways;
- **Equipment ID tags** to show that certain equipment was mutually verified and authenticated by both parties.

All technologies and procedures were explained and practiced during training sessions at the beginning of the exercise. Manuals and exercise documents were provided to the participants a few weeks in advance of the exercise.

Figure 2: *Top left*: Polaris-H Compton camera;
Top right: Operation tablet for Compton camera;
Bottom left: Template verification with TRIS;
Bottom right: EOSS on SNM container.

2.2 Scenario

In harmonization with a scenario developed during IPNDV phase III (which itself was inspired by the 2019 NuDiVe scenario), instead of “Urania” the inspected state became “Ipindovia”. This lead to changes of names, flag and map only. Nuclear arsenal, delivery systems and weapon types were the same as in the 2019 scenario.

In contrast to 2019, where “one of the first inspections” had been simulated, NuDiVe 2022 assumed a consecutive inspection, meaning the dismantlement of multiple warheads has already been verified. On one hand, this was intended to allow for a less versatile environment where there is already a certain amount of trust built between the teams. The fact that some of the participants already took part in the 2019 exercise and therefore knew the facility and the basic conduct of the exercise was supporting this effort along with reassigning these participants to different teams than in 2019. Having lunch at the same place (while seated at separate tables) was another intent to support a trustful and cooperative inspection approach. Nonetheless participants were still accommodated in different hotels according to their team affiliation with separate transport. On the other hand, this allowed for certain verification equipment to be already (still) in place. It was declared that the portal monitor and the CCTV system as well as adhesive seals on potential diversion pathways in the dismantlement room persisted from a previous inspection. By that, the exercise did not need to simulate the lengthy processes of portal monitor and CCTV commissioning and decommissioning and was intended to require less seals to be applied. The “gained” time allowed for the introduction of the new verification technologies.

As in 2019, the simulated inspection focused on the special nuclear material and excluded the dismantlement of high-explosives, since handling of high-explosives requires a facility which could not been simulated adequately. The term “treaty accountable item” therefore referred to a warhead where high-explosives have already been removed.

2.3 Steps and procedures

The NuDiVe 2022 exercise built on an extremely detailed set of documents describing the whole inspection framework in great detail, from general inspection steps down to single interactions between participants.

With several of the inspection tasks not trivial to perform, also given a limited number of Inspectors on site, participants by improvising always face a risk of taking actions which turn out to be impractical or even invalidate the chain of custody. Giving thorough, tried and tested steps and procedures can provide a solid foundation which Inspectors can fall back to when in doubt. The modular structure allows for adaption to a changing inspection environment.

The inspection framework was initially developed for the NuDiVe exercise in 2019 by drafting first concepts which then were discussed, tested, and redrafted in multiple iterations by the organizers using tools such as dry runs and tabletop exercises. For NuDiVe 2022 the resulting steps and procedures were revised and adapted in a similar process with the aim of increasing the overall efficiency of operations while encouraging some higher flexibility in their application[10]. They were also modified to include the deployment of the new inspection technology.

10 This was also a major recommendation in the NuDiVe 2019 evaluation report.

The inspection framework was built from several types of documents ordered in a hierarchical manner with extensive cross-references. All of these documents are considered in-game.

Flow chart: The flow chart, introduced in 2022, gives a single-page overview over the whole inspection and the particular steps simulated (or not simulated) during the exercise. Steps come in squares with short specifications, and they are numbered from 0 to 11. Arrows indicate the sequence of steps.

Step guide: Each step appearing in the flow chart is described in more detail in the Step guide. The Step guide gives a description of each step, lists the required equipment, marks the location where it takes place and indicates the amount of Host and Inspector personnel required to execute it. The tasks are listed in form of checkboxes which specify whether they are to be executed by Hosts, Inspectors or both. The Step guide, introduced for NuDiVe 2022, was intended to be an orientation for Inspectors and Hosts without replacing the more detailed Procedure descriptions.

In order to avoid redundancy, extra sections at the end of the Step guide are dedicated to frequently occurring tasks such as sealing, data transfer and equipment retrieval/locking. At other points they are therefore not described in full detail.

If the heads of Host and Inspection team agreed, the option was provided to modify the order of steps and to add or remove procedures.

Procedure descriptions: The Procedure descriptions are the commonly agreed inspection baseline and explain key aspects of each step in a high level of detail. Major activities also appearing in the Step guide are marked in red. Conceivable incidents and possible solutions are given under “Events” and “Provision to be taken in case of event”.

