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Topical Papers

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Mission Statement

The Institute of Nuclear Materials Management is dedicated to the safe, secure and effective stewardship of nuclear materials and related technologies through the advancement of scientific knowledge, technical skills, policy dialogue, professional capabilities, and best practices.

INMM INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

President's Message

Susan Pepper
INMM President

This is my first column in the *Journal of Nuclear Materials Management (JNMM)* after having become President of the INMM on October 1, 2020. I am so happy to have the opportunity to serve the Institute, which has given so much to me. I became a member of the INMM in 1993, shortly after entering the field of international safeguards. My mentors, Ann Reisman and John Skalyo, told me that the INMM was THE professional organization serving the international safeguards community and related fields. My first impression of the INMM was that its leadership and members were welcoming and supportive of newcomers, and I wanted to become involved. My first official position with the INMM was as Secretary of the Vienna Chapter. Since then, I have taken on different roles and each has contributed to my professional development and expanded my network. I hope that over the next two years I have the opportunity to help members get similar benefits from the Institute.

As this issue of the *JNMM* was being prepared, the nuclear materials management community lost a prominent friend and colleague, Denny Mangan, who passed away in Albuquerque, New Mexico on September 28, 2020. In addition to many other contributions, Denny served as the Editor of the JNMM for 18 years from 1998 to 2016. As a tribute to Denny, this issue includes a memorial column in his honor; take a moment to read our tribute to Denny's life and his many contributions.

At the time of this writing, the world is still being battered by the COVID-19 pandemic, which is affecting our personal and professional activities. My heartfelt thoughts go out to everyone whose family, friends, and colleagues have suffered from the virus. The INMM has postponed several workshops due to travel restrictions and social distancing requirements, but we are making use of virtual platforms to continue to deliver relevant content to our members. A webinar on "Emerging Digital Threats" was held on September 11 and the "Workshop on Quantifying the Risk of an Attack" is scheduled for November 9-11. We will continue to use virtual meeting tools to continue our outreach, as long as it is required.

As President, I will often encourage you to get involved, because the INMM is a volunteer organization and needs its members to complete its mission. You'll also see me promoting the INMM to segments of our professional community who can benefit from the INMM's technical divisions, student and regional chapters, meetings and workshops, and the *Journal*. Increasing volunteerism and membership will strengthen the INMM, as well as provide professional development opportunities to those who participate. I look forward to working with the members of the INMM and those who participate in our activities over the next two years.

Work Continues Amid the Pandemic

Markku Koskelo
JNMM Technical Editor

Two more contributed manuscripts have made it through the peer review process and are included in this issue. The first article is an interesting take on the use of neutron scatter cameras in safeguards. In particular, the article discusses the fact that while neutron scatter cameras have existed for years, their full potential has not been utilized for some safeguards scenarios where they might apply. For reference, the article also discusses how neutron scatter cameras compare against the alternatives.

The second article discusses the regulatory framework needed for secure uses of radioactive sources. Radioactive and nuclear materials are not only used in the countries where a robust regulatory and oversight for their use already exists. A lot of international guidance already exists for the countries that may need it, and this paper examines how the IAEA international recommendations for establishing regulatory frameworks for safety and security relate to one another.

The *Journal of Nuclear Materials Management (JNMM)* lost one of its long-time leaders when Dennis Mangan passed from this life on September 28. Denny was the Technical Editor for the *JNMM* for 18 years, and my mentor for my current role for the INMM. About 10 years ago, he recruited me to be the Assistant Technical Editor in order to share some of his *JNMM* workload. Eventually, I became his successor as the Technical Editor. He left a legacy that I am trying to carry on. Denny's role in the INMM went well beyond the *JNMM*. In his memory, we are publishing remembrances from several past INMM presidents about how they interacted with Denny and what they most remember about him.

In his column, "Taking the Long View in a Time of Great Uncertainty: Hunkered Down, but Still Facing Global Security Challenges," Jack Jekowski, Industry News Editor and the INMM Historian, takes us through the various world situations that have not disappeared just because we happen to have a pandemic that affects us all. These situations may have morphed a bit, but they still exist and should not be ignored. As usual, Jack's column is well worth reading.

The book review provided by our Book Review Editor, Mark Maiello, talks about something that most of us probably pay little attention to. He has reviewed two books, *What Was the Bombing of Hiroshima?* and *Nuclear Deterrence,* which are intended for 8-12 year olds and young adults, respectively. There is undoubtedly little in either of the books that serious professionals in our field don't already know. However, the style of writing in each case is educational, and may well teach all of us something about how to communicate to people outside our field what it is that we do for a living. I know we have all been in that situation a time or two.

Should you have any comments or questions, feel free to contact me.

Markku Koskelo
JNMM Technical Editor

Applications and Deployment of Neutron Scatter Cameras in Nuclear Safeguards Scenarios

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Abstract

Neutron scatter cameras (NSCs) are a type of directionally sensitive neutron detector that rely on two consecutive neutron scattering events to localize a source of neutrons. NSCs can be used to locate, image, and identify unknown neutron sources or verify the geometry and identity of known sources. Much technical progress has been made in improving NSC designs, but little literature exists exploring the full range of practical application of neutron scatter cameras. This paper seeks to identify scenarios related to nuclear security and non-proliferation where deployment of NSCs may be useful. These situations could include: limited searches for sources during cargo screening, counting nuclear warheads for treaty verification, verification of special nuclear material during inspections, imaging nuclear contamination, imaging nuclear reactor cores, searching for lost sources, and matching neutron images in shipper/receiver or inventory management scenarios. These scenarios are examined with respect to existing NSC designs and proposed designs in terms of usefulness and practicality of deployment when compared to currently used detection systems.

Introduction

The field of nuclear safeguards seeks to stop the spread of nuclear weapons by developing technologies and polices intended to prevent the misuse of nuclear materials and technology.[1] Essential to the nuclear safeguards paradigm is the use of radiation detectors to monitor and verify the quantity, identity, and movement of radioactive sources relevant to both peaceful and weapons programs. Of particular interest is Special Nuclear Material (SNM), such as uranium and plutonium, which can be monitored and identified using a variety of gamma[2] and neutron[3] detection techniques. Detection systems can also be used to address accident scenarios involving nuclear reactors or nuclear material.

Neutron detectors are attractive for safeguards and accident scenarios because of the long attenuation length of neutrons when compared to gamma rays and the low natural background for neutrons. The high cost of helium-3 has led to several alternatives to gas proportional counters in safeguards detection systems.[4] A subtype of neutron detector that has seen increased interest in the last decade is the neutron scatter camera (NSC), a detector type that can provide data on the direction of a source of neutrons along with count rate and spectroscopic data. This paper seeks to survey the existing and proposed designs for neutron scatter cameras and identify measurement scenarios in which such detectors may be useful within the nuclear safeguards regime. Neutron scatter cameras may prove useful in a number of measurement scenarios, as they can provide directional information on neutron sources, can perform fast neutron spectroscopy, can discriminate between gamma rays and neutrons, can be made portable, can be powered by batteries, and contain no moving parts.

Neutron Scatter Camera Technical Overview

Neutron scatter cameras operate by detecting two consecutive elastic scatters of a single fast neutron emitted by a nearby source. The kinematic principle involved in determining the original particle trajectory from two consecutive scattering events is similar to the operating principle of Compton Cameras,[5] though NSCs use fast neutrons rather than gamma rays. The detector active volume present in all currently existing NSCs use either organic liquid or plastic scintillators. The initial trajectory of individual neutrons is determined by finding the approximate (x,y,z) position of both the first and second scatter in the scintillator volume. The position of each scatter is found by either using spatially separated volumes of scintillators or by comparing the position and timing of the arrival of light to a series of photodetectors within the same scintillator volume. Spatially separated arrays of scintillators may be arranged in either two or more planes or positioned in a radially symmetric arrangement. Examples of the three general types of neutron scatter cameras are shown in Figures 1, 2, and 3. Mascarenhas et al.,[6] Goldsmith et al.,[7] and Weinfurther et al.[8] provide detailed technical discussions of the kinematics of scattering in plane-based, radial, and single volume designs respectively. After the determination of two consecutive scatter positions, the cones encompassing the possible trajectories of individual neutrons are back projected in 3-D space. The region of space where the surfaces of all the back projected cones overlap is determined to be the direction of the neutron source.

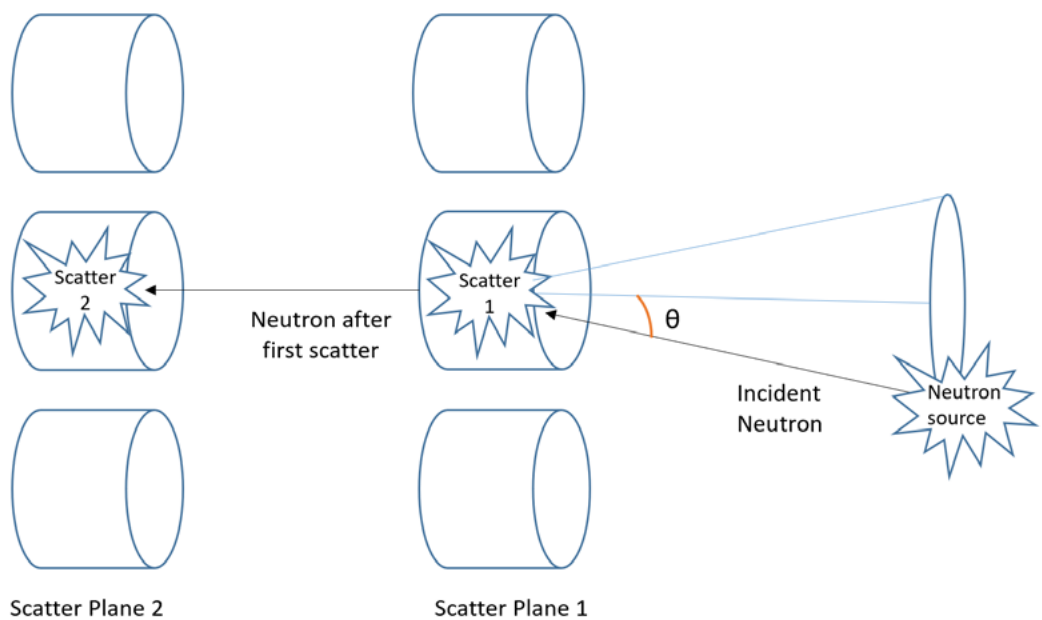

Figure 1. Two-plane Scatter Camera, Multiple Scintillator Volumes

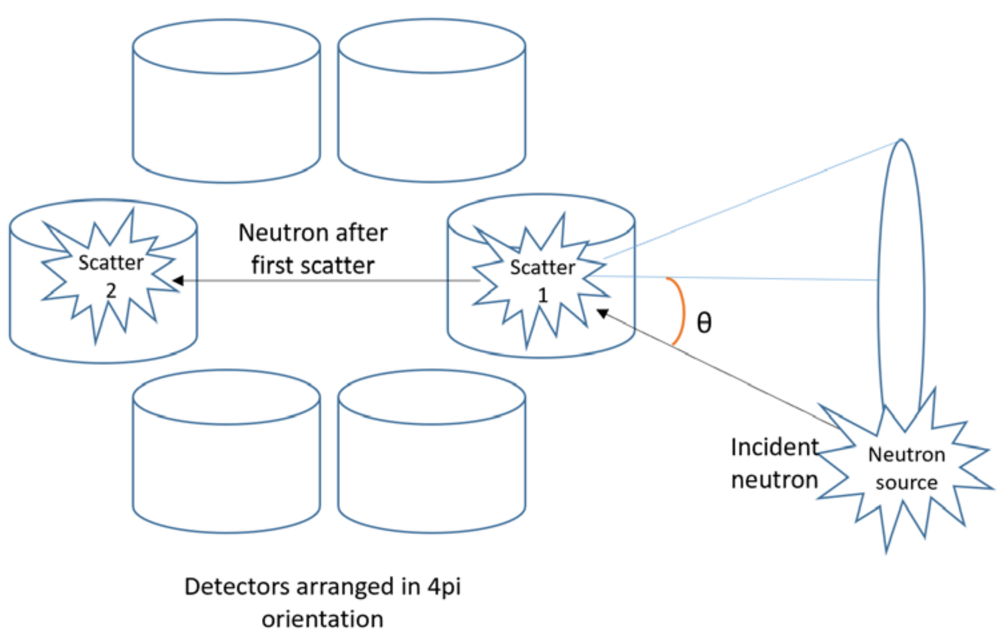

Figure 2. Radially Symmetric Scatter Camera, Multiple Scintillator Volumes

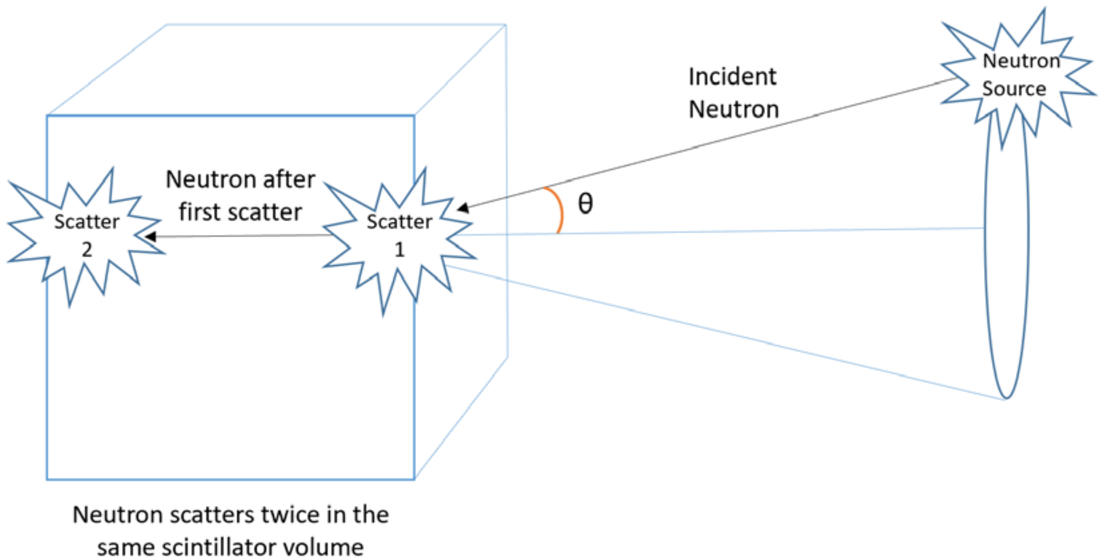

Figure 3. Single Volume Scatter Camera, Requiring Fast Timing and a Special Arrangement Of Photodetectors

If the neutron source is sufficiently far enough from the detector to be approximated as a point source, then the back projected cones will converge on a point which can be described by the ordered pair (θ, ϕ), where θ is the azimuthal and ϕ is the polar coordinate in a spherical coordinate system with the position of first scatter within the detector as the origin. The standard neutron scatter camera design cannot determine the radial distance from detector to source, though the application of a coded aperture system or multiple measurements at different locations can give some information about the distance to the source.[9] If the neutron scatter camera is close enough to the source so that it cannot be approximated as a point source, then the scatter camera can perform a rough imaging of the neutron-emitting parts of the source given a sufficiently long measurement time. Figures 4a and b show simulation results from a neutron scatter camera localizing a distant source approximated as a point with an increasing number of cones, while Figures 5a and 5b show a nearby, distributed source measured for a “long” counting time.