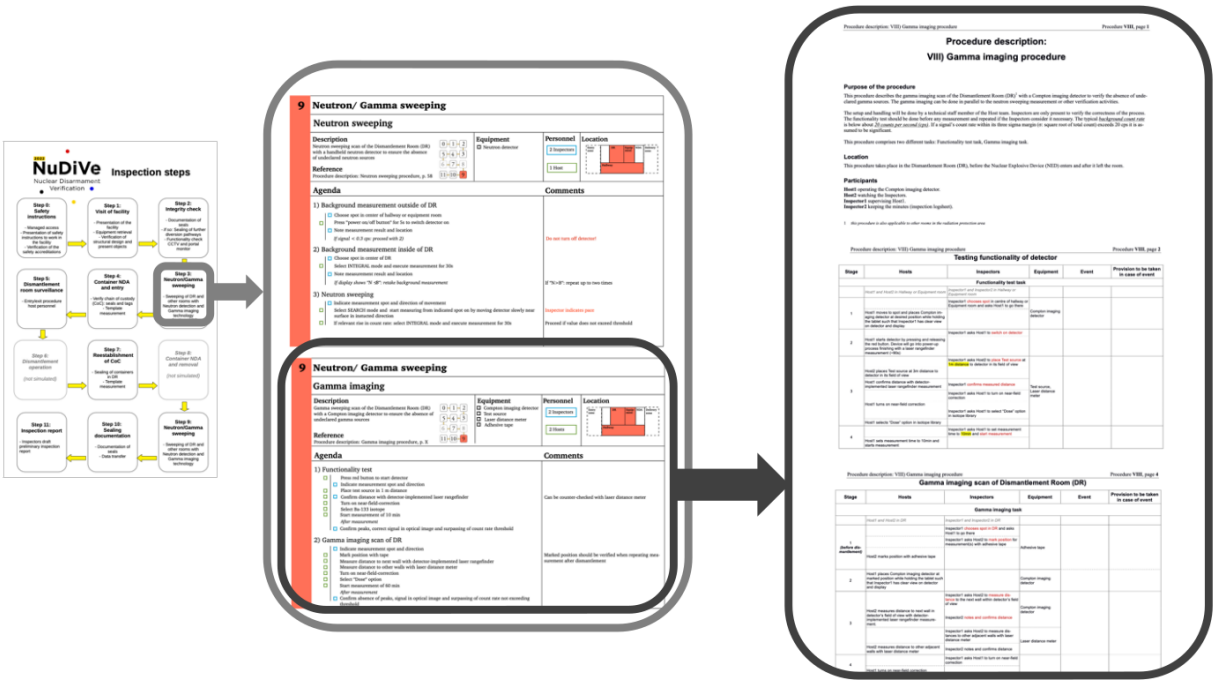


Figure 3: Hierarchy of exercise documents.

Procedure descriptions were developed with the idea of reducing the potential of dispute between Hosts and Inspectors to a minimum. However, due to the high level of detail, it may be impractical to follow the Procedure descriptions strictly at all time during the inspection. While inspection operations might be guided by the Step guide, it is still important to consider the details of the Procedure descriptions to grasp the whole complexity of an inspection and to ensure continuation of knowledge.

Equipment manuals: For each piece of equipment, a detailed manual provides information on how it is set up and used. The handling of this equipment was also trained in advance of the exercise. The portal monitor, the gamma imager and TRIS were operated by experienced staff.

For illustration, a part of the new NuDiVe 2022 Step is added in Appendix 1. The full Step guide, adapted Procedure descriptions and modified or newly introduced exercise documents are published in a supplementary document[11].

3. Course of the exercise

Day 1 was used for a joint welcoming event for all participants and specific training sessions for the two teams afterwards. While teams remained separate most of the time, in contrast to the 2019 exercise the day was still considered “out-of-game”. This change was intended to make a clearer separation of “player role” (participants, out-of-game) and “character role” (Hosts/Inspectors, in-game) by encouraging participants to ask questions and check their understanding of the inspection logic.

The “out-of-game” training sessions were continued in the morning of **Day 2**. After that, the “in-game” inspection started with an opening event where the Hosts received the Inspectors and gave a short presentation. This was followed by first negotiations about the inspection plan and a familiarization visit of the radiation protection area with two members of the inspection team.

Day 3 started with the documentation of already applied adhesive seals and proceeded with functionality checks of the portal monitor and the CCTV system. Additional adhesive seals were applied during this process. At the end of the day, the teams conducted a data transfer to verify the seals’ integrity.