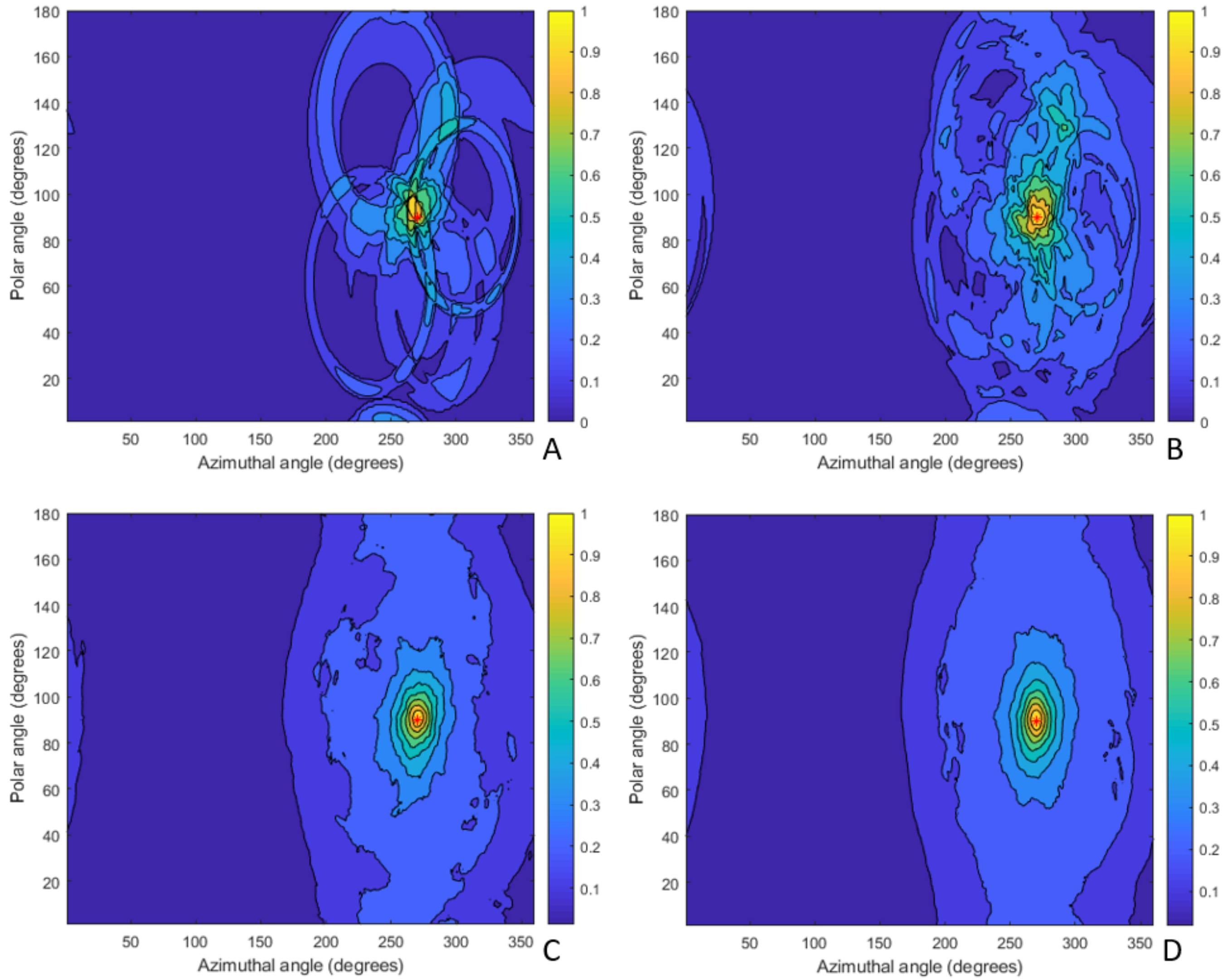

Figure 4a. Simulated Localization of a Distant Neutron Source at (270,90) with A) 10 B) 30 C) 300 and D) 1000 Back Projected Cones

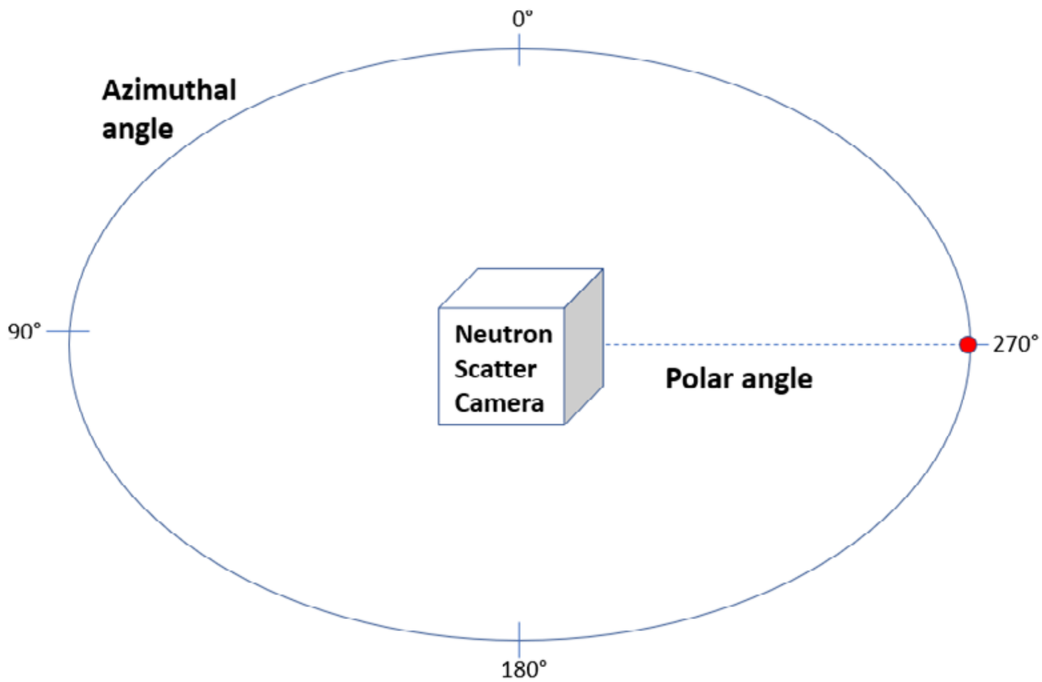

Figure 4b. Diagram of Simulated Measurement Setup for Distant Point Source

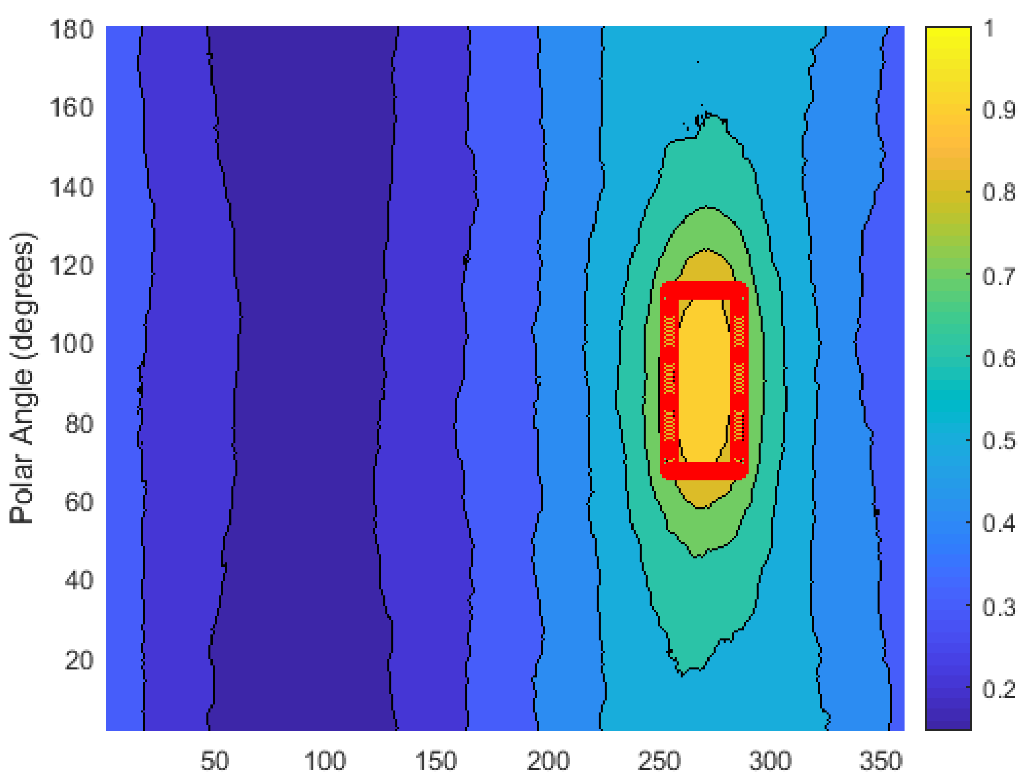

Figure 5a. Simulated Distributed Spontaneous Fission Source in Shape of a Barrel Placed One m from Detector Over a Long Measurement Period

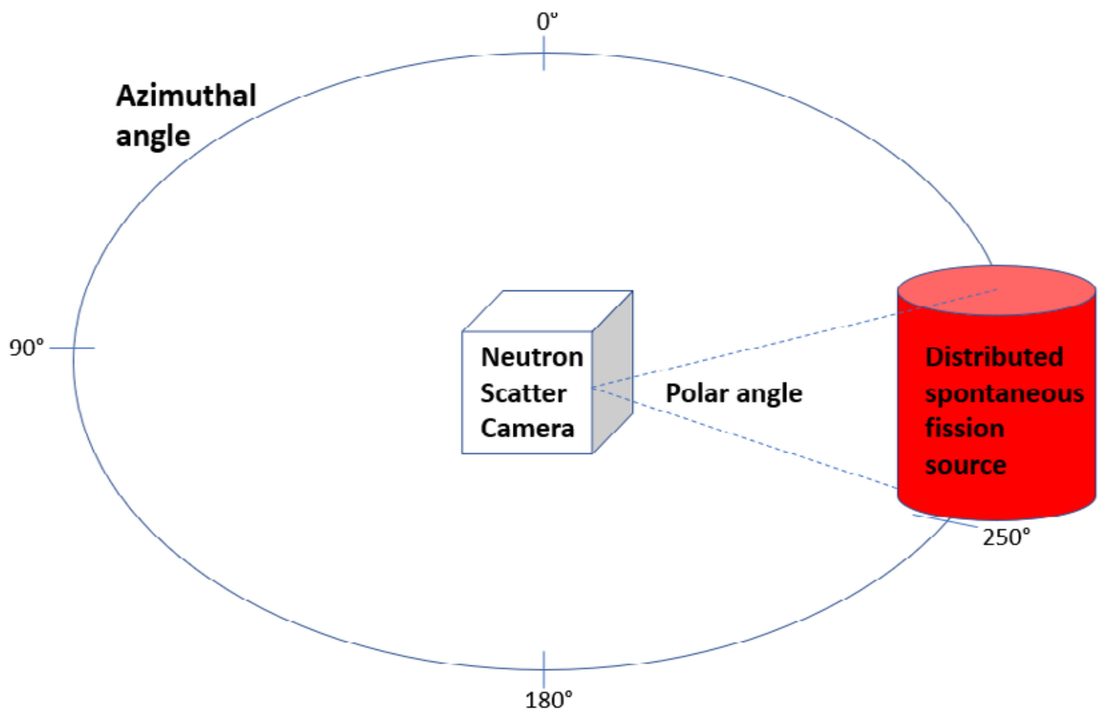

Figure 5b. Diagram of Simulated Measurement Setup for Distributed Source

Neutron scatter cameras are not the only neutron detection systems with source imaging capabilities. Coded aperture systems[9] and time projection chambers[10] also allow for neutron source localization, though neutron scatter cameras offer several advantages over these systems. Neutron scatter cameras are capable of comparable imaging resolution given sufficient measurement time and can identify the general direction of an unmoderated source in only minutes.[11] NSCs using scintillators are also capable of low-resolution neutron spectroscopy, which can be useful in identifying unknown sources, and can distinguish neutrons from gammas by either using pulse shape discrimination or through time-of-flight methods. NSCs with a radial multi-volume arrangement or single volume designs are capable of 4π fields of vision, which can be useful if the source direction is totally unknown. Low numbers of output channels and the potential for photodetectors to be powered with mobile batteries[7] are features promising for deployment in measurement scenarios where power is scarce. NSCs can also be made relatively compact and low weight at the expensive of lower sensitivity.[7,8,12,13] Finally, most NSCs contain few to no moving parts and do not require pressurization of the detection medium, making them relatively simple and safe to transport and operate.

Survey of Existing and Proposed Neutron Scatter Cameras

The first camera-type detectors to rely on fast neutron double scatters were used to determine the primary direction of the flux of solar neutrons. The first such detector, developed by Grannan et al., used two planes of liquid scintillators separated by 1 m to detect double scatters for neutrons in the range of 2 to 100 MeV.[14] A similar design by Herzo et al. added the capability to determine the gamma flux direction by using the scintillator volumes as both gamma and neutron detectors.[15] Neutron imaging using a two-plane design was proposed for use in nuclear warhead measurement by Sailor et al. and was explored with a series of Monte Carlo simulations and prototype measurements. This project found that a warhead emitting 10^5 n/s could be imaged in about 2 minutes.[16] Several decades later, the SONTRAC imaging spectrometer presented a device utilizing stacked scintillation plastic fibers to image neutrons between 20 and 200 MeV.[17] This design was the first to focus on a compact design where the scintillation volumes were not spatially separated but were instead optically columnarized. A similar design featuring segmented layers of plastic scintillators was used by the Fast Neutron Imaging Telescope.[18] The FNIT was able to locate 98g of weapons-grade plutonium 1 m away from the detector with approximately 80 double scatter events.[19] Around the same time, Vanier et al. achieved similar imaging results using eight separate scintillator volumes arranged in a two-plane configuration.[20] All of these systems most closely resemble the two-plane, multi-volume design shown in Figure 1, save the SONTRAC, which more closely resembles the schematic of the single-volume design shown in Figure 3.

A major improvement in the neutron scatter camera design (and the first device to be called such) was the system developed at Sandia National Laboratory to image neutron sources in the fission energy range.[6] Improvements to the sensitivity of the Sandia NSC were made by increasing the number of detector volumes used, lowering the energy deposition threshold, and implementing more effective neutron-gamma discrimination by using both pulse shape discrimination and time-of-flight methods.[21] Further results showed that the Sandia NSC could locate a hidden ^{252}Cf source within the hold of a tanker ship with 5 minutes of measurement time, and could locate the same source at a standoff distance of 30 m.[22] Later results claimed that the Sandia NSC could be applied to warhead monitoring and treaty verification through the implementation of a track to adjust the spacing between the detector planes and the use of maximum likelihood estimation methods (MLEM).[23] The adjustable track allows the NSC to switch between a high efficiency mode, in which the detector planes are closer together, and a high angular resolution mode, when the detector planes are farther apart, as demonstrated by Figure 6. MLEM, often used in astronomy and medical imaging, can be applied to images generated by the camera to improve the imaging resolution without any changes to the hardware itself. This technique is especially useful when more than one neutron source is present.

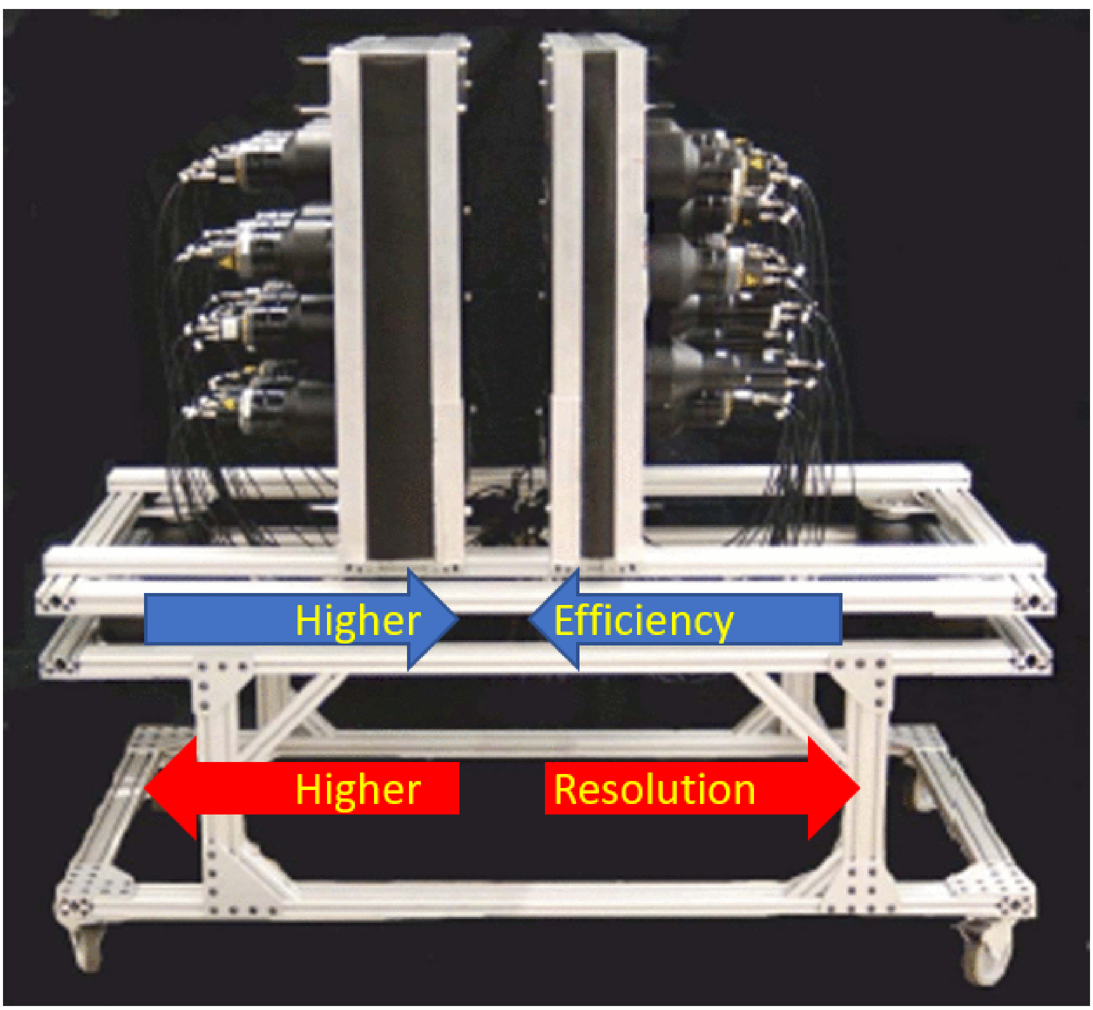

Figure 6. Sandia Neutron Scatter Camera with a Track Allowing Variable Spacing of Detection Planes.

When the planes are closer together, the system has a higher double scatter efficiency. When the planes are farther apart, the system has a high imaging resolution, as the greater time of flight between planes allows for more accurate cone back projection.