The most relevant inspection activities happened during **Day 4**. The teams started with a neutron sweep and the gamma imaging scan of the dismantlement room together with a neutron and gamma sweep of the Non-destructive assay (NDA) room. Afterwards the container with the Treaty-accountable item (TAI) was brought to the facility and moved into the NDA room to execute the gamma template verification measurement with the TRIS system. The TAI container was then moved into the dismantlement room, where the notional disassembly of the warhead was conducted. The Inspectors consequently returned to the dismantlement room and requested the sealing of all containers. The empty TAI container and the “other components” container were sealed with adhesive seals and removed from the facility after passing the portal monitor without an alarm. The NDA of these containers was not simulated. In the next step, Inspectors requested the application of the EOSS seal on the Special nuclear material (SNM) container. The Host proposed an application in the equipment room which the Inspectors agreed to, such that the container was moved to this room while still unsealed. After some problems with the verification of the seal via

11 https://www.znf.uni-hamburg.de/media/documents/forschung/nudive2022-supplement.pdf

the EOSS terminal the seal was set with a back-up terminal. Only a single Inspector was present in the equipment room during this process. The CCTV system faced some technical problems and for a few minutes covered the equipment room only with a single camera. The sealed SNM container was then moved to the NDA room where a new radiation template was generated using TRIS. The contained was removed from the facility afterwards. A transfer of photos and video footage was performed before the dismantlement room was sealed over-night.

On **Day 5**, the last day of the exercise, neutron and gamma sweeps as well as the gamma imaging scan were repeated and a fraction of the seals was documented. Both teams then had internal meetings followed by a joint meeting. At this event the Inspectors stated that they could not confirm the successful dismantlement due to the inconsistencies occurring during the EOSS application. Hosts, Inspectors, Evaluators together with the organizers concluded the NuDiVe 2022 exercise with a debriefing.

Figure 4: *Left*: Meeting of Inspection and Host team;
Right: Ongoing inspection operation in equipment room.

4. Adaptions and incidents

In the light of the 2019 evaluation the organizers wanted to allow participants to be slightly more flexible in the execution of the inspection. As the exercise went, participants made adaptions to the inspections steps and procedures as they were initially presented by the organizers. Some of these adaptions were made intentionally and in a mutually agreed way. Other adaptions were more spontaneous and produced incidents with minor to major impact on the continuity of knowledge. Beyond that, technical problems contributed to one of these incidents.

- First intentional and agreed adaption was the execution of neutron and gamma sweeps in the NDA room where the TRIS system was deployed. As the Step guide and the Procedure descriptions explicitly allowed for sweeps in other rooms if the Inspectors deem it necessary, this adaption was an additional measure which did not corrupt the inspection integrity but comforted Inspector interests.
- After the gamma imaging scan, Inspectors requested the output file given in the form of an image in JPG data format. The Host team agreed to that. The data transfer procedure did not foresee this whereupon the hashing of the data was conducted at the gamma imaging

terminal, a computer which was ad-hoc declared to be authenticated. After having hashed the image file, it was transferred together with other inspection data in the agreed way.

- At some point during Day 4, Inspectors asked the Host to transfer data with a storage device which was brought in by themselves. The Host agreed to use that device and returned it to the Inspectors after storing the files on it. This was a serious breach of the agreed procedure as the teams endangered the terminal software's integrity by connecting it with an unauthenticated storage device with unclear content.
- After the inspection activities at Day 3, Inspectors requested additional sealing of the door to the hallway where the inspection-related rooms were located. The Host team agreed on that and both teams, in the anticipation of the controlled area possibly being in "out-of-game" use as well, agreed on the application of notional ("invisible") seals. This happened without the organizers proposing it as such.

After dismantlement, a series of adaptions and unplanned incidents arose around the sealing and movement of containers. Some or a combination of this were identified as potential breaches in the chain of custody by Inspectors and Evaluators:

- For the first step after dismantlement, procedures foresaw that containers are sealed immediately, starting with the SNM container. Container movement was planned to happen afterwards. Both teams agreed on sealing and removing the empty TAI container and the OC containers first before dealing with the SNM container. During that process, an Inspector oversaw the entry to the dismantlement room at all times.
- The sealing of the SNM container was intended to take place in the dismantlement room using the EOSS. In contrast to that, Host team members present in the controlled area proposed the application to take place in the equipment room. Present Inspectors agreed to that process without consulting their team leader. In the course of this spontaneous adaption, the unsealed SNM container was moved to a room that was not checked on the absence of radiation sources or potential diversion pathways while being observed by only a single Inspector among various Hosts.
- During the EOSS application, CCTV camera No. 3 had a temporary outage such that only one of the two cameras in the equipment room covered the process. This prevented a seamless reconstruction of the operation beyond the statements of present persons.
- Due to the EOSS terminal facing technical problems, the Host technical personnel introduced a "back-up terminal" into the game which was missed to be declared as "authenticated". As unauthenticated hardware this would have compromised the SNM container sealing in a significant way and would have resulted in an irreversible interruption of chain of custody.

5. Evaluation

5.1 Host and Inspectors

Both teams drafted inspection reports after the conclusion of the exercise. Their observations and opinions will be summarized in the following.

Host team

The Host team perceived that the inspection was conducted professionally and in the spirit of good collaboration. However, certain parts proved more labour intensive and time consuming than they initially expected. Absence verification tasks were nonetheless executed in an efficient and effective manner.

While the inspection team mostly conducted their inspection according to the plan agreed upon on beforehand, deviating requests were granted by the Host team in two occasions as they did not challenge safety, security or non-proliferation.

They faced the inspection team's concerns about having only one Inspector monitoring the chain of custody, especially when sealing the SNM container after dismantlement, with their interest to keep the number of people present as low as reasonably achievable. Furthermore, in their perception, a higher number of Inspectors and Hosts inside the controlled area at the same time made it increasingly difficult to ensure that unwanted activities were not taking place.

Because of problems with internal communication in both teams, they suggested that team leaders should have been easily accessible or physically present in the controlled area to quickly resolve any problems that may arise. The Host team members were using WhatsApp instead of the provided walkie-talkies and admit that thereby they were not communicating as openly and transparently as they would have liked to do.

The Host team recognized a mistake on both sides, when the SNM container was moved to the Equipment Room for sealing. They were mistakenly under the impression of the process to require the CCTV terminal and therefore proposed to move the container there. The Inspectors agreed and did not ask to consult with their team lead. In their perception, Inspectors did not lose visual contact with the SNM container during the whole process as one Inspector was clearly positioned next to it at all times.

They conclude that the incident with the SNM container should never have happened, and the misunderstanding was partly the fault of the Host Team. They request the incident and its consequences to be evaluated later by the Treaty Commission. The Host Team is confident that no SNM could have been diverted at any point during the inspection.

In order to avoid such incidents, in retrospect, the Host team states that they could have been better drilled on the procedures and on the actual use of all relevant equipment.

Inspector team

The Inspectors shared the impression that throughout the verification activity, a cooperative environment with the Host team existed. Disputes were discussed and there were concerted efforts to resolve them in mutually acceptable ways.

They appreciated the Host's responses to request for past inspection reports, data regarding previously applied seals, and other information requests for the purposes of the inspection, e.g. dimensional data for the dismantlement room.

The Inspection team noted the significant value added to the inspection by new technologies, which improved efficiency and provided more physical data for gaining confidence in non-diversion of SNM.

On several occasions, Inspectors observed a disproportionate number of Hosts in the controlled area which, in their perception, caused unnecessary confusion, distraction and was not in agreement with the mutually agreed procedures.

In the Inspectors' perception there were several occasions in which the Host team did not always follow procedures. They attribute incidents which caused delays or a serious breach of chain of custody to that behavior. A Host repositioning a CCTV camera during commissioning without being instructed to do so by an Inspector is one example. The application of the EOSS seal in a room that had not undergone gamma and neutron sweeping or sealing activities to rule out diversion pathways is another. The latter incident was perceived as a serious concern which, after reviewing the CCTV footage, in their evaluation created several opportunities for diversion.

As the unsealed SNM container was placed at the back of the room, it was monitored by one CCTV camera only. Inspectors could not rule out that it was put against the back wall of the room. They criticize that only a lone Inspector was present when the EOSS seal was applied. In addition, they could not rule out the possibility that a Host leaning over the container was engaged in a diversionary action by placing or removing items from the still unsealed SNM container or the cart it was on. When the second CCTV camera froze, two Inspectors were overseeing the process. Inspectors still did not want to fully rely on their record as they potentially might have been distracted, or perhaps coerced or bribed into facilitating diversion.

The Inspection team states that the cart, where the SNM container was placed on, was never swept for gamma and neutron sources. Thus, Inspectors could not rule out the possibility that some SNM was separately adhered to the cart as a means of diversion.

As a result, the Inspection team concluded that the inspection was unable to determine with confidence that the dismantlement activity took place without diversion of SNM.

5.2 Evaluation team report

Evaluation methodology

The Evaluation team observed all Inspector-Host interactions and most internal team game discussions and captured as frequently as possible comments and behaviors of the exercise players. Interviews were conducted with exercise organizers and team leaders, and all players completed questionnaires at the beginning and end of the inspection phase of the exercise. Evaluators also noted comments from the post-exercise debriefing.

The Evaluation team comprised of the team lead Leesa Duckworth (USA) and Ichiro Akiyama (JPN), Nico van Xanten (NDL), and Jens Wirstam (SWE). While three of the evaluators

participated in NuDiVe 2019, the team combined NuDiVe 2019 experience with general exercise experience and external expertise.