Another device with fast neutron imaging capabilities developed to detect and localize SNM is the Dual Particle Imager (DPI) introduced by Polack et al.[24,25] This system was designed to image both neutron and gamma sources with the hope of localizing and identifying sources in standoff scenarios. This design includes three arrays of detectors arranged into three seperate planes: two consisting of EJ-309 liquid scintillators and one of NaI scintillators. Both neutrons and gamma rays may scatter in the two liquid scintillator planes, while the NaI plane is only sensitive to gamma rays. The dual particle approach presents a few advantages when it comes to detecting and localizing sources. Only one of the two modes could be used to image a neutron- and gamma-emitting source with the presence of intervening shielding: high-Z shielding could be addressed using the neutron-only mode, while plastic or other low-Z shielding could be addressed using the gamma-only mode. Additionally, a neutron-only mode could provide a less noisy source image when the gamma background field is high. Neutron and gamma modes could be used simultaneously with dual-emitting sources to characterize the source identity with high confidence. Results with the DPI system demonstrated its ability to resolve two MOX canisters separated by 20° at a standoff distance of 2.5 m. This system was also able to distinguish between a spontaneous fission source and an (α,n) source, showing the applicability of such a system in safeguards and non-proliferation scenarios.[26]

Another advance in the development of neutron scatter cameras with nuclear security applications was the introduction of the Mobile Imager of Neutrons for Emergency Responders (MINER) by a group at Sandia National Laboratory[12] (also called a compact neutron scatter camera for field deployment, with the MINER name dropped in a later paper[7]). Improvements with the MINER system include a true 4π field of view and a compact, less massive design. Instead of separate planes of detectors, MINER uses radially configured scintillator volumes. MINER's mass is 40 kg, a significant reduction when comparing to the full-size Sandia NSC, which weighed around 330 kg including electronic racks. MINER, along with its electronics, can be transported in a single high-performance, injection-molded, watertight case and can be set up in 10 minutes. When fully set up, the system measures 0.9 m high and has a 0.4 m diameter. In an early test measurement, MINER was able to resolve an unshielded ^{252}Cf source at a standoff distance of 28 m in 30 minutes. MINER's features and capabilities could prove useful in a variety of field measurement scenarios that require a "portable" detector. The compactness of this system comes at the expense of imaging resolution, as this system consists of 12 large, unsegmented, closely-spaced scintillator volumes, an arrangement that leads to high uncertainties in time of flight and distance between scattering events.

Several proposed design changes have been made for further improvement of the results and versatility of neutron scatter cameras. One major area of interest is reducing the total detection system size and improving mobility while maintaining reasonable efficiency, spectroscopic capability, and imaging quality. One method for reducing the size of neutron camera systems is to use more compact photodetectors instead of relatively bulky photomultiplier tubes. Silicon photomultipliers (SiPM) have been considered as an alternative to PMTs with an eye toward creating a handheld NSC.[13] Ruch et al. demonstrated that SiPM coupled to stilbene scintillators showed similar timing resolution to PMTs, an important consideration when designing neutron scatter cameras that rely on accurate time-of-flight measurements for imaging and spectroscopy. Later work with a prototype eight-barred stilbene detector using SiPMs showed plutonium sources could be accurately localized with as few as 20 back-projected cones.[27]

More recent proposals have sought to make the NSC more compact by confining both neutron scatters to a single scintillation volume rather than spatially separated volumes. Chief among these proposals is the work done by the Single Volume Scatter Camera Collaboration, an alliance of several National Laboratories and universities.[28] This collaboration has produced prototype compact detectors using both monolithic and optically segmented concepts. In the monolithic design, light is emitted by scattering events in a single scintillator volume. The timing and arrival positions of light to a series of photodetectors mounted to the scintillator surface is used to reconstruct the original neutron direction and energy. In the optically segmented design, light is confined to pillars which in turn are coupled to individual photodetectors. Weinfurther et al. performed simulations on an optically segmented detector consisting of a 20 x 20 x 20 cm block of optically segmented pillars with a fast timing response coupled to either SiPM or Micro-Channel Plate Photomultipliers (MCP-PM). Both neutron scatters occur in the single plastic volume, but the scintillation light produced at each scatter location is confined to a single 1 cm x 1 cm column by total internal reflection. The x and y coordinates of each scatter are determined by the geometry of photodetectors coupled to each column that "see" scintillation light, while the z coordinate is found by comparing the intensity of light pulses collected at opposite ends of each column. The MCNP-PoliMi (for neutron transport) and GEANT4 simulation (for light transport) of this detector showed a root mean square error of the neutron-proton scattering position of <1 cm and an energy deposition error of <50 keV when proton recoils were confined to 1 MeV or greater. These low errors suggest a single volume scatter camera such as this one can still provide satisfactory imaging resolution while also increasing double-scatter efficiency, though due to the idealized nature of simulations actual results from such a detector are not expected to be so precise. The timing resolution of photodetectors and electronics also play a role in image quality, and such effects are not considered here.

Another detector that could potentially be used for directional neutron detection is the Segmented AntiNeutrino Directional Detector[29] (SANDD), which uses an 8 x 8 array of plastic scintillators coupled to 5 x 5 cm 64 channel SiPM arrays. The operational principle for this detector is very similar to the optically segmented Single Volume Scatter Camera. The SANDD system has recently demonstrated pulse-shape discrimination capabilities for distinguishing neutrons and gammas, lending credence to its usefulness as a directional neutron detector in addition to its primary use as an antineutrino detector.

Another proposal for a single volume scatter camera relying on a monolithic scintillator volume is the miniTimeCube, which has primarily been used as an antineutrino detector.[30] This design uses 24 MCP-PMs coupled to each of the six sides of a 13 x 13 x 13 cm cube of boron-doped plastic scintillator. The ratios of light arriving at the 1536 channels are used to localize the position of consecutive scatters. Consecutive scatters are resolved in time by using a plastic scintillator with a fast light pulse response and fast timing electronics. Geant4 and a MATLAB Monte Carlo algorithm were used to determine that this design could yield errors in scatter position of 5 mm and timing errors of 100 ps, though again this does not account for uncertainties in the timing of the photodetectors and electronics.

NSC designs that rely on many electronic readout channels can lead to more compact detectors, but these detectors can become prohibitively expensive and complex. One solution to reduce cost and digital pulse data produced is the use of signal multiplexing, in which the pulses from several readout channels are digitized into a single channel for analysis. Wonders and Flaska have demonstrated that an imaging array of 64 plastic scintillator coupled to SiPMs can be multiplexed into 8 or 16 digital channels at the expense of losing some meaningful events.[31] Despite the reduction in double scatter detection efficiency because of this, multiplexing could prove a useful tool in reducing the digitization equipment needed for an affordable and mobile system.

The existing and proposed neutron scatter camera designs surveyed here present a variety of capabilities in double-scatter efficiency, imaging resolution, neutron versus gamma discrimination effectiveness, portability, and cost. It is difficult to construct an NSC with good values for all these characteristics, as improving some have negative consequences for others. For example, the double-scatter efficiency of a detector can be improved by increasing the size or number of scintillation volumes, but doing this will require a larger and heavier detection system, thus decreasing portability and increasing cost. Similarly, increasing the average time of flight between consecutive scatters will lead to more accurate measurements of energy deposition, thus improving the imaging resolution, but only at the expense of a lower overall detection efficiency and longer measurement times.

Implementation in Nuclear Safeguards and Non-Proliferation Scenarios

Most of the research into neutron scatter cameras and similar directional fast neutron imaging systems has focused on the technical capabilities of such systems, with the actual usefulness and versatility mentioned mostly as an afterthought. The goal of this section is to identify scenarios where the use of neutron scatter cameras or similar systems capable of neutron source localization and imaging may be useful, particularly in the realm of nuclear materials safeguards and non-proliferation. A list of possible measurement scenarios follows, with a brief speculative description of how an NSC system could be used in each scenario.

1. Neutron Source Localization in Limited Search Scenarios

Radiation portal monitors are large-volume detectors designed to detect radioactive sources passing through chokepoints along roads, railroad lines, or pedestrian walkways. These detectors may also be put in place at the entrances of nuclear facilities, at international borders, or other areas where the illicit transport of nuclear material may be a concern.[32] The high sensitivities of these detectors make them excellent at detecting the presence of both neutron and gamma-emitting radioactive sources hidden in large vehicles or shipping containers. If a portal monitor were to identify the presence of an unexpected source in a vehicle, container, or other object moving through the portal, a limited search would be needed to identify and secure the source. Checking a large vehicle or shipping container “blind” could be both hazardous and inefficient for searchers, so having some prior knowledge about the exact location of the source within the larger container would be desirable. Imaging radiation detectors, like Compton or neutron scatter cameras, could be used to pinpoint compact sources within large containers. Neutron imagers may be of special interest as neutrons are far more penetrating in shipping containers due to the presence of high-Z materials, which shield gamma rays. Several of the systems discussed above have already been employed to this end in mock search scenarios for locating neutron sources, most notably the MINER system. That system was also able to distinguish between ^{252}Cf and AmBe sources and localize those sources at a standoff distance of 28 m.

In limited search scenarios of containers or vehicles, measurement times of 30 minutes may be unacceptably long in urgent situations. Measurement times with an NSC system could be reduced by adaptably changing the location of the NSC as measurements go on. A brief measurement with an NSC or other portable radiation detector could be used first to establish the general direction of the source, whether it be on the left, right, or center of a shipping container, for example. Next, the NSC could be moved closer to the area of interest with the goal of pinpointing the position of the source inside the container without going inside of it. The neutron image generated from a few minutes of measurement time could be coupled with an infrared, gamma or x-ray radiographic image[33,34] of the container to ascertain the source location and distribution along with the internal components of the area of interest. Knowing the general location of the source and the internal components surrounding it in advance would then make the task of retrieving and securing the source safer and more effective for the search team.

2. Verification of Nuclear Warheads

Counting nuclear warheads is a vital component of the New START treaty[35] between the United States and Russian Federation, which limits the number of warheads that can be present on intercontinental ballistic missiles (ICBMs) and submarine-launched ballistic missiles (SLBMs). The possibility of using an NSC to verify the presence of nuclear weapon warheads has been explored by Brennan et al.[23] The use of NSCs to this end is particularly interesting because a neutron imager with suitable angular resolution could identify the number of warheads present in a reentry vehicle without revealing classified, proprietary, or other sensitive information about the specific design of the weapons, information that could be revealed when using gamma detection methods. Utilizing an NSC without utilizing gamma spectroscopic abilities can act as an information barrier,[36] a method that can verify the presence and number of warheads without giving away classified or proprietary information. NSC systems could be integrated into the existing framework of arms control verification that already utilizes neutron multiplicity counting and high-purity germanium detectors. Parties subject to an arms control treaty must mutually agree that such imaging neutron systems as NSCs are not too intrusive but still provide information valuable to treaty inspectors.

As a technical consideration, NSCs may be desirable in the measurement of warheads because neutrons have a better chance of fully penetrating the high-Z structural materials present in reentry vehicles containing the missile-mounted warheads. By applying MLEM, Brennan et al. have shown promising results in resolving individual sources, even at stand-off distances realistic to treaty-enforced verification.

3. Verifying the Presence and Movement of Nuclear Material in Inspection Scenarios

Nuclear facility inspectors, such as those employed by the International Atomic Energy Agency (IAEA), are tasked with performing regular and special inspections of nuclear facilities to confirm proper use of materials and technologies.[37] Such inspections generally involve the verification of declared quantities of nuclear material, with a focus on fissionable, fissile, and fertile isotopes due to their significance in nuclear proliferation. Inventories are usually verified by visual inspection (counting of materials) and by measurement using several non-destructive assay (NDA) techniques, including using radiation detectors. Because of the time constraints placed on inspectors, it is often impossible to verify each inventory item separately, so typically a random sample of material is selected for analysis by NDA. When dealing with neutron-active materials in such an inspection situation, the employment of an NSC could be useful in completely verifying an inventory. Say, for example, an inspector wished to verify that a waste storage room contains 30 drums containing plutonium. Standard protocol would call for the random selection of several of these barrels for individual analysis, with the hope that these will be a representative sample of the waste. Instead of employing this approach, an NSC could be set up in this room and left to measure while the inspectors continued to inspect the rest of the facility. The neutron image generated at the end of a sufficient measurement period could then be cross referenced against the declarations made of the plutonium content of each of the drums to discover any irregularities in the declared quantities based on the image, which could indicate a diversion of material.

Inspectors may also find that their access to certain parts of a facility is restricted by the personnel of the host facility for safety-related or other reasons. NSCs or other imaging detectors could then be used to confirm the presence of sources from a distance, without the need to enter an inaccessible area. Neutron images would not need to stand on their own in inspection scenarios: data collected from visual cameras, count rate data, and specifics about facilities would need to be coupled with the neutron images for inspectors to draw useful conclusions about the nuclear material subject to inspection.

4. Wide-area Search in Accident or Lost Source Scenarios

A portable NSC system could also be of use in a wide-area search for lost sources or in mapping the distribution of widely dispersed sources from an accident or attack. The IAEA has published guidelines[38] aimed at providing inspection for search of lost radioactive sources, indicating that there is some need for devices that can grant the searchers some footing in such scenarios. If a neutron source was lost within a nuclear facility, NSC measurements at several points in the facility could help searchers narrow down search areas by comparing the 4π images generated at different points in the facility. Neutron sources could also be spread over a large area in nuclear reactor or in nuclear material shipping accidents. A neutron image produced by an NSC system could be useful when coupled with visual identification and more traditional radiation detectors for the radiological response team tasked with securing the sources in such an accident scenario. NSC measurements need not be taken at a single fixed point; neutron imaging in the field could be adaptive. A short initial measurement near the center of the identified search area could show which radial directions are most "neutron hot." Next, the NSC could be moved in the direction of an area of interest identified by the initial measurement and another short measurement could be taken to further zero in on any sealed sources or areas of contamination. The iterative process of measurement-move-measurement could be done across a wide search area as many times as necessary to locate any and all nuclear material in the accident area.

5. Mapping Neutron Source Contamination in an Enclosed Space

An NSC could be used to map the distribution of a diffuse neutron source that has contaminated a room or other enclosed space at a nuclear facility. Typically, the distribution of contamination in a room or enclosed space must be mapped by moving a radiation detector throughout a room and recording the relative count rate at different locations. This process is problematic because it unnecessarily exposes the operator of said detector to possible high dose rates and could lead to the spread of contamination. To reduce exposure time in contaminated areas, an NSC or other imaging device could be set up in an area of interest and left to measure for an appropriate counting time, as it would not require an operator to move the system around. The 4π neutron image produced could be coupled with a 4π 3-D image of the room in question to surmise the relative levels of contamination throughout the room. In 2014, Kishomoto et al.[39] demonstrated a novel Compton camera capable of identifying gamma source hotspots in contaminated zones, lending credence to the analogous use of an NSC or dual particle system in a similar way to identify zones of neutron source contamination.

6. Monitoring of Diversion of Nuclear Fuel

A large effort in nuclear safeguards focuses on securing and analyzing spent nuclear fuel, as fuel contains large amounts of material that is of concern for nuclear proliferation. Cherenkov cameras,[40] passive neutron/gamma detectors,[41] muon tomography,[42] and guide-tube-based partial defect detectors[43] have all been employed to check for fuel pin diversion for spent fuel residing in pools. Measuring fuel using these methods may not be applicable in all cases, as some require fuel to be placed in accessible positions, require clear water, or may not function properly after long cooling times. Neutron emission tomography has also shown promise for detecting missing pins, though this method requires access to the ends of the fuel assemblies and requires collimation of individual pins.[44] An NSC could function in much the same way as currently existing neutron tomography systems, though it would not necessarily require neutron collimation or even be next to the assembly, given enough measurement time. Both axial and radial neutron images of a measured assembly could be generated to check for diversion of entire rods or individual pellets along the length of the assembly. Generating images detailed enough to make determinations about fuel diversion would require long measurement times, on the order of hours or days, depending on the fuel's activity and the distance from NSC to fuel, so this method would likely not be appropriate in a time-constrained measurement situation. Additionally, performing this type of measurement would work best with a large NSC system with widely separated detector volumes to ensure proper angular image resolution, which in turn will make the system less portable. This reality makes a case for there being no one-size-fits-all NSC system: applications such as fuel assays require high resolution, while search applications favor a mobile system with shorter measurement times.

7. External Imaging of Reactor Cores

Knowledge of the neutron distribution within a nuclear reactor core is vital in ensuring the safe operation in standard and accident scenarios. Normally, in-core neutron monitors relay information about neutron distribution to reactor operators, though these systems may be damaged in accidents, making operators "blind" to the full situation inside a core. Beaumont et al. have presented a method of monitoring the neutron and gamma distribution inside a reactor core externally using a scintillator equipped with a moving slit collimator capable of determining the particle distribution in space.[45] An NSC system could potentially be used to these same ends, as a reactor could be imaged using fast neutrons escaping from the core and moderator by using double-scatter back projection. It is unknown how long the measurement time for imaging an entire reactor core with an NSC system would be when compared to the slit-collimated method discussed by Beaumont et al, but a Monte Carlo simulation of a small research or test reactor and neutron scatter camera could be done to gauge if experimental measurements are worthwhile. An external neutron image of a reactor core could be useful to reactor operators if data from in-core instruments are temporarily unavailable, or in reactor designs lacking internal instruments.