The Evaluators provided a final evaluation report with observations made during the exercise (which were also presented during the post-exercise debriefing) and results from their post-exercise evaluation. This report can be found in the supplementary document[12]. In the following, key points will be summarized.

Observations during the exercise

Aside of the appreciation of the efforts to reproduce a realistic exercise environment the Evaluation team recognized Covid19's influence on the timing, planning and participation availability for this exercise and on readiness activities, planning and communication, both with the organizing team and between the Host and Inspector team participants. In their perception, this led to many participants not becoming sufficiently familiar with the full procedure to make the step-by-step procedure effective.

Because the Step guide was a checklist only, in their view the full-length procedures should have been the governing document. Conflicting personnel numbers listed in these two documents created unnecessary tension, loss of time, and ongoing arguments.

Interruption of inspection activities for a lunch hour in the Evaluators' opinion was unnecessary as in reality you would not stop mid inspection to go to a cafeteria. They see rotating shifts and lunch boxes as a more likely option.

The Evaluation team criticized the fact that there were several situations where Inspectors were only allowed to have a single Inspector conducting a task while Host personnel limits were not followed in most of those circumstances. As a single inspector would never be allowed by the Inspectorate due to safety reasons, a two-person rule should have been enforced always – be it by participants or organizers. Evaluators see further asymmetry arising from the "technical support personnel" used beyond their technical support role to also "watch the Inspectors" or carry inspection equipment filling a Host role. Given these ambiguous roles, Evaluators see serious difficulties in maintaining the continuity of knowledge, e.g. of equipment as the TRIS.

Evaluators observed a relative absence of command post function in both team rooms as well as a need for better communication between command personnel and teams in the controlled area. The consequence was decisions being made in the Controlled Area without the direct authorization and confirmation of the Command. These decisions included deviations from agreed procedures that seriously endangered the continuity of knowledge. The Evaluators state that deviations should only have come as an inject by a "Controller" (an organizer who intervenes in the exercise) and be communicated to all before action was taken. Deviations from approved procedures should be realized only in response to unexpected situations that would have hampered the inspection otherwise.

Evaluators extend this comment to the injection of equipment to the exercise by the organizers. Instead of simply bringing in non-authenticated equipment, this could have been addressed through a formal "Controller" inject stating that both teams have witnessed verification information.

12 https://www.znf.uni-hamburg.de/media/documents/forschung/nudive2022-supplement.pdf

Otherwise Evaluators see the chain of custody seriously endangered, e.g. when the EOSS terminal was failing and a “back-up” system was introduced.

Key results of the Evaluation team’s observations are the need of following procedures in a strict way and of considering the introduction of a Controller to take immediate action if necessary.

Post-exercise evaluation results

In addition to the immediate observations, the post-exercise evaluation identified problems and improvement capacities in various areas.

With regard to inspection technologies, the Evaluators argue that the CCTV system was the key element that could have saved or destroyed Inspectors’ confidence. Due to its problems during the time when the deviation occurred, confidence could not be recovered. They state that additional cameras, facilitation of footage verification and streamlining of the set-up verification process would also have helped.

As already criticized after NuDiVe in 2019, the application and verification of adhesive seals once again took a significant amount of time and could have been reduced or paired with sweeping techniques. The adhesive seals with reflective particle matrix created inconsistencies and were applied too extensively without a proper sealing strategy. This could have been communicated to the Inspectors in advance, including information on general characteristics of the dismantlement end product and how it might be diverted. The professional EOSS seal unexpectedly endangered the inspection due to technical problems.

The Evaluation team describes problems in local communication. While at the beginning of the exercise not possible at all, Inspector’s on-site to off-site communication was sometimes directly conducted and at other times relayed by a Host with limited consistency. This contributed to the problems in command structure.

With the exercise spaces being quite warm and the Inspector rotation strategy not sufficiently controlled, high-density polyethylene (Tyvek) suits for Inspectors operating in the controlled area once again were criticized for creating communication challenges and health issues.

A major problem identified by the Evaluators was the organizers’ assumption of self-educating participants who autonomously prepare in advance of NuDiVe 2022. The already mentioned Covid19-related aspects were complemented by various participants identifying themselves as novices to verification with little technical understanding.

The Step guide assumed the users to be well-trained teams who know the details of the Procedure descriptions sufficiently to use the checklist style guide. This not being the case, Evaluators observed participants performing inspection procedures not always in an effective way but following too strictly the Step guide.

Further problems arose from a sometimes very crowded and chaotic controlled area.

The Evaluation team found that the interaction between Inspectors and Hosts started in a collaborative atmosphere, that appeared to diminish with the days going on. Their post-exercise evaluation indicates that inconsistencies in inspection personnel numbers authorized in the controlled area were met with little to no flexibility. Exercise artificiality, limited understanding of

the larger context of verification, and high-risk/high-security protocols were identified by the Evaluators to influence how each side responded to differences in perspectives. While managed respectfully, not all disputes were resolved to the satisfaction of both sides.

When the inspection team could not achieve verification and non-diversion confidence, to the Evaluators the Hosts seemed surprised when this became obvious, and the organizers concerned and disappointed. However, the Evaluation team emphasized that, the exercise resulted in a large number of lessons learned, despite of the inspection's negative outcome.

5.3 Lessons learned

The NuDiVe 2022 exercise's outcome and the question "What made the inspection fail?" bare the potential of identifying challenges of an inspection in the context of nuclear disarmament verification as well as lessons learned from them.

First of all, **preparation** of participants turned out to be a key factor. In 2019, at the fringes of in-person IPNDV meetings, participants had multiple occasions to meet in the teams in person before the actual exercise took place. Personal familiarization, inspection strategy and distribution of roles were be developed and key moments of the inspection were identified in advance. Organizers also emphasized the importance of knowing the procedures in various meetings. Already familiar with each other, the teams even met the day before the exercise to once more run through the documents.

The Covid19 pandemic made most of this impossible. No in-person team meetings, a volatile list of participants due to changes in travel policies of governments and organizations and resulting short-term changes in team assignment complicated the preparation efforts of team leaders. Issues like the not always clear communication within teams, e.g. between team lead an their on-site team members probably were rooted in that. Further technical facilitation, e.g. allowing for more direct communication between on-site and off-site Inspectors, could have also helped. Organizers still could have stronger encouraged the team leaders to set up online meetings with their colleagues before the actual exercise.

Documents, preparations and training sessions could have pointed out better the necessary focus on the inspection's key moments: the movement of TAI and SNM containers together with the SNM container sealing. While the other steps are not less relevant for a successful inspection outcome, failures in these steps can hardly be corrected by repetition. Therefore they would have needed more thorough preparation and observation.

Further, several potential sources of **ambiguity and confusion** could have been avoided. Color ambiguity and an unclear role distribution arose from Host technical personnel (in the same red shirts like the Host). While appearing like regular Host personnel they were not always prepared an included in the Host team's communication. Sometimes they executed tasks as other Host team members (e.g. guarding an Inspector or carrying equipment), sometimes they were just waiting for their support to be requested. Separating Host technical personnel from Host team members in a clearer way or making them full Host team members (with all the consequences of number limits etc.) would have helped here.

A similar situation was observed for the organizers. They were not part of the Host team but neither "invisible" as the observers. They were sometimes just answering questions from the Host, in other

occasions organizers even took actions a Host would do. Perceived by the interceptors as Hosts, Host technical personnel and organizers contributed to their impression of a “disproportionate” number of Hosts which deviated from the agreed numbers in the procedures.

With Inspectors, Hosts, Host technical personnel, Evaluators, observers, organizers, PR personnel and guests, at some times during the NuDiVe 2022 exercise too many people were present in the controlled area. Resulting crowded rooms and high noise levels created confusion which further complicated the work of participants. A more limited number of non-players would have helped.

A more consistent handling of mid-exercise introductions of new technology such as terminals for detectors or seals, which were not planned or included by the organizers in advance, would also have been helpful.

NuDiVe 2022 also showed the difficulties of finding a balance between the desire for more **flexibility** (as requested 2019) and a solid (and sometimes rigid) inspection framework with a stronger focus on **control** (as Evaluators recommend 2022).

On one hand, the Step guide was meant to facilitate the execution of procedures by providing an easy-to-read “check list”. On the other hand, potentially useful for well-trained and experienced users, under the constraints of limited preparation time the Step guide was not only an additional document for the participants to read but it also partially overshadowed the more complex and detailed Procedure descriptions – the basic document which grasps the inspection logic by taking into account all necessary details and many eventualities.

Flexibility and the resulting possibility of making (helpful) errors were key elements of NuDiVe 2022 but clearly are not the only – and probably not the most realistic – way. With the introduction of a possible “observer controller” or “management team”, or more active involvement of the organizers some incidents could have been avoided and the inspection might have been “a full success”.