8. Neutron Image Matching in Shipping/Receiving and Facility Management

An NSC, like any imaging system, can provide a "snapshot" of how the radiation distribution for a particle source or location "looked" at a particular moment in time. When producing a neutron or gamma image of a source distribution, it is vital to also record factors such as the location of the detector system relative to the source being measured, the source's position in the room being analyzed, the measurement time, and the various energy threshold and neutron/gamma discrimination settings. A radiation image, along with this set of information about its production, could be of use in detecting diversion of nuclear material during shipping or between two inspection times at a facility by a system of image matching. For example, a source or set of sources could be imaged by an NSC upon being loaded into a truck for transport, with special attention paid to the position of the NSC relative to the source or sources and the measurement time. Following transport and the arrival at a new nuclear facility, another image could be generated with the same measurement parameters. The before-shipping and after-shipping images could be visually or algorithmically compared to detect any diversion of material during the transit process. Before-and-after comparison of shipments of nuclear material are already performed, though these processes often focus on visual inspection and mass comparisons, which could be spoofed.[46] This image matching technique would naturally need to be implemented in tandem with visual and mass-based inspection of shipped materials as a sort of "triple check" for radioactive material, along with tamper-indicating seals on vehicle and facility doors. Implementing such a system would require both the shipper and the receiver to operate identical or near-identical NSC systems and measure the source or sources with the exact same parameters to ensure that the pre- and post-shipment images will indeed match when they should.

In analogy to shipper-receiver image matching, a similar system could be implemented to verify inventories within a single nuclear facility. When taking inventory of nuclear materials, facility material managers could also take a neutron image of the room or rooms where the radioactive material is stored. This image, along with the relevant parameters concerning its acquisition, could be saved along with more typical inventory data such as the number, identity, volume, mass, and activity of sources present. Having such a radioactive "snapshot" of a collection of sources at particular moment could be useful for nuclear material managers in maintaining a continuity of knowledge about sources and their arrangement, which could be useful as a historical record to consult in the event of an instance of material unaccounted for.

Strength and Shortcomings of Neutron Scatter Cameras When Compared to Alternative Systems

Neutron scatter cameras are not the only type of directional radiation detector that could be of use in safeguards scenarios. Neutron or gamma-coded aperture systems, Compton scatter cameras, and time projection chambers can also be used to gain information about the spatial distribution of radiation sources of interest. Additionally, suites of spatially-separated detectors and iteratively moved non-directional detectors have long been used to map source distributions in safeguards contexts. Fully evaluating NSCs for use in safeguards must also account for these alternative methods of source localization and imaging.

Several neutron-detecting coded aperture systems have been applied to nuclear safeguards and security applications.[9,47,48,49,50,51,52] Coded aperture systems image sources by using a mask featuring a known pattern placed in front of a detector. In neutron coded aperture systems, the mask can be made a neutron absorbing shield or can be another detector. The "shadows" of neutrons that pass through the mask to the detector can be convolved to form an image of the radiation source, providing both direction and distance information about the source. Gas detectors and liquid and plastics scintillators have been used as the detectors in various neutron coded aperture systems. In general, neutron coded aperture systems demonstrate superior imaging resolution when compared to neutron scatter cameras, typically <5°. This excellent imaging resolution makes coded aperture systems desirable in situations when multiple nearby sources are present, when the source location needs to be known to a precise degree, or when the radial distance to sources is relevant. Coded aperture systems require longer exposure time to neutron sources to generate images when compared to NSCs. It is also more difficult to gain real-time imaging results from coded aperture systems because of the high amount of data processing needed for image convolution when compared to the event by event back projection used by NSCs. The large size of several[9,47,48,50] of the neutron coded aperture systems makes application where system mobility is a concern challenging, though several more compact and transportable time-encoded systems have been demonstrated.[50,52]

Compton scatter cameras and gamma coded aperture systems have wide applications in the field on nuclear safeguards because of their high accuracy and efficiency in localizing gamma sources and the portable size of several designs.[5,24,53-55] Gamma imagers can provide accurate images of spatial gamma source distribution within minutes, making them useful in a variety of safeguards settings. The main drawbacks of using gamma imagers are mostly due to the nature of gamma ray's measurement environments rather than the systems themselves: the natural gamma ray background is much higher than the neutron background and gammas are less penetrating than neutrons for most intervening materials. Gamma spectroscopic capabilities provided by such imagers can also be detrimental in safeguard scenarios where gamma spectra can reveal classified or proprietary information about source or weapon design.

Time projection chambers have also been shown to be capable of directional neutron measurement by tracking ionization paths created by fast neutrons traveling in a gas.[10] Though this type of design is not as well-researched as NSC or coded aperture systems for directional neutron measurements, results from Bowden et al. suggest that such system may provide comparable resolution and sensitivity results to NSCs.

Non-directional neutron and gamma detectors can also be used to gain spatial information about source distribution in safeguards scenarios. Portable, non-imager detectors can be iteratively moved by individuals[38] or unmanned vehicles[55] to map the radiation field of an area. Arrays of radiation sensors can also be used to passively monitor source distribution and movement through facilties.[56] These methods do not provide data equivalent to that of true imaging systems and are in many cases limited by the physical accessibility of sources, but data from these methods can be valuable when paired with directional radiation and other spatial data.

When compared to these other directional detection methods for safeguards applications, NSCs feature a unique set of strengths and shortcomings. They are summarized as follows:

Strengths

- Can construct neutron images using individual particle scattering events rather than a flux: only 10s of acceptable counts are needed for a general indication of source direction
- Statistical uncertainty can be calculated for each event based on energy deposition and time of flight uncertainty
- Low cost when compared to other options: plastic and liquid scintillators are typically inexpensive when compared to He-3 gas or semiconductor-based detectors
  - Cost can be increased if compact NSC use more expensive electronics like SiPMs or MCPs rather than standard PMTs
- NSC systems have been made transportable, with some prototype systems approaching handheld size
- Sensitive to wide energy range of fast neutrons; no moderator needed to slow neutrons
- NSC systems can be made into dual particle imagers, sensitive to both neutrons and gammas, by using the appropriate scintillator materials
- Because of the low amount of data processing needed per scattering event, real-time image back projection is possible

Shortcomings

- Poor energy resolution of organic scintillators leads to uncertainties in cone overlap
  - Poor spatial imaging resolution when compared to Compton scatter cameras and coded aperture systems
  - Trouble with situations featuring multiple, close together sources
- Poor energy resolution leads to poor spectroscopic capabilities compared to semiconductor detectors and other detectors with better energy resolution
- Cannot gauge radial distance to source without moving the camera
- Some NSC designs may use scintillators without strong pulse shape discrimination capabilities and must rely on time of flight to short pulses into neutrons or gammas, leading to some particle misclassification

- In some cases, localization of a source in a search scenario can be performed faster by adaptively moving a non-imaging detector in the direction of greater count rate

The information in Table 1 provides some estimates for the expected measurement range, target measurement time, target spatial imaging resolution, and alternative methods that can approximate each of the safeguards scenarios discussed in the section, "Implementation in Nuclear Safeguards and Non-Proliferation Scenarios." The target measurement times and resolutions are estimates based on both the demonstrated efficiency and imaging resolution of the systems surveyed above and the needs for each scenario. In general, source search applications require systems with higher efficiency and lower resolution, whereas scenarios that involve determining the absence or presence of one source among many emitters require better resolution.

Table 1. Neutron Scatter Camera Characteristics for Safeguards Scenarios

Safeguards Scenario	Typical Measurement Distance Range [m]	Target Measurement Time	Target Resolution	Alternative Methods for Achieving Similar Goal
Neutron source localization in limited search scenarios	1 to 30	<2 minutes before each iterative movement of system, <5 minutes for more detailed neutron image once source is localized	<30°	Iteratively moving non-imaging neutron detector, Compton camera, transportable coded aperture
Verifying nuclear warheads	~1	<1 hour	<5°	Coded aperture system
Verifying the presence and movement of nuclear material in inspection scenarios	1 to 5	<10 minutes	<5°	Coded aperture system, Compton camera
Wide-area search in accident or lost source scenarios	highly variable	<30 seconds before each iterative movement of system	<45°	Handheld Compton camera, handheld or unmanned vehicle-mounted non-imaging detector
Mapping neutron source contamination in an enclosed space	0.1 to 10	<1 hour	<10°	Coded aperture, Compton camera
Monitoring of diversion of nuclear fuel	1 to 10	<1 hour	<5°	Coded aperture, Compton camera, count rate matching with non-imaging detector
External imaging of reactor cores	2 to 10	<24 hours	<10°	Coded aperture, Compton camera
Neutron image matching in shipping/receiving and facility management	0.1 to 2	<5 minutes	<5°	Coded aperture, Compton camera, count rate matching with non-imaging detector

Conclusion and Proposals for Future Work

The measurement scenarios described here are proposals for where the emerging technology may prove useful, though it is important to note that the practicality of many of these proposed scenarios has not been experimentally explored by existing technology. Laboratory experiments that approximate standoff detection similar to a limited search scenario and monitoring of nuclear warheads have demonstrated promising results in the practical application of already-existing designs to scenarios one and two. The application of NSC systems to the remaining six scenarios are yet to be explored with simulation or experiment and may be fertile ground for future work for teams researching directional neutron detection systems.

Implicitly throughout this paper it has been assumed that all measurement with the NSC systems discussed are passive neutron measurements: that is, they detect and image sources with significant spontaneous fission or (α,n) rates. Relying only on passive neutron measurements would preclude the detection and localization of nuclear material with lower passive neutron rates, such as uranium sources, which would require active neutron interrogation to properly image. An NSC system could indeed be coupled with an active interrogation source, though no example of such a system has yet been reported in the literature. Additionally, active interrogation is not a viable method for source localization or imaging if the location of the source is unknown, such as in search scenarios. Still, imaging an induced fission source like a drum of uranium at close range with an active integrating NSC could be possible, though the usefulness of such a setup is questionable.

A clear concern when surveying NSC measurement scenarios is the inherent tradeoff between imaging resolution and detection efficiency. Small, compact detectors are more portable and have a higher double scatter efficiency, while large, less mobile detectors can provide better resolved images with fewer total counts. This reality suggests that a "one-size-fits-all" NSC design applicable to all measurement scenarios may not be desirable. Wide- and limited-area searches, as described in scenarios one and four would naturally require a portable or at least transportable system, preferably one that could be moved and set up by a single person or a small vehicle. Systems for these applications would also benefit from a wide-field of view, making radially arranged designs, like the MINER/Compact Neutron Scatter Camera, or single volume designs–like the Single Volume Scatter Camera, the miniTimeCube System, or the handheld stilbene camera–most practical for applications in which the detector is moved for a series of consecutive measurements. Larger detector systems consisting of planar arrays of detectors–like the original Neutron Scatter Camera and the Dual Particle Imager system–could still prove useful in scenarios where frequent transport of the detector system is not a concern, such as measuring inventories in nuclear facilities, externally imaging reactor cores, or producing images for shipper-receiver records.

As electronic pulse timing becomes better time-resolved and new scintillation materials are developed, the technical capabilities of neutron imaging systems may further improve, making the practicality of the measurement scenarios explored here increasingly more relevant to those working in the field of nuclear safeguards and non-proliferation. Current scatter camera technology has shown promising results in localizing and identifying neutron sources, though more experimental studies and Monte Carlo simulations should be performed to verify the feasibility of the measurement scenarios outlined in this paper.

Keywords

Neutron scatter camera, neutron imaging, nuclear safeguards, detection applications, image matching, source search

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Establishing a Sustainable Regulatory Framework for the Security of Radioactive Sources Through Harmonization with a Safety Regulatory Framework

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Abstract

In order to establish and maintain sustainable nuclear security regulatory infrastructures for radioactive sources, it is important for states to develop nuclear security regulations with regulatory requirements and relevant criteria for security, which are consistent and well-integrated with those for radiation safety. In establishing national regulations, experts worldwide follow the international recommendations on safety and security of radioactive sources published by the International Atomic Energy Agency (IAEA). Within IAEA publications on the safety and security of radioactive sources, some international recommendations are identical or very similar for both safety and security (for example, the requirement for the establishment of a national registry of radioactive sources). However, some other international recommendations are unique to the security area, such as the recommendation to examine the trustworthiness of employees, or to the safety area, such as the need to establish public exposure controls. Additionally, many international recommendations fall somewhere in between, such as the need for effective authorization of facilities and activities, a regulatory inspection and enforcement regime, and the graded approach to establish and apply regulatory requirements. This paper examines how the IAEA international recommendations for establishing regulatory frameworks for safety and security relate to one another.

Introduction

Regulating nuclear safety and nuclear security are national responsibilities (to avoid unnecessary repetitions, in this article "nuclear and radiation safety" is abbreviated to "safety" and "nuclear security" to "security").[1,2] This is one principle that has been stated in all international instruments and supporting publications in the nuclear field. In order to comply with their national responsibilities, states have already established or are making efforts to build sustainable regulatory frameworks for both the safety and security of facilities and activities involving the use of radioactive sources and/or radioactive material. Safety and security frameworks are both meant to achieve the fundamental objective of protecting—now and in the future—people, society, and the environment from the harmful effects of ionizing radiation.

The IAEA is mandated to "seek to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world."[3] Through its Safety Standards Series and Nuclear Security Series, the IAEA supports states to establish, maintain, sustain, and continuously develop their national safety and security frameworks and to effectively fulfill their obligations under the international, legally binding instruments. The international recommendations included in the IAEA safety and security publications reflect an international consensus on what represents a high level of protection and safety. They are based on previous experiences with facilities and activities in the nuclear field, and incorporate lessons learned, best practices, and state of the art scientific developments.

While establishing safety standards has been a priority for the IAEA since its inception, in recent years the agency has focused its efforts on developing parallel security recommendations in compliance and close coordination with the existing safety recommendations.

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In time, states worldwide have adopted the international recommendations within their national legislative and regulatory frameworks, in order to ensure high levels of safety and security and to harmonize with safety and/or security systems in neighboring countries and globally. The challenge some states currently face is to integrate and harmonize internally, at national level, their regulatory frameworks for safety and security, so that "security measures do not compromise safety and safety measures do not compromise security."[1,2] In doing this, a thorough understanding of existing international recommendations in IAEA safety and security publications is required. There are common elements–such as concepts, principles, mechanisms, terms, or functions–which are addressed in both safety and security publications, overlapping areas of interaction between safety and security, and specific topics which are unique for one or the other discipline.

The present paper is intended to support international experts from regulatory bodies and other stakeholders in the nuclear field who are responsible for establishing or improving the security regulatory framework in harmonization with an existing safety regulatory framework. A comprehensive comparative analysis has been performed in order to identify common and differing elements in both sets of international recommendations (for safety and for security). The results are provided below. For the purpose of this paper, only the international recommendations for the safety and security of radioactive sources and radioactive materials in use, storage, and transport have been considered. For future work, the proposed methodology can be used and the analysis can be expanded to include facilities and activities that involve nuclear material or the safe and secure management of radioactive sources and/or radioactive material which is out of the regulatory control.

Sources and the Methodology Used for a Comparative Analysis of International Safety–Security Recommendations

Sources for the Comparative Analysis

The source documents (see "References") used for this comparative analysis are the IAEA Safety Standards Series and the Nuclear Security Series, publications on the use, storage, and transport of radioactive sources, radioactive material, and associated facilities. In addition, the *Code of Conduct on the Safety and Security of Radioactive Sources*[4] has been included in this analysis as one important, well-accepted, non-legally binding international instrument.

To some extent, the structure of IAEA safety and security publications follows the same pattern. The drafting and review processes are compatible and fully integrated through the internal processes of IAEA. In addition, the hierarchy of documents is similar: the *Fundamentals* (as top-level publications) form the basis for the international recommendations in both disciplines; they are followed by international recommendations and technical guidance. The *Safety Fundamentals*[1] includes the fundamental safety objective and 10 principles for protection and safety, which provide the basis for all international safety recommendations. The *Nuclear Security Fundamentals*[2] contains objectives and essential elements for a nuclear security regime and provides the basis for all international security recommendations. The next level of IAEA publications include: *General and Specific Safety Requirements* and *Safety Guides,* for safety, and *Security Recommendations* and *Implementing Guides,* for security.

Of all of the aforementioned, only the relevant publications for the purpose of this work have been considered for the present analysis. In addition to the *Safety Fundamentals*, other publications of particular importance for safety of radioactive sources have been analyzed: The *General Safety Requirements GSR Part 1 Rev 1* to *GSR Part 7*,[5-10] the *Special Safety Requirements SSR-6 (Rev. 1)*,[11] and the *Safety Guides SSG-26,*[12] *RS-G-1.9,*[13] *RS-G-1.10,*[14] *GSG-13,*[15] *SSG-17,*[16] *SSG- 45,*[17] *TS-G-1.2* to *TS-G-1.6*,[18-22] and the *Guidance on the Import and Export of Radioactive Sources*.[23] As for security publications, besides the *Security Fundamentals*, of particular importance are the *IAEA Nuclear Security Recommendations on Radioactive Material and Associated Facilities NSS-14,*[24] the *Implementing Guide on Security of Radioactive Sources,*[25] and its final draft, revised in 2019,[26] the *Implementing Guide on Security of Radioactive Material in Transport,*[27] and its final draft revised in 2019,[28] the *NSS-7,*[29] *NSS-23-G,*[30] *NSS-29-G,*[31] and *NSS-30-G.*[32]

The IAEA safety standards are not legally binding on member states but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The IAEA safety standards are, however, binding on the IAEA in relation to its own operations and on member states in relation to operations assisted by the IAEA. Because the safety standards are binding in this way, they include "requirements," and additional "guidelines" on how to implement the requirements. At the same time, the IAEA security series publications include "recommendations" and "guidelines."

For clarity, this paper calls all the IAEA safety requirements, security recommendations, and safety and security guidelines as "international recommendations." When adopted and transposed into national regulations, these international recommendations become regulatory requirements, and therefore, legal instruments to be enforced for the regulatory control of the safety and security of radioactive sources.

Methodology

The comparative analysis presented in this paper is based on the assumption that safety and security operate in different ways in order to achieve the same fundamental goal of protecting people, society, and the environment against the harmful effects of ionizing radiation. While overlapping in relation to their fundamental goal, safety and security differ in that safety is generally aimed at preventing or mitigating accidents, and security is aimed at preventing intentional unauthorized or criminal acts that might result in the dispersion of nuclear or radioactive material or the theft of such materials. According to the *IAEA Safety Glossary 2018,*[33] safety means "the achievement of proper operating conditions, prevention of accidents, and mitigation of accident consequences, resulting in protection of workers, the public, and the environment from undue radiation risks," whereas security[34] means "the prevention and detection of, and response to, criminal or intentional unauthorized acts involving nuclear material, other radioactive material, associated facilities, or associated activities."

Concepts, principles, mechanisms, terms, and/or functions for reaching a high level of safety and security may be identical or very similar in their form, content, and objective, but may apply to different "objects." For example, while regulatory functions and processes are very similar in their essence (the same type of functions, with the same type of processes, with similar arrangements to perform them) for both safety and security, the "objects" are different for the two disciplines. Safety recommendations address objects relevant for safety (e.g., the documentation for authorization should include the occupational radiation protection program with a description of the operator's arrangements for the monitoring of workers and the workplace and the maintenance of personal protective equipment and equipment for radiation detection), while security recommendations address some other objects which are relevant for security (e.g., the documentation for authorization should include the security measures proposed by the applicant, such as access control features, cages, fences, and gates, intrusion detection systems, key control procedures, or video monitoring).

Once this assumption is made–that objects may be different based on the safety or security disciplines–the analysis compares the international recommendations in order to find common elements, which may show *identical*, *similar,* or *different* patterns and specific elements which are *unique* and relevant only for one or the other discipline.

The international recommendations on safety and security describe the actions which should be taken by states and the conditions which should be met by regulatory bodies, other competent authorities, operators, and other relevant stakeholders in a state for ensuring a high level of safety and security of facilities and activities in the nuclear field. Overall recommendations are addressed at the state level, to states' governments for taking actions to ensure safety and security. Overall recommendations are followed by more detailed ones, including specific conditions to be met by different organizations such as regulatory bodies, other competent authorities, operators of facilities and activities, and various stakeholders (e.g., manufacturers of radioactive sources, carriers/transporters of radioactive materials cargos, etc.), in accordance with their specific roles and responsibilities for safety and, respectively, for security. Specifically, states are responsible for ensuring that regulatory and legislative frameworks are developed, organizations are established, and infrastructures are built for ensuring both safety and security. Regulatory bodies and other competent authorities are responsible for establishing regulatory systems, processes, and functions for safety and security, while operators are mainly responsible for performing their activities with due consideration and by complying with the regulatory requirements for safety and security enforced by the regulatory body. In order to reflect the distinction between various roles and levels of responsibility, for the analysis described in this paper the international recommendations on safety and security have been split in three categories: international recommendations at the state level, international recommendations for the regulatory functions and processes, and international recommendations for operators of facilities and activities involved in the use, storage, and/or transport of radioactive sources and/or radioactive material.

Criteria have been defined to perform the comparative analysis and are presented in Table 1. Main topics have been identified for each category and the below criteria have been applied in order to determine if the topic is addressed in both types of publications identically, similarly, differently, or uniquely.

Table 1. Criteria Used for the Comparative Analysis

No.		Criterion	Description
1	Common Elements	Identical Pattern	Identical description and use of the international recommendation in terms of form, content, and objective as it applies to the same object.
2		Similar Pattern	Similar description and use of the international recommendation in terms of form, content, and objective, but the “object” is different, with one being related to safety and the other related to security; usually such recommendations are less developed in security publications.
3		Different Pattern	Different description and/or use of same concept, principle, mechanism, term or function, due to safety or security specificity.
4		Specific Element	Concept, principle, mechanism, term, or function is specific to either safety or security.

By using the criteria in Table 1, the comparative analysis is mainly qualitative. In order to associate quantitative (numerical) evaluation to the analysis for each type of recommendation (topic), the criterion fully met has been assigned the number “1” and all the other criteria have been assigned number “0.” In this way, graphical representations in the form of pie charts have been prepared to show the percentages of identical, similar, and different recommendations in the *common, overlapping area* of safety and security, and the percentages of uniqueness of special topics for either safety or security.

Results

To show the results of the analysis, two types of graphical representations have been selected: Venn diagrams (for the qualitative visualization of common topics and unique elements of international recommendations for safety and security) and pie charts (for the quantitative evaluation of how many topics are described identically, similarly, or differently in the overlapping area of safety and security, and how many topics are unique for one or the other discipline). Each topic presented in the figures on the following pages is addressed by a number of international recommendations in the IAEA publications. While the total number of international recommendations for each topic would not bring any particular value for the analysis, the methodology focuses on the information contained within each topic, as described in Table 1.

The results presented on the next few pages provide a global picture of international recommendations for safety and security, and the way they are linked within the IAEA publications. Moreover, the results demonstrate the strong interdependence of the two disciplines, and provide a solid justification for the need for harmonization of regulatory frameworks for safety and security and for practical integration of safety and security systems and measures at facilities and activities working with ionizing radiation. In addition, for states that have implemented a safety infrastructure and may believe this is sufficient, the work shows clearly the interactions between safety and security and those elements of a security infrastructure that lay outside the safety infrastructure and need to be addressed for completeness.

International Recommendations at State Level

A number of international recommendations are included in both safety and security IAEA publications, which are addressed at the state level, as described in the section, “The Methodology.” Some of them are identical in form, content, and objective for both safety and security and have the same object; for example those addressing the establishment of a national register of radioactive sources. The object in this case is the *unique national register of radioactive sources*; the information included in such a national register is to be used for both safety and security purposes. Some other international recommendations are similar; for example, the establishment of an independent regulatory body for safety and respectively, for security. If a single authority is appointed at a national level to act as a nuclear safety regulator, then the object will be *the one regulatory body* for both safety and security. When distinct regulatory authorities are appointed for safety and respectively, for security, the objects will be distinct: international recommendations for safety will apply to regulatory processes and functions of the safety regulator, and the international recommendations for security will apply to the security regulator. In their essence, the international recommendations are the same (appoint the regulatory body; the regulatory body shall be independent and given appropriate authority and resources for performing their regulatory functions; the regulatory functions are the same: authorization, review and assessment, inspection, law enforcement, elaboration of regulations and guides for the use of operators, etc.), but it will apply to two distinct objects, which are the two regulatory bodies. Some other international recommendations are specific either to safety (e.g., radiation risk and dose limitation) or to security (e.g., information security). For the purpose of this analysis, the main topics addressed at the state level have been considered, as they are described in the IAEA publications and the *Code of Conduct.*[4]

The results presented in Figure 1 show that for the main set of international recommendations addressed at state level, more than 55% are common topics for both safety and security disciplines, showing mostly a similar pattern. Of these, about 12% are identical recommendations, which are described in exactly the same way in both disciplines and are directed to the same object, such as: fundamental objective, cooperation, and information sharing among competent authorities, leadership and management systems, the establishment of a national register of radioactive sources, and the safety-security interfaces. The object of the fundamental objective is for both the safety and security of the *public, the society, and the environment,* which must be protected, for now and future generations, against the harmful effects of ionizing radiation. The recommendations on cooperation and information sharing among competent authorities are addressed to all competent authorities with responsibilities for either safety (including competent authorities for emergency management) or security, so that they can work together closely to achieve benefits from each other's experience, and the consistency and harmonization of interfaces for safety-security. The international recommendation on establishing a national register of sources is to be applied, as described previously, by both safety and security regulatory bodies when building and maintaining *one, unique, national register* for the use of all responsible organizations. The international recommendations on interfaces between safety and security are addressed to all competent authorities–or to safety and security–for the coordination and consistency of regulatory requirements and processes. At the same time, the international recommendations on interfaces between safety and security address the roles and responsibilities of operators for the integration of safety and security measures within the management system of their organizations in such way that "safety will not compromise security, and security will not compromise safety."[1,2]

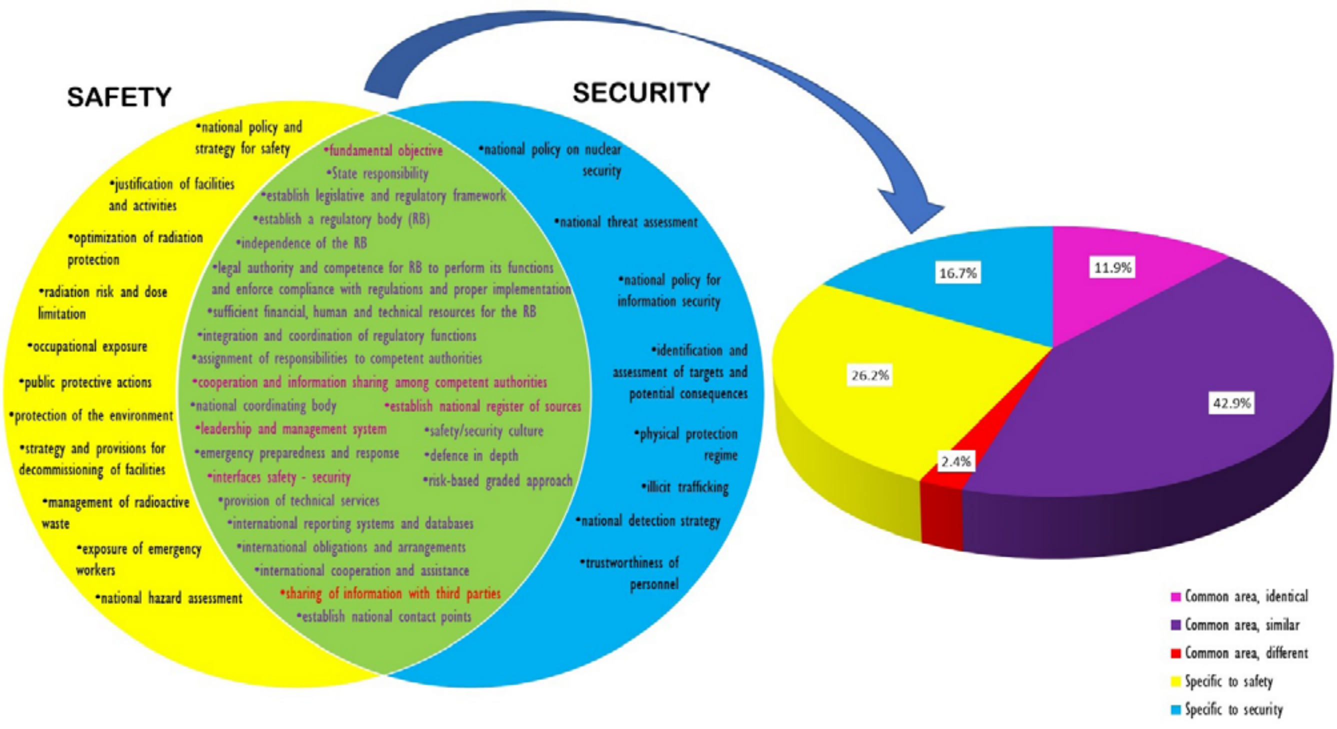

Figure 1. Common and Specific Elements for Safety and Security in International Recommendations Addressed at State Level

The set of international recommendations on "leadership and management," which are addressed in security publications as part of the essential element "Sustaining a nuclear security regime,"[3] are meant to support the building of effective leadership and a management system in every organization, for both safety and security. The management system should integrate both safety and security measures, systems, and cultures. While international recommendations on leadership and management show identical patterns, it is more complicated when it comes to "safety culture" and "security culture." Definitions of safety culture and security culture are similar, and a state's responsibilities to promote both safety culture and security culture are fully consistent. Nonetheless, in terms of implementing safety culture and security culture in organizations (operators, regulatory bodies, and competent authorities) things are different due to the specificity of the security discipline. These differences are explained in the section, "International Recommendations for Operators of Facilities and Activities Dealing with Radioactive Sources and/or Materials in Use, Storage or Transport," wherein international recommendations on safety culture and security culture have been considered from the perspective of their implementation at the operators' level.

More than 40% of international recommendations presented in Figure 1 show a similar pattern, which means that they are to be used in same way, in parallel, in both disciplines: states have the responsibility to regulate both safety and security, to establish legislative and regulatory frameworks and independent regulatory bodies for both safety and security, to designate other competent authorities for safety and security, to empower regulatory bodies with legal authority, competences, and resources for both safety and security, and so on. In addition, main concepts such as "defense-in-depth" and "risk-based graded approach," which are primarily safety concepts, have been adopted and adapted for security purposes by keeping their initial meaning. In both disciplines, defense-in-depth represents a combination of successive layers of systems, equipment, and procedures or measures for the prevention of accidents or nuclear security events and mitigation of consequences, in the case that accidents or nuclear security events occur. The risk-based graded approach is a concept which is being applied in both safety and security disciplines from the establishment of national high-level policies and strategies until safety and security measures are implemented by operators of facilities and activities.

In terms of differences in recommendations belonging to the common area of safety and security, the topic of "sharing of information with third parties" is treated differently in security than in safety. While safety publications recommend transparency and openness in sharing relevant information, in security most information is sensitive and has to be treated confidentially.

About 43% of the international recommendations addressed at the state level are in the specific areas of the two disciplines. Of particular interest are recommendations for states to "perform national hazard assessments" (in safety) and "national threat assessments" (in security). While the recommendations are initially on performing, and afterwards, periodically reviewing and revising the national hazard and threat assessment with due participation of regulatory bodies, other competent authorities and operators are fully consistent. The two national assessments are used for different purposes and have completely different content. For this reason, they have been presented as specific topics and not as part of the common area in Figure 1. The national hazard assessment is to be performed by states in relation to preparedness and response for a nuclear or radiological emergency. As part of the national hazard assessment, those facilities and activities in the country and abroad which may pose significant radiological risk in the case of accidents are identified, and emergency arrangements are developed for the response to a nuclear or radiological emergency. The operators of main facilities and activities in that country contribute to the national hazard assessment in the sense that the operators' hazard assessments–which are based on operators' safety assessments–form the basis for the national one. The national threat assessment is performed in order to identify all threats (internal and outside the state) that could cause the occurrence of nuclear security events. The results of the threat assessment are considered by operators when they develop their security plan and establish security measures for the protection of their facilities and/or activities.

International Recommendations for Regulatory Functions and Processes

Main international recommendations addressing regulatory functions and processes have been selected for the analysis and the criteria in Table 1 have been applied. In this category, topics have been considered in relation to the regulatory functions and processes (e.g., elaboration of regulations and guides, authorization, review and assessment, inspection, enforcement, functions for emergency preparedness and response, and communication and consultations with interested parties) and the concepts and criteria developed by regulatory bodies for performing their functions and processes (e.g., categorization of radioactive sources, D-values, dangerous source, dose limits and constraints, clearance levels, security levels, exemption levels, activity threshold levels, emergency preparedness categories, and generic and operational criteria for emergency response). The distribution of international recommendations for regulatory functions and processes is presented in Figure 2.