NEUTRON SWEEPING/ GAMMA IMAGING

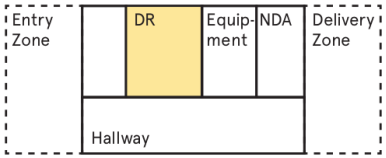
NEUTRON SWEEPING

DESCRIPTION
Neutron sweeping scan of the dismantlement room (DR) with a handheld neutron detector to ensure the absence of undeclared neutron sources

REFERENCE
Procedure description: Handheld neutron sweeping procedure p. 39

EQUIPMENT
☐ Handheld neutron detector

LOCATION



PERSONNEL
2 Inspectors | 2 Hosts

AGENDA

1) BACKGROUND MEASUREMENT OUTSIDE DISMANTLEMENT ROOM

- ☐ Choose spot in center of hallway or equipment room
- ☐ Press "power on/off button" for 5s to switch detector on
- ☐ Note measurement result and location

If signal < 0.3 cps: proceed with 2)

2) BACKGROUND MEASUREMENT INSIDE DISMANTLEMENT ROOM

- ☐ Choose spot in center of DR
- ☐ Select INTEGRAL mode and execute integrated measurement for 30s
- ☐ Note measurement result and location

If display shows "N ≤ B": retake background measurement

3) NEUTRON SWEEPING

- ☐ Indicate measurement spot and direction of movement
- ☐ Select SEARCH mode and start measuring from indicated spot on by moving detector slowly near surface in instucted direction

If relevant rise in count rate

- ☐ Select INTEGRAL mode and execute measurement for 30s

COMMENTS

Do not turn off detector

Inspector indicates pace

Proceed if value does not exceed threshold

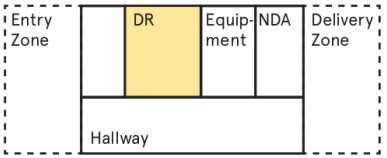
NEUTRON SWEEPING/ GAMMA IMAGING

GAMMA IMAGING SCAN

DESCRIPTION
Gamma imaging scan of the dismantlement room (DR) with a Compton imaging detector to ensure the absence of undeclared gamma sources.

REFERENCE
Procedure description: Gamma imaging procedure p. 45
Back-up: Handheld gamma sweeping procedure p. 51

EQUIPMENT
- ☐ Gamma imaging detector
- ☐ Test source
- ☐ Laser distance meter
- ☐ Adhesive tape

LOCATION


PERSONNEL
2 Inspectors | 2 Hosts

AGENDA

1) FUNCTIONALITY TEST

- ☐ ☐ Press red button to start detector
- ☐ Indicate measurement spot and direction
- ☐ ☐ Place test source in 1 m distance
- ☐ ☐ Confirm distance with detector-implemented laser rangefinder
- ☐ ☐ Turn on near-field-correction
- ☐ ☐ Select Ba-133 isotope
- ☐ ☐ Start measurement of 10 min

After measurement

- ☐ Confirm peaks, correct signal in optical image and count rate exceeding threshold

2) GAMMA IMAGING SCAN OF DISMANTLEMENT ROOM

- ☐ Indicate measurement spot and direction
- ☐ ☐ Mark position with tape
- ☐ ☐ Measure distance to the next wall with detector-implemented laser rangefinder
- ☐ ☐ Measure distance to other walls with laser distance meter
- ☐ ☐ Turn on near-field-correction
- ☐ ☐ Select "Dose" option
- ☐ ☐ Start measurement of 60 min

After measurement

- ☐ Confirm absence of peaks, signal in optical image and count rate not exceeding threshold

COMMENTS

Test source brought by radiation protection officer

Can be counter-checked with laser distance meter

Marked position should be verified when repeating measurement after dismantlement

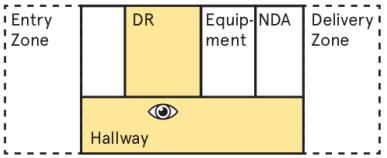
ESTABLISHMENT OF DISMANTLEMENT ROOM SURVEILLANCE 7

ENTRY AND EXIT PROCEDURE

DESCRIPTION
During the actual dismantlement process, a host might enter or leave the dismantlement room (DR). The inspectors supervise entry and exit with the radiation portal monitor.
In case the portal monitor raises an alarm, a body scan is performed with neutron and gamma detectors.