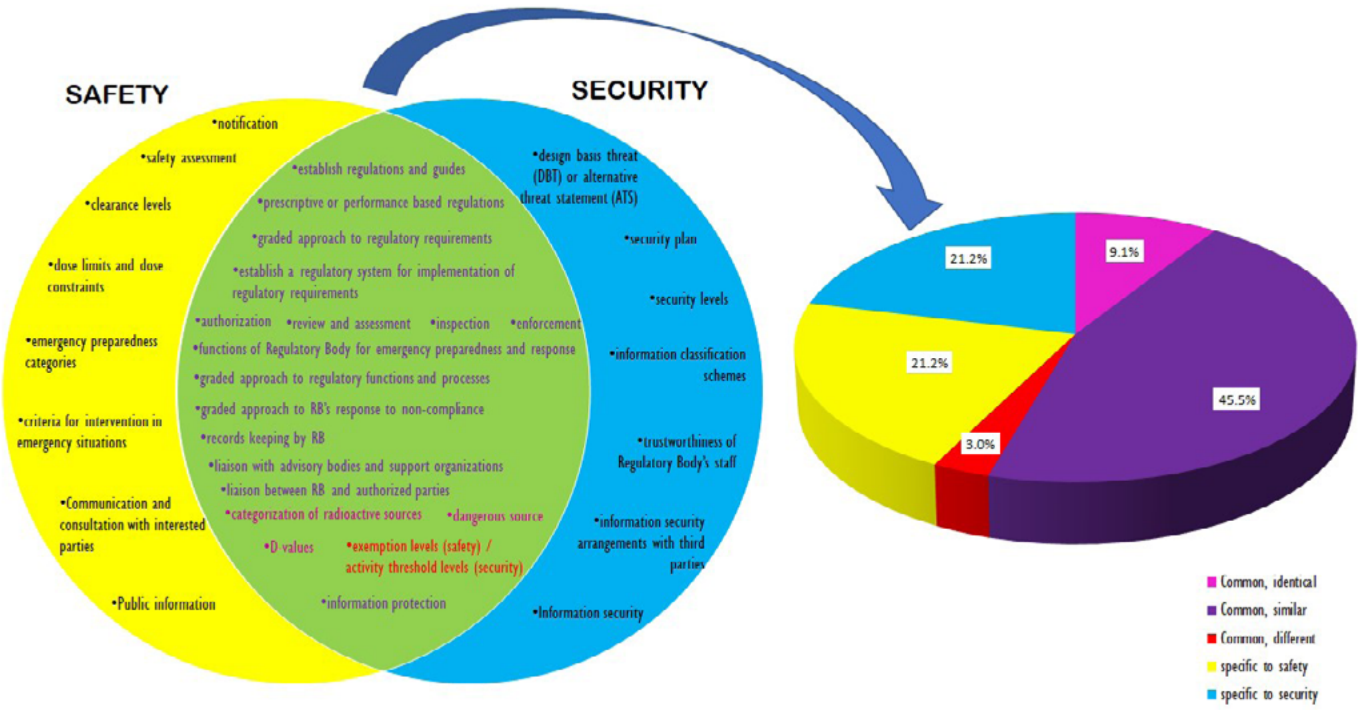

Figure 2. Common and Specific Elements for Safety and Security in International Recommendations for Regulatory Functions and Processes

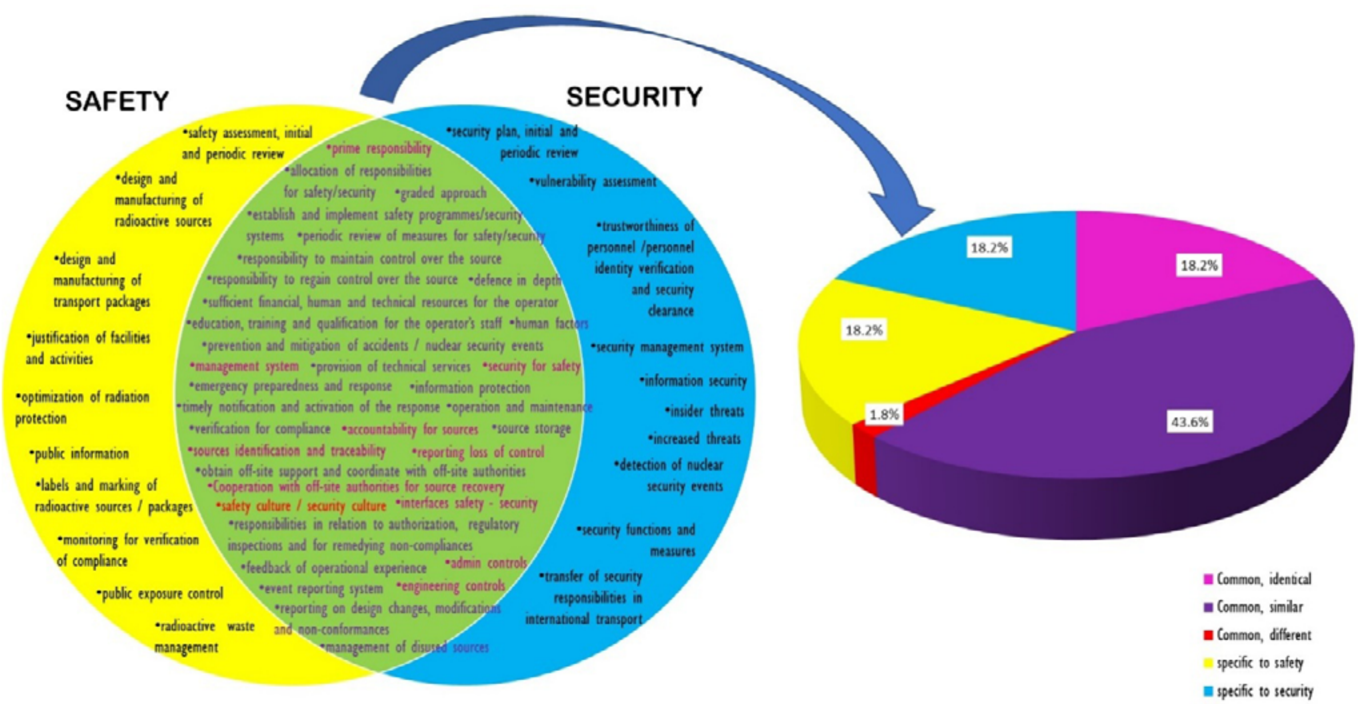

Figure 3. Common and Specific Elements for Safety and Security in International Recommendations for Operators of Facilities and Activities Involving Radioactive Sources or Material in Use, Storage or Transport

The results display a very similar trend as the one shown for the international recommendations addressed at the state level, with more than 55% of topics included in the common area of safety and security. Of these, about 9% of topics are identical (recommendations for safety and security contain the same message, and are addressed to the same object), while about 45% of topics show a similar pattern (recommendations for safety and security contain the same message, but are addressed to different objects). The rest of the topics, about 42%, are split into international recommendations on topics specific for safety, and international recommendations on topics specific to security.

The elements described identically for both safety and security are the "concept of a dangerous radioactive source," the "D-values," and the "categorization of radioactive sources." They are treated and used identically in both safety and security publications and in the *Code of Conduct.*[4] In security, the categorization of sources is used when establishing security levels. While states may choose a different approach for setting up security levels, based on intended application of the source or radioactive material,[26] the system of source categorization is one for both disciplines.

The topics belonging to the overlapping area between safety and security which are used in a different way are those related to exemption levels (in safety) and activity threshold levels (in security). While the approaches are similar and consistent in terms of establishing limits above which authorization is to be required, the limits themselves are different for safety and security. In safety, the regulatory body is asked to establish exemption levels in support of notification and authorization process, and use them for a graded approach for authorization by registration and authorization by licensing for all other (not exempted) facilities and activities. In security, there is no authorization by registration and the activity thresholds levels are the A/D ratios above which authorization is required, and security systems and measures have to be implemented based on security levels: Security Level A for sources in Category 1, Security Level B for sources in Category 2, and Security Level C for sources in Category 3. This means that radioactive sources with activities higher than the exempted levels but less than the D-values are covered only by security for safety recommendations in terms of authorization and protection.

Most of the international recommendations addressing the regulatory functions and processes display a similar pattern in both safety and security publications, as shown in Figure 2. While safety publications describe in deep detail the regulatory core functions and processes,[15] the security publications include a less thorough description of the regulatory core functions, usually spread over more than one chapter and more than one publication. Some topics are only partially addressed; there is no notification process, only authorization; review and assessment performed by the regulatory body is now to be addressed in the revised version of *NSS-11;*[26] and more about authorization, inspection, and enforcement is included now in the same publication.[26] The regulatory core functions and processes are also addressed–in an integrated manner–in the *Code of Conduct.*[4] When it comes to the graded approach to regulatory functions and processes, the pattern is similar: the approaches are the same but the topic is thoroughly addressed in safety publications, and only partially in the revised version of NSS-11.[26]

The approaches used for establishing regulations and guides are consistently described in both types of publications. The regulatory body has three options for developing regulations: a prescriptive option, a performance-based option, and a combined approach. They are addressed in similar ways in safety and security.

In relation to the authorization of facilities and activities, while the regulatory function and the processes associated with it are similar for both disciplines, the operators are requested to submit (for the purpose of demonstrating safety and, respectively, security) separate documents for authorization, with specific content: a safety assessment for safety and a security plan for security. That is why the authorization function is included in the common area in Figure 2 and the safety assessment and the security plan are displayed in the specific areas of safety and security, respectively.

Although some topics are not specifically described in the security publications, they are indirectly addressed (for example, the international recommendations on "liaison of RB with advisory bodies and support organizations" and "liaison between RB and authorized parties"). For this reason, they have been included in the common area as being similarly addressed and used.

"Information protection" is a topic specific to security, and therefore it is much more detailed in security publications (e.g., classification system, national policy, and strategies for information security). At the same time, the topic is collaterally addressed in safety publications, when it comes to public information. Protecting sensitive information in emergency situations is one example of similar consideration for this topic.[10] Therefore, the topic is included in the common area, displaying a similar pattern.

International Recommendations for Operators of Facilities and Activities Dealing with Radioactive Sources and/or Materials in Use, Storage, or Transport

While the first two categories of international recommendations addressed in the preceding two sections are to be applied by states, competent authorities, and regulatory bodies in relation to all facilities and activities, the category of international recommendations described in this section is about international recommendations for operators of facilities and activities involved in the use, storage, and/or transport of radioactive sources and/or radioactive material. When transposed into national regulations, these international recommendations become regulatory requirements, legally binding for all operators of facilities and activities to which they are addressed.

When it comes to the application of concepts, principles, and mechanisms for the safety and security of radioactive sources and/or radioactive material, the international recommendations for operators of facilities and activities display even more similarity for the two disciplines. As shown in Figure 3, almost 20% of international recommendations are described and used identically in safety and security, and more than 40% are showing similar patterns.

The international recommendations for this category which are identical for both safety and security are in relation to prime responsibility, management systems, administrative and engineering controls and security for safety, accountability for sources and sources identification and traceability, safety-security interfaces, reporting loss of control over the source, and cooperation of operators with off-site authorities for source recovery. Prime responsibility is identically reflected in all safety and security publications, for all facilities and activities, starting with the *Fundamentals*. The one and only management system of the operating organization has to integrate both safety and security systems and measures in a coherent, harmonized way. The safety-security interfaces address mainly the same aspects of coordinated coexisting systems and measures for both safety and security. Some measures for safety incorporate elements for the security of sources (e.g., administrative and engineering controls). They are addressed in the "security for safety" international recommendations, and are in full compliance with security measures as described in security publications.

"Accountability for radioactive sources, sources identification, and traceability," "reporting loss of control over the source," and "cooperation of operators with off-site authorities for source recovery" are topics which address same object (the radioactive source itself) and show identical patterns in both safety and security publications and in the *Code of Conduct*.[4]

As presented in Figure 3, the only difference that could be observed in the present analysis for the common area of safety-security is in relation to the implementation of "safety culture" and "security culture" within the operating organization. Definitions and international recommendations on promoting, developing, and maintaining safety and security cultures have been addressed in the section, "International Recommendations at State Level," and have been found to show a similar pattern. However, in terms of implementation, there are differences which are derived from specificity of security discipline. As described in NSS-7,[29] security culture considers not only the risk of inadvertent human error, but also risks associated with deliberate, malevolent acts which are intended to cause harm. The consideration of deliberate acts occurrence is specific to security. Therefore, different, additional attitudes and behaviors are to be required for security culture in order to cope with deliberate acts, which are not considered in safety culture, and specific international recommendations are addressed for security, such *as* confidentiality of information or trustworthiness of the personnel.

"Verification of compliance" and "monitoring for verification of compliance" are two distinct topics included in international recommendations. Verification of compliance is addressed consistently in both safety and security publications and relate to the responsibility of operators to verify their own systems and arrangements for compliance with regulatory requirements. Safety assessments and independent assessments conducted for safety are similar in terms of objective, with the vulnerability assessment conducted for security. However, the assessments themselves and their contents are specific to the relevant discipline. For this reason, the topics on "safety assessment" and "vulnerability assessment" are included in the specific areas for safety and for security, respectively. The monitoring for verification of compliance is specific to safety (as shown in Figure 3), while monitoring in security is mainly related to detection and response to nuclear security events, rather than checking compliance with regulatory requirements.

"Public information" and "security information" are two distinct, separate topics as well, which are addressed differently in safety and security. While international recommendations in safety promote public information in both normal operation and emergency conditions, in order to provide the public with timely, effective, and reliable information on radiological risks, the information relevant for security must be evaluated for its sensitiveness and confidentiality and treated accordingly. Therefore, the topics have been considered to belong to the specific areas of safety and security, respectively.

International Recommendations for Transport of Radioactive Sources or Materials

International recommendations addressing transport activities involving radioactive sources and/or radioactive material are very similar in terms of topics and patterns with those dealing with radioactive sources in use or storage. International recommendations for transport safety and transport security, addressed at the state level or related to regulatory functions and processes include the same topics (e.g., state responsibility, legislative and regulatory framework, management systems, etc.) and follow the same patterns as those described in the sections, "International Recommendations at State Level" and "International Recommendations for Regulatory Functions and Processes." The international recommendations for operators of facilities and activities involving radioactive sources or material in use, storage, or transport have been described in the section, "International Recommendations for Operators of Facilities and Activities Dealing with Radioactive Sources and/or Materials in Use, Storage, or Transport" and is graphically presented in Figure 3.

While the common aspects of transport-related international recommendations have been addressed and covered within the previous sections, a couple of aspects are of particular importance when it comes to transport safety and transport security, and these will be described below.

One particular aspect is that the IAEA international recommendations for the safety and security of transport activities with radioactive sources and/or radioactive material are aligned with existing international instruments, recommendations, and guidance for the transport of dangerous goods and the *Code of Conduct*.[4,11,28] This approach leads to similar use on an international basis and to better harmonization of safety and security international recommendations for transport activities.

In addition, the international recommendations for transport safety and transport security provide for a similar use of the *graded approach* concept, based on the properties and quantities of radioactive material to be transported and their potential radiological consequences in case of accidents or incidents that may occur during transport. The safety publication on *Transport Regulations*[11] uses "basic radionuclide values" expressed as A1 and A2 values, "activity concentration limits" for exempted material, and "activity limits" for exempted consignment; if a material contains radionuclides where either the activity concentration or the activity for the consignment is less than pre-established limits, then the transport regulations do not apply. Furthermore, the A1 and A2 values are used to express activity limits for different types and categories of packages. At the same time, the security documents use "activity thresholds" to determine the security level of a package. Both the D-values and the A2 values from *Transport Regulations* are used to define the activity thresholds; D-values are used for radionuclides included in *Code of Conduct,*[4] while A2 values are used to define thresholds for radionuclides other than those included in *Code of Conduct.*[4] In security, the relative attractiveness of a radioactive material is considered in addition to the potential radiological consequences resulting from a malicious act.

At the same time, the means and ways used by the two disciplines to regulate transport activities are different and specific to either safety or security. While the overall goal is the protection of the public, society, and the environment against harmful effects of ionizing radiation, safety requirements on transport focus on the "containment of radioactive material, control of external radiation levels, prevention of criticality, and of damage caused by heat,"[11] while security requirements focus on "minimizing the likelihood of losing control over the radioactive material during transport and of malicious acts (e.g., theft or sabotage) occurrence."[24] In other words, the international recommendations for transport safety address "package designing, preparation of the consignment" and "regulatory approval and control." Safety features such as shielding, criticality control, or prevention of damage due to heat are built into the design of different types of packages (Figure 3). Therefore, most safety-related measures are taken before the transport itself. On the other hand, the international recommendations on transport security ask for security measures to be taken during the transport (based on pre-defined security levels)[28] to deter, detect, and delay unauthorized access to the radioactive material while in transport and during storage in transit. For this reason, "transfer of security responsibilities in international transport" is a topic specific to transport security (Figure 3).

Conclusions

The fact that the IAEA international recommendations for safety and security have overlapping elements has been acknowledged in previous publications. The present analysis takes this evidence a step forward by examining the overlapping areas in detail, in order to show how much international recommendations are similar or different.

Three categories of international recommendations have been considered: those addressed at the state level, those related to regulatory functions and processes, and those addressed to operators of facilities and activities dealing with radioactive sources or radioactive material in use, storage, or transport. The general conclusion is that for all categories, more than 40% are common recommendations which are described and used in similar way for safety and security. Approximately 10% or more of the recommendations address a particular topic identically in both safety and security, while about 2% of common topics are used in a different way, due to the specific features of the two disciplines.

These numbers, along with the qualitative evaluation presented here, may provide a better perspective on the need for and considerations to manage safety and security together, in an integrated manner. States should build safety and security legislative and regulatory frameworks with due consideration of relevant safety-security interfaces. Joint mechanisms, processes, and coordination should be established at the level of each relevant organization (e.g., operator, regulatory body, other competent authority) for implementing both safety and security international recommendations.

In terms of regulatory functions and processes, the international recommendations show compatible approaches. Consensus has been reached at an international level that regulatory frameworks for safety and security should be established in similar way, with due consideration of the particularities of each discipline. In some countries there is only one regulatory body responsible for both safety and security. In such cases, both safety and security regulatory functions and processes should be integrated within the management system of the organization. The existing guidance provided in safety publications could prove to be beneficial for reaching a high level of consensus and harmonization within the organization.

Only a few topics have been identified, which are used differently. "Sharing of information" is one topic which is addressed differently in the two types of publications. It relates to "public information" (safety), "information protection" (for both safety and security) and "information security" (security). While the importance of sharing information with third parties (public included) is recognized by both disciplines, the way it is done is different. Levels defined by regulatory bodies for authorization ("exemption levels" in safety and "activity threshold levels" in security) are also addressed, with some differences which have been described in this paper. The third topic which has been found to display different usage is in relation to "safety culture" and "security culture." All differences, as explained in the third section of this paper, derive from the specific features which define the two disciplines.

When it comes to transport activities involving radioactive sources and/or radioactive material, the importance of both safety and security measures and the way they complement each other is even more clear; while safety measures are to be taken mostly before the transport and relate to package design, package choosing, preparation of the transport, and of transport documents, the security measures are focused on the actual transport, in order to protect and secure the cargo.

The results of this analysis, along with the insights into the application of international recommendations for the safety and security of radioactive sources and/or radioactive material, demonstrate the strong interdependence of the two disciplines and the fact that a safety infrastructure is not sufficient for states to ensure that the international security recommendations are being met. Safety could not exist without security, and security could not exist without safety. Only when applied together can international recommendations on safety and security achieve the fundamental objective of protecting people, society, and the environment against the harmful effects of ionizing radiation.

At the same time, the results obtained may contribute to a better understanding and use of international recommendations for safety and security, and support experts worldwide in their efforts for building or improving security frameworks in harmonization with the already existing safety frameworks.

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In Memory of Dennis “Denny” Mangan January 18, 1939 – September 28, 2020

By Susan Pepper
INMM President

Our friend and colleague, Dennis Mangan, passed from this life on September 28, 2020. “Denny” graduated from Notre Dame in 1960 with a degree in electrical engineering and worked at Sandia National Laboratories for 41 years, establishing himself as an expert in international safeguards and physical protection. Denny was a member of the INMM since 1980. He was Vice-President, President, and Immediate Past President of the Institute from 1991 to 1996, he was elevated to the membership grade of Fellow in 1998, and he served as the Editor of the *Journal of Nuclear Materials Management (JNMM)* for 18 years. Denny received the INMM's Meritorious Service Award in 1996, the Charles E. Pietri Special Service Award in 2012, and the Vincent J. DeVito Distinguished Service Award in 2016. He served on the INMM's Awards Committee and the Technical Program Committee for many years. Even when he did not hold an official position that required his attendance, he attended the Executive Committee's in-person meetings to provide his input and mentor his successors in leadership. In 2018, the INMM's Southwest Chapter established a student award in Denny's honor.

As a tribute to our friend and supporter, I have asked the Past Presidents of the INMM to share their memories of Denny. The following reminiscences are from Cary Crawford, Ken Sorenson, Nancy Jo Nicholas, John Matter, Jim Tape, and Yvonne Ferris. Their thoughts convey a sense of Denny, his contributions to his profession, his zest for life, and his strong support of the INMM.

“I have been an INMM member and attendee for the past 24 consecutive years and have been in the industry for 27 years. I met Denny in the second year of my career, while working at the Pantex Plant. Denny was, at the time, a senior program manager at Sandia. My interaction was challenging, as I was responsible for informing a group of senior U.S. federal staff and SNL management that we were having difficulties integrating several technologies that Denny had the oversight for. As an early career staff member, it was an intimidating task dealing with inter-organizational sensitivities. Denny, however, proved to be very direct in his approach, but more than fair with an eye towards resolving issues rather than finding fault. It was one of the first interactions I had with a multi-organizational meeting, and I remained highly impressed with Denny's mix of leadership in addressing the concerns while maintaining strong relationships in what could have been tense, even confrontational interactions. I have, of course, had many interactions with Denny through the years since then and always maintained a close relationship with him, primarily through our interactions during INMM Annual Meetings and other workshops. However, it is the interpersonal interactions that stick with me more than his vast technical experience. Denny always proved to be open to conversations, insightful and curious to explore new opportunities and scientific growth, and eager to push others to grow in those experiences. I have always brought my family with me to INMM Annual Meetings and even mark years by where we happened to hold the meeting any given summer. A most recent

Southwest Chapter Annual Winter Dinner Meeting in Santa Fe, New Mexico, on January 17, 2014.

From left: John Matter, Nancy Jo Nicholas, Ken Sorenson, keynote speaker Bruce Held, NNSA Acting Undersecretary for Nuclear Security, Yvonne Ferris, Denny Mangan, and Jim Lovett.

and memorable exchange with Denny was at the last Annual Meeting that he was able to attend. Denny was in failing health and had spent much of his time at the conference discussing his memories of the INMM through the years. On one occasion in the concierge lounge, he pulled out a historical document that had come across his desk that detailed the leadership of the INMM from the first year until the present time, and we reminisced about many of those names who are no longer with us. With my 14-year-old daughter with me, we fondly reminisced about the many names and faces and experiences we've had because of the INMM. Diana had gone home early and we were all looking out for Denny to ensure he was able to get around. My daughter will forever recall the time we spent talking with Denny as she loved talking with him, and I'm grateful that I can still share that joint experience with Denny with my daughter. Denny was a key reason for the INMM being where we are today. He is and will be sorely missed for many years to come."

—Cary Crawford, INMM President 2019-2020

"I first met Denny when we were both working at Sandia National Laboratories. I was an engineer working on nuclear

Denny receiving the Vincent J. DeVito Distinguished Service Award in 2016.

Left to right: Corey Hinderstein, Denny Mangan, Larry Satkowiak.

materials packaging programs that were increasingly moving from Safety R&D to Security and Safeguards topics. Although I did not know Denny personally at the time, I did know he managed programs at Sandia in these areas. I gave him a call and asked if I could meet with him to talk about his programs. He said, "Sure!" and I met with him that first time for a near three-hour drink from his fire hose of knowledge. So began a journey that vastly broadened my knowledge in these areas, and opened up an expanded career path. Denny was a central part of this journey for me, always there with support, giving of his time and knowledge, and being an ever-present role model.

Oh yes, at that first meeting, the subject of INMM did come up. He said that the best way for me to get involved was to join INMM and start networking, going to meetings, and volunteering for the Institute. Good advice! Denny's impact on the INMM has been clear; from countless hours of volunteering for specific tasks for the Institute, holding numerous leadership positions (including President), and mentoring and supporting individual members, to serving as Technical Editor for the *Journal* for 18 years. Denny was a mentor, role model, colleague, and a good friend. The lasting legacy he leaves with all his friends, colleagues, and the INMM will endure for a very long time."

—Ken Sorenson, INMM President 2013-2014

"I first met Denny Mangan in the late 1990s when we had the opportunity to work together on the U.S.-Russian-IAEA Trilateral Initiative. Denny was the INMM Immediate Past President, but he loved to remind me that he never was INMM President. The title he held was "INMM Chair." During his term leading the Institute, he clearly grew the role into something bigger and so the position was redefined and called "INMM President." One of the greatest things about Denny was his willingness to help and mentor everyone. No matter where they worked or what they did, he regarded everyone he met–especially at an INMM meeting–as a future leader in the nuclear materials management industry, and someone deserving of his time and attention. Denny was especially great at encouraging and mentoring women and minorities. Even in retirement, he was loyal to INMM and regularly attended meetings and events. He never stopped mentoring me."

—Nancy Jo Nicholas, INMM President 2007-2008

"Denny Mangan and I were friends and colleagues for about four decades, through INMM and at Sandia National Laboratories (SNL). I first saw his name on an office at SNL, but it was empty most of the time–I found out that he traveled a lot for business. In my experience, the two best words that described Denny are "advocate" and "mentor." He had a pervasive, contagious, and quiet enthusiasm that permeated all his work and play. When he met new people at SNL or on the road he never let them get away without making them aware of INMM and encouraging them to come see what our organization is all about. He urged them to get professionally involved with some aspect of nuclear materials management, whether related to one of INMM's technical divisions or his work program at SNL. He was especially invigorated by recruiting new talent into these career paths. This was especially true for the next generation of staff and students. Dozens of new and advancing STEM professionals have listened to his encouragement and then chose to follow his lead. These persons included several of our more recent and current INMM leaders. Denny was adept at taking advantage of the opportunities for advancement at SNL, beginning with MS and PhD educational assistance programs. He later climbed onto the management ladder as Division Supervisor and Senior Manager, and finally retired as a Senior Scientist after more than 40 years of service. But he was not done yet and continued to make significant contributions as a consultant for almost another decade. During his long career he left his mark on domestic physical protection, international safeguards, nuclear nonproliferation and arms control, and international nuclear security. Denny displayed an unabashed passion for the two organizations that he served and helped lead, and while he occasionally enjoyed tweaking another national lab colleague, he well understood that success is based on teamwork. Many of us had a professional opportunity to travel to far corners of the world with him, and sometimes he was the source of good humor. For example, he was not your most adventurous eater; whenever and wherever the mission team went to dinner, which was often an international culinary experience, Denny always ordered–wait for it–one plain cheeseburger, an order of French fries (this term is not universally understood), and a draft beer!"

—John Matter, INMM President 2003-2004

"The first interactions I had with Denny Mangan are lost to me in the fog of time, but they involved nuclear materials safeguards and security R&D collaborations between Sandia and Los Alamos, starting in the late 1970s, and professional society activities with INMM.

Rather than try to cover years of interactions and collaborations with Denny, I want to focus on a key period, the end of the Cold War and the breakup of the Former Soviet Union (FSU). In the early 1990s these historic events led to new and unique opportunities for the INMM, when the U.S. government undertook major initiatives to help secure FSU nuclear weapons and materials. At the beginning of this period, (the late) Darryl B. Smith was INMM President and Denny Mangan was Vice President, with responsibilities for the Annual Meeting. At the 33rd Annual Meeting in Orlando, Florida, the keynote addresses marked the beginning of a role for INMM in facilitating professional collaborations between experts from former Cold War adversaries when the head of the U.S. Safe and Secure Dismantlement Delegation, General William F. Burns, and Ambassador I. M. Palenykh of the Ministry of Foreign Affairs of the Russian Federation made presentations on weapons dismantlement activities.

When Denny became INMM President and I assumed the role of Vice President, these efforts continued and were broadened as the new U.S. administration increased the programs designed to secure weapons and nuclear materials. Experts from Russia and other FSU countries began to attend INMM meetings in greater numbers, and new INMM chapters were established. Denny's leadership and enthusiasm were central to INMM's growth as a professional society making contributions to international security.

Around 1997, Denny and I were assigned to serve as senior technical advisors to the U.S. delegation negotiating with the IAEA and the Russian Federation under the Trilateral Initiative to explore the technical, legal, and financial issues associated with IAEA verification of nuclear materials removed from defense programs. Once again, Denny's high professional standards and enthusiasm for his work were evident in his contributions to this challenging program. And again, INMM provided an important forum for reporting on the work being undertaken under the Trilateral Initiative.

There is, of course, much more to be said about Denny's contributions to INMM, in particular the *Journal*, but those stories are better left to others. It was always a pleasure to work with Denny, and he was great company on long overseas trips when the jet lag was dragging us down and we were a long way from home. He will be missed."

—Jim Tape, INMM President 1995-1996

"Describing Denny is much like attempting to describe Maria, the subject of *The Sound of Music*. He was a wonderful scientist–always questioning, probing, discussing, and guiding to a conclusion. Since I am a statistician I always appreciated his insight, his obvious scientific knowledge, and his ability to lead to a consensus. He was a brilliant scientist and a formidable debater. His leadership of the INMM definitely led the Institute to higher scientific and international levels. He was diplomatic when dealing with the many factions that inevitably evolve in an international setting. Lest Denny sound a bit stodgy, he was anything but. He had a marvelous sense of humor, a warmth that brought consensus when it was sorely needed, and plainly, he was just a lot of fun to be with. He was a dear friend and colleague and will be sorely missed."

—Yvonne Ferris, INMM President 1985-1986

Hunkered Down, but Still Facing Global Security Challenges

Jack Jekowski
Industry News Editor and INMM Historian

The INMM has demonstrated a remarkable resilience. Despite the global "shutdown" due to the COVID-19 pandemic, an incredible group of volunteers–which include the Executive Committee, the INMM Association Headquarters (AH) staff, as well as many others–put together a successful 61st Annual Meeting in a virtual environment while most of us were hunkered down either in our own homes, or some in a desolate work environment.

Originally scheduled to be held at the Inner Harbor in Baltimore, Maryland, this year's Annual Meeting allowed many participants to "attend" who might not otherwise had been able to make the weeklong trip. We had over 700 participants this year, including 330 first-timers, 322 non-members, and 81 students. From most accounts, the event provided broad access to technical presentations, opportunities for networking in an Internet Café, and a new era of participation with the ability to go back and review paper presentations and Q&As that might have been missed the first time around (the presentations will now be online for attendees through June of 2021[1]).

Most people in our "nuclear world" have found themselves to be even busier than normal despite the shutdown, juggling technology, new work schedules, and additional reporting requirements during the pandemic. In many cases we have had to strike a new balance with children and other family members in need, as well as navigating the supply chain and other quality of life issues. The pandemic is a significant challenge to our societies and political structures.

Strategic Global Security Challenges Impacting the Institute

In the previous "Taking the Long View" column, I posed these questions in the context of the disruptions caused by the COVID-19 pandemic:

- *Will the global community recover economically to continue new scientific and engineering discoveries?*
- *Will this event reinvigorate investment in the "inherently safe" new generation of nuclear power technologies?*
- *Will the new "Zoom generation" change the standard for face-to-face meetings?*

One might also ask the question:

- *Will the pandemic be a tipping point for the world to come together to address cataclysmic events that are existential threats to humankind?*

Since we have not yet seen an end to the pandemic, this latter question is still yet to be answered completely. However, despite all of these new challenges brought about by the pandemic that the world is facing, it has been somewhat remarkable (and discouraging) to note that the existing global security challenges we faced prior to the emergence of the virus not only are still there, but continue to escalate, as the world seems to be hurtling toward some onerous future.

I have provided an update below on these challenges to ensure that we all continue to take a "long view" of the future.

International

- **Continuing Tensions Between the West and Russia.** Tensions continue between the United States and Russia as both countries have withdrawn from the Intermediate Range Nuclear Forces (INF) Treaty, and both are perilously close to seeing the New START agreement expire in February 2021. If this Treaty does end, it will be the first time in more than several decades that the United States and Russia do not have an active, bi-lateral nuclear weapons reduction arms control agreement in place.[2] U.S. Congressional concerns over this situation have led to inquiries about the budget impact if New START were to end, and a recent report by the Congressional Budget Office (CBO) analyzed various scenarios identifying the potential costs associated with the expiration of the Treaty.[3] So startling was the prospect of the expiration of this Treaty and the deteriorating relationship between the two nations to the Arms Control community that a letter was sent to President Trump in early August signed by 103 foreign policy experts making recommendations for reestablishing a dialog with Russia and opening further diplomatic discussions on a number of issues.[4] The United States has also announced its intention to withdraw from the Open Skies Treaty,[5] and previously had withdrawn from the Joint Comprehensive Plan of Action (JCPOA) agreement.[6] All of these actions come amidst announcements by both countries of new weapons systems, giving rise to concerns that the world is on the verge of a new Cold War.[7]

- **Escalation of Tensions Between China and the United States, and Territorial Claims in the East and South China Sea.** The long-standing territorial conflict between China and Japan, as well as other Southeast Asian nations, over islands and sovereignty in the East and South China Sea continues. Some analysts are now speculating that a military confrontation is inevitable.[8] China's increasing success with hypersonic vehicles also is a great concern to the West, as is its increasing investment in military technologies, including a recent assessment by the United States that it has the capability to double its nuclear stockpile.[9] The unusual relationship between China and North Korea, and now, the U.S. Trump Administration, creates a complicated environment. With the additional uncertainties associated with tariffs and the ensuing threat of a major trade war, even the creation of future scenarios for how these issues will be resolved becomes difficult. Additionally, the recent events surrounding the COVID-19 pandemic have dealt a significant blow to China's economy that it is struggling to overcome,[10] as well as its relationships worldwide. Also, domestic issues have arisen with the transition of Hong Kong to Chinese rule, tensions have been increasing with Taiwan, and growing border issues with India have raised new concerns.[11]
- **Iran.** The decision by President Trump to withdraw from the Joint Comprehensive Plan of Action (JCPOA - the "Iran Deal") on May 8, 2018 has triggered international turmoil as the other members of the Iran Deal have maintained their support for it, and as Iran, in reaction to the United States' withdrawal, has taken steps away from its JCPOA obligations, including increased enrichment activities.[12] In September, progress was made through a direct intervention with Tehran by the new IAEA Director General on inspector access to locations in question.[13] However, the killing of General Qassem Soleimani in early January by a U.S. drone strike, and the subsequent retaliation by Iran with a missile attack on U.S. bases in Iraq, has created a highly tense international situation that is yet to be fully understood with respect to future hostilities between the two nations. During this summer, several "mysterious" fires and explosions occurred at critical Iranian facilities, including the Natanz nuclear facility which houses centrifuges. These events are still being investigated, although some sources have speculated that Israel or the U.S. is behind them.[14]
- **North Korea (DPRK).** The summits between President Trump and Kim Jong-un appear to have fallen short of creating a long-term meaningful solution to nuclear issues that plague the Korean Peninsula.[15] The recent COVID-19 outbreak in China has also led to speculation concerning its impact on North Korea, both with respect to reduced cooperation as well as the potential for the virus to have a devastating impact on the DPRK if it spreads to that country with its limited health care infrastructure.
- **Global Instability.** The unrest in the Middle East continues, although recent "peace" agreements brokered by the United States between Israel and the United Arab Emirates and Bahrain appear to offer a glimmer of hope for reduction of tensions, but may also result in tension between Arab states in the region.[16] The impact of the COVID-19 pandemic is yet to be fully understood, as efforts mount globally to find a vaccine. New technologies, including hypersonic weapons, the modernization of the world's nuclear deterrents, artificial intelligence, and continuing cybersecurity threats as the world becomes more and more dependent on high technology networks and computing outpace the ability to develop counter strategies. This is the 21st century world that has emerged in the third decade of the new millennium. At times, the magnitude of these driving forces brings an overwhelming sense of despair to many, which may ultimately contribute to a global economic downturn.
- **Nuclear Renaissance.** The United Arab Emirates (UAE) has brought the first of four nuclear reactors on line (the Barakah Nuclear Energy Plant in Al Dhafra), as other countries such as Saudi Arabia are in the planning stages of similarly using nuclear power to meet their long-term energy needs. In fact, the

nuclear power plant world market is booming, with the principal suppliers being Russia, China, and the Republic of Korea. South Korea, in fact, was the primary contractor supporting the installation of the successful UAE reactors, with Russia assisting a build in Turkey and China building in Bangladesh. Although the United States is not currently a player in this boom, that may change with the introduction of Small Modular Reactors (SMRs) and new "safe" nuclear fuels.[17] Promise continues to be held for SMR technology as evidenced by the recent signing of a Memorandum of Cooperation with the U.S. Nuclear Regulatory Commission (NRC) and the Canadian Nuclear Regulatory Authority, and the acceptance and recommendation for approval by NRC staff of the first SMR design by the NRC (NuScale Power).[18] However, SMR pilot installations have yet to be implemented and demonstrated. Despite these advances, however, technological struggles continue in Japan to contain the spread of radioactive contamination at the Fukushima site, as the nation struggles with a decision to dump millions of gallons of contaminated cooling water into the ocean in their continued efforts to mitigate the 2011 event.