REFERENCE
Procedure description: Dismantlement room Entry/Exit procedure p. 69

EQUIPMENT
- ☐ Portal Monitor
- ☐ Handheld gamma detector
- ☐ Handheld neutron detector

LOCATION


PERSONNEL
2 Inspectors | 4 Hosts

AGENDA

1) PREPARATION
If deemed necessary
- ☐ Prepare handheld neutron and gamma detector

2) HOST DISMANTLEMENT ROOM ENTRY
- ☐ Stay in center of portal monitor for 20s

If there is no alarm
- ☐ Permit host entry to DR

3) HOST DISMANTLEMENT ROOM EXIT
- ☐ Inform host outside DR about exit
- ☐ Announce exit to inspectors outside DR
- ☐ Leave DR and stay in center of portal monitor area for 20s

If there is no alarm
- ☐ Permit host to leave portal monitor area

Repeat for every person entering/exiting the DR

COMMENTS

The neutron detector should always be turned on as initial background measurement takes a lot of time

If there is an alarm: neutron and gamma body scan
(see Procedure Description: p. 70)

If there is an alarm: neutron and gamma body scan
(see Procedure Description: p. 70)

CONTAINER VERIFICATION

8

TEMPLATE CONFIRMATION

DESCRIPTION

A gamma template measurement with the TRIS system of the Special Nuclear Material (SNM) signature emitted by the Treaty Accountable Item (TAI) container is taken to verify its integrity. Inspectors can verify the SNM in advance of the dismantlement by comparing the signature to a previously measured template.

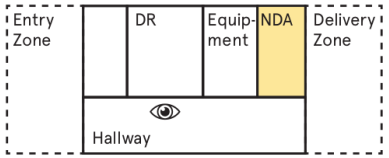
REFERENCE

Procedure description: Template procedure p. 61

EQUIPMENT

- ☐ TAI container
- ☐ TRIS system
  - ☐ Firmware hash key
  - ☐ Red & black hash side value
  - ☐ Public key iButton
  - ☐ Template iButton

LOCATION



PERSONNEL

2 Inspectors | 2 Hosts

AGENDA

1) PREPARE TRIS SYSTEM

- ☐ Start TRIS system
- ☐ Give firmware hash key
- ☐ Verify red and black side hash values
- ☐ Reject option to generate new template
- ☐ Give host public key iButton to connect it to black side of trusted processor
- ☐ Execute functionality test
- ☐ Connect template iButton to red side
- ☐ Ensure that trusted processor verifies template signature with public key

2) ARRIVAL OF TAI CONTAINER (→NEXT PAGE)

3) COMPARING TAI SIGNATURE TO AN EXISTING TEMPLATE (→NEXT PAGE)

COMMENTS

Caution: DR surveillance maintained

CONTAINER VERIFICATION

TEMPLATE CONFIRMATION

AGENDA

2) ARRIVAL OF TAI CONTAINER

- ☐ Enter dismantlement room (only one host)
- ☐ Ensure that portal monitor terminal is closed
- ☐ Move TAI container from delivery zone to NDA room
- ☐ Confirm container's id and integrity of its seal
- ☐ ☐ Document seal

3) COMPARING TAI SIGNATURE TO AN EXISTING TEMPLATE

- ☐ Confirm position of NaI detector
- ☐ Background collection and calibration
- ☐ Spectrum collection
- ☐ Ensure that measurement is confirmed against template

COMMENTS

Host must enter dismantlement room before TAI container arrives at dismantlement area

CONTAINER VERIFICATION

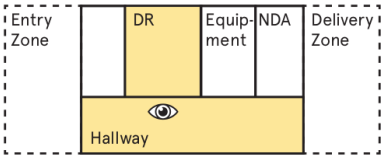
10

CONTAINER MOVEMENT

DESCRIPTION
Transfer of containers from the non-destructive assay (NDA) room to the dismantlement room (DR) with a portal monitor measurement.

REFERENCE
Procedure description: Container movement procedure p. 55, Handheld neutron sweeping procedure p. 39, Handheld gamma sweeping procedure p. 51

EQUIPMENT
- ☐ Portal monitor
- ☐ Handheld gamma detector
- ☐ Handheld neutron detector
- ☐ TAI container
- ☐ Empty SNM container
- ☐ Empty OC container

LOCATION


PERSONNEL
1 Inspector | 2 Hosts

AGENDA

1) TAI CONTAINER TRANSFER: NDA ROOM → DISMANTLEMENT ROOM
- ☐ Verify presence of one host in the DR
- ☐ Ensure that portal monitor terminal is closed
- ☐ Move TAI container from NDA room to portal monitor measurement area
- ☐ ☐ Verify gamma and neutron alarm of portal monitor flashlights
- ☐ Hand over TAI container to host in DR

2) TRANSFER OF EMPTY CONTAINERS: NDA ROOM → DISMANTLEMENT ROOM
Execute task seperately for empty SNM and empty OC container
- ☐ Move empty container from delivery zone to portal monitor measurement area
- ☐ Verify container ID
- ☐ Verify absence of portal monitor`s gamma and neutron alarm

If deemed necessary by inspectors
- ☐ Perform gamma and neutron sweeping on empty container
- ☐ Hand over empty container to host in DR

COMMENTS
Caution: DR surveillance maintained

Nobody must enter the DR simultaneously with the TAI container