- **India-Pakistan Relations.** Tensions between these two nuclear armed nation states rise and fall as both nations continue to strengthen and modernize their strategic weapons systems. Recent public statements by leaders on both sides over the continuing tensions in Kashmir have escalated, leading many news outlets to speculate on a potential nuclear war between the nations.[19] The United States' relationship with Pakistan has also ebbed and flowed over the past year. In a recent talk in Los Alamos, former Laboratory Director Sig Hecker stated that the most dangerous nuclear threat to the world today is the tension that exists between these two nuclear-armed adversaries.
- **Cyber Threat.** The growing threat posed by both state and non-state hackers to infiltrate even the most secure networks has created an alarming vision of the future, and U.S. Congressional investigations continue on the possibility of foreign governments intervening in the United States elections. Another important aspect of the cyber issue is the growing threat to critical infrastructure using remote communications, particularly those that are associated with nuclear facilities. The International Atomic Energy Agency (IAEA) and others have focused on providing guidance for nuclear facility operators to enhance the cybersecurity posture of those facilities.[20] As a result of the growing threat by state and non-state actors, the United States has named both space and cyberspace as "warfighting domains," raising the level of importance in the defense posture for both of these new areas. The DOE has launched a new initiative to establish a special cyber program and named an Assistant Secretary for Cyber and Infrastructure Protection; the Pentagon has stood up CYBERCOM as a Unified Combatant Command; and a new National Institute of Standards and Technology (NIST) cyber security control compliance requirement is now in all DoD contracts and subcontracts, and will be implemented in 2020.
- **Nuclear Modernization.** Growing international tensions and security uncertainties continue to drive modernization efforts of all the major nuclear weapons-possessing states, particularly as aging infrastructure, weapons and delivery systems bring into question their ability to meet deterrent needs, and new technologies including hypersonic delivery vehicles and artificial intelligence create new challenges for deterrence strategies. Despite efforts to reduce the size of nuclear stockpiles, these modernization programs, including those of the United States,[21] are a harbinger of a new Cold War. A U.S. Congressional Budget Office study identified the planned 30-year modernization effort of the U.S. alone will be in excess of $1.2 trillion. These plans were confirmed with the release of the 2018 Nuclear Posture Review on February 3, 2018. Future efforts, however, will hinge on the 2020 U.S. Presidential election as questions have been raised about the validity of some aspects of the modernization program. Of note, there is interest in the United Kingdom in some of the modernization efforts planned in the United States that would impact their own strategic posture.[22]
- **Brexit.** The withdrawal of the United Kingdom from the European Union has been initiated, creating a further unknown to the development of Western economic and security collaborations, including issues surrounding its own nuclear weapons

deterrent. The election of Boris Johnson as the Prime Minister has added yet another uncertainty into the global environment that will not be fully understood until the transition period is over at the end of 2020.

- **Ukraine.** This topical area has been added to address the increasingly complex relationship between the United States, NATO, and Russia with respect to the independence and role of this country in international security. Further complicating those issues are the failed U.S. Presidential impeachment efforts that raised the undertone of political influence emerging from this nation-state. The unique relationship that the Ukraine has to the world of nuclear material management dates to the decision in 1994, following the breakup of the Soviet Union, to remove nuclear weapons from the state under the Budapest Memorandum on Security Assurances.[23]

United States

- **U.S. Administration.** The impact to U.S. nuclear policy resulting from the election of President Trump has been addressed in previous "Taking the Long View" columns. It behooves the Institute to closely monitor this dramatically changing environment, particularly as it pertains to the technical and policy issues associated with the JCPOA; North Korean nuclear issues; geologic storage of spent fuel and high-level defense waste; nuclear power; and nuclear weapons modernization efforts.
- **U.S. Budget Deficit and National Debt.** The economic malaise that has impacted the global community is also reflected in the growing U.S. budget deficit, which has been significantly impacted by the economic relief packages associated with the COVID-19 pandemic. The World Economic Forum speaks to the "The Great Reset" that will be needed following the unprecedented impact of the COVID-19 pandemic. Podcast discussions entitled, "The World vs. Virus" predict the impact of the virus will be greater than the global impact of the 2008 financial crisis. Global economies can change national policies and attitudes, and impact decisions about investments made for activities that are supported by our Institute.[24] In the United States, our national deficit was originally expected to exceed $1 trillion in 2020, creating a national debt that exceeded $23 trillion. The FY2020 budget deficit is now estimated by the Congressional Budget Office to be in excess of $3.8 trillion,[25] and could become larger if additional funding is appropriated to assist in the economic recovery. These economic uncertainties that continue to be exacerbated by global conflicts, the uncertain future of the European Union, and global oil markets impacted by the U.S. withdrawal from the Iran Deal as well as the reduced demand due to the COVID-19 pandemic add unknowns to the stability not only of the U.S. economy, but the world.

U.S. Nuclear Security Enterprise

- **MOX and Pits, Interim Storage, WIPP, and Yucca Mountain.** As the WIPP site continues to ramp up its operational capability six years after the accidental release of contamination resulting from a breached storage container, there was a growing optimism that the nation's efforts to permanently dispose of legacy waste were on track. There were initial efforts by the new Administration to restart the Yucca Mountain project, and proposals for the licensing of a Consolidated Interim Storage Facility (CISF) to hold spent fuel from nuclear plants across the United States. Caught up in the politics of the upcoming presidential election, however, the Yucca Mountain Project is once again stalled for FY2021. Political struggles also continue with the decision by NNSA to establish a new Pit manufacturing facility at SRS using the shell of the Mixed Oxide Fuel Fabrication Facility (MFFF), while the Governor of New Mexico has said she would fight the CISF facility proposed for Southeastern New Mexico. Interim "short-term" storage for spent fuel continues to appear to be the most viable solution to safely store the waste of current nuclear power plants, although licensing of those interim storage facilities, and the associated transportation of that waste to those sites continue to encounter many roadblocks from anti-nuclear and environmental organizations.
- **Future of the Nuclear Security Enterprise.** The future of the NNSA Nuclear Security Enterprise (NSE) is yet to be determined. The *NNSA Strategic Vision* and *Governance & Management Framework* (May 2019) have set the stage to address the issues identified in the Augustine-Mies and CRENEL reports as

competitions for the Management & Operating (M&O) contracts abound. These include the new contract for the Savannah River National Laboratory (SRNL), which was split from the Savannah River Site (SRS), and the NNSA Production Office contract which includes Y-12 and Pantex. These competitions will introduce variables, including the possibility of new contractor entities. The President's budget request for FY2021 of more than a 20% increase to $19.8 billion demonstrates the Administration's focus on meeting the requirements set in the 2018 NPR. However, an internal conflict over that budget has prompted language in the FY 2021 draft National Defense Authorization Act that proposes to place more authority for NNSA in the Secretary's office by removing language from the NNSA Act which stipulates its employees, "shall not be responsible to, or subject to the authority, direction, or control" of any DOE officials, except the Secretary of Energy.[26] Of note, an earlier proposal by the Senate would have placed more authority with the DoD in the review of NNSA budgets, potentially upsetting the long-standing policy position associated with civilian control over nuclear weapons.[27] Additionally, some significant turmoil occurred in May when it was revealed that discussions occurred in White House meetings that the President was interested in how long it would take to resume nuclear testing.[28] That news story spawned many articles revisiting this topic and the Comprehensive Test Ban Treaty (CTBT) which has never been ratified by the Unites States. The NNSA is charged with the responsibility of being prepared to resume nuclear testing if a national security issue arises with respect to the reliability, safety, or security of the nuclear stockpile.[29]

INMM

- The INMM itself faces "history in the making" in its 62nd year as it attempts to adapt to this dramatically changing global environment, including the continuing impact of U.S. government restrictions on conferences, the loss of participation from Russia due to international tensions, the changing demographics of its membership, and the long-term impact of the COVID-19 pandemic. Other organizations, including the American Nuclear Society (ANS), have recently indicated they are facing similar challenges due to the new generational issues, the political divide, and international complexities. It would behoove the INMM to monitor the actions of those similar organizations and identify best practices that may be applicable. The successful implementation of the first virtual Annual Meeting due to COVID-19 has also set a new standard for the Institute, as challenges exist worldwide to address the pandemic. The first planned International Annual Meeting, scheduled to be held in Vienna, Austria in August of 2021 is still on track. However, the Institute will have to monitor how rapidly international travel and large conference gatherings come back, if a vaccine is successfully deployed, and whether a component of that Annual Meeting could also be virtual for those who cannot meet the travel requirements.

Where Do We Go from Here?

Monitoring critical issues as outlined above is an important element associated with scenario planning, as we track paths to the future. This is the process of connecting the dots. By rehearsing potential future worlds and what events might occur to get there, we can better prepare for those worlds to ensure success, or at least survival.

Such is the world that we are facing in the third decade of the new millennium, with a new realization of how fragile the environment is that we live in, and how interdependent we all are on one another.

This column is intended to serve as a forum to present and discuss current strategic issues impacting the Institute of Nuclear Materials Management in the furtherance of its mission. The views expressed by the author are not necessarily endorsed by the Institute but are intended to stimulate and encourage JNMM *readers to actively participate in strategic discussions. Please provide your thoughts and ideas to the Institute's leadership on these and other issues of importance. With your feedback, we hope to create an environment of open dialogue, addressing the critical uncertainties that lie ahead for the world, and identify the possible paths to the future based on those uncertainties that can be influenced by the Institute. Jack Jekowski can be contacted at jpjekowski@aol.com.*

Endnotes

1. To access recorded sessions, simply log into the virtual meeting platform with the same credentials you used to login to the meeting in July (https://inmm.org/page/AM61). Attendees who registered for the full event will continue to have access to all recorded sessions. Attendees who registered for single days will have access to the sessions available from those days.
2. See Chapter 12, Nuclear Treaties and Agreements, in the *2020 Nuclear Matters Handbook*, https://www.acq.osd.mil/ncbdp/nm/nmhb/docs/NMHB2020.pdf (9-12-20).
3. See https://www.cbo.gov/publication/56475 (9-12-20). Also see, *"*What if New START Expires? Three National Perspectives.*"* https://www.armscontrol.org/act/2020-01/

features/what-if-new-start-expires-three-national-perspectives (9-12-20) and, "U.S. Nuclear Weapons Budget Could Skyrocket if Russia Treaty Ends," https://www.defensenews.com/congress/2020/08/25/cbo-us-nuclear-weapons-budget-could-skyrocket-if-russia-treaty-ends/ (9-12-20).
4. See "It's Time to Rethink Our Russia Policy." https://www.politico.com/news/magazine/2020/08/05/open-letter-russia-policy-391434 (9-12-20).
5. See "U.S. to Withdraw from Open Skies Treaty." https://www.armscontrol.org/act/2020-06/news/us-withdraw-open-skies-treaty (9-12-20).
6. Although the United States withdrew from this agreement in 2018, other signatories have not (Germany, France, Britain, China, and Russia). Despite the other signatories' efforts to sustain the agreement, however, Iran has chosen to violate terms of the agreement in steps. See "U.N. Agency Says Iran is Violating All Restrictions of Nuclear Deal." https://www.defensenews.com/global/mideast-africa/2020/06/05/un-agency-says-iran-is-violating-all-restrictions-of-nuclear-deal/ (9-12-20). An attempt by the United States in late August to reinstate international economic sanctions through the United Nations failed, however, leaving the status of the agreement in limbo. See "U.S. Fails in Bid to Extend U.N. Arms Embargo on Iran." https://www.ft.com/__origami/service/image/v2/images/raw/https%3A%2F%2Fd1e00ek4ebabms.cloudfront.net%2Fproduction%2F97cdf6c0-b9eb-475f-8120-884307795d55.jpg?fit=scale-down&source=next&width=700 (9-12-20).
7. See "What Is Trump's New Nuclear Weapon?" https://www.popularmechanics.com/military/weapons/a33982748/what-is-trumps-new-nuclear-weapon/ (9-12-20). Also, see: "Russia's 'Doomsday Drone' Prepares for Testing." https://www.themoscowtimes.com/2020/05/26/russias-doomsday-drone-prepares-for-testing-a70386 (9-12-20). https://fas.org/blogs/security/2020/01/w76-2deployed/ (9-12-20) .
8. See "'Prepare for War', Xi Jinping Tells Military Region that Monitors South China Sea, Taiwan," https://www.scmp.com/news/china/military/article/2170452/prepare-war-xi-jinping-tells-military-region-monitors-south?utm_medium=email&utm_source=mailchimp&utm_campaign=enlz-scmp_today&utm_content=20181027&MCUID=cd44527c13&MCCampaignID=b554b112f8&MCAccountID=3775521f5f542047246d9c827&tc=1&utm_source=RC+Defense+Morning+Recon&utm_campaign=909e6566d8-EMAIL_CAMPAIGN_2018_10_27_11_35&utm_medium=email&utm_term=0_694f73a8dc-909e6566d8-83889689 (9-18-20).
9. See "China Plans to Double Nuclear Arsenal, Pentagon Says," https://www.defensenews.com/congress/2020/09/01/china-planning-to-double-nuclear-arsenal-pentagon-says/?utm_source=Sailthru&utm_medium=email&utm_campaign=EBB%2009.02.20&utm_term=Editorial%20-%20Early%20Bird%20Brief (9-12-20). A full copy of the DoD's Annual report to Congress on "Military and Security Developments Involving the People's Republic of China" can be found at: https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF (9-12-20).
10. See "China's Economy Has Rebounded After a Steep Slump - but Challenges Lie Ahead." https://www.weforum.org/agenda/2020/07/chinas-economy-rebounds-after-steep-slump-u-s-tensions-weak-consumption-raise-challenges/ (9-14-20).
11. See "What Does the China India Standoff in Ladakh Mean for Pakistan?" https://thediplomat.com/2020/06/what-does-the-china-india-standoff-in-ladakh-mean-for-pakistan/ (9-12-20).
12. See "Iran's Fifth Step." https://www.armscontrolwonk.com/archive/1208721/irans-fifth-step/ (9-18-20). For more information, see this timeline on Iran nuclear issues published by the Nuclear Threat Initiative: https://www.nti.org/learn/countries/iran/nuclear/ (9-18-20).
13. See "IAEA Inspectors Visit Iran Nuclear Site After Stand-Off as Tehran Expands Uranium Stockpile." https://s.france24.com/media/display/8c6514a8-e7a5-11ea-9183-005056a98db9/w:1280/p:16x9/2020-08-26T130857Z_1001132262_RC2PLI92RLKJ_RTRMADP_3_IRAN-NUCLEAR-IAEA.webp (9-17-20).
14. See "Experts Blame Israel for the Recent Explosions. Why Won't Iran?" https://thebulletin.org/2020/07/experts-blame-israel-for-the-recent-explosions-why-wont-iran/ (9-12-20).
15. A timeline of North Korean nuclear negotiations from 1985 through this past year can be found at https://www.cfr.org/timeline/north-korean-nuclear-negotiations (9-18-20).
16. See "Israel Signs Pacts with Two Arab States: A 'New' Mideast?" https://apnews.com/7544b322a254ebea1693e387d83d9d8b (9-18-20). Also see "What's Behind the New Israel-UAE Peace Deal?". https://www.cfr.org/in-brief/whats-behind-new-israel-uae-peace-deal (9-18-20), and "Iran Warns of 'Dangerous Future' for UAE After Historic Deal with Israel." https://www.cbsnews.com/news/iran-warns-of-dangerous-future-for-uae-after-historic-deal-with-israel/ (9-18-20).
17. See "Why TRISO Particles Could Open a New Age for Nuclear Power." https://www.zmescience.com/other/feature-post/triso-particles-nuclear-04062020/ (9-17-20).
18. See https://www.energy.gov/ne/articles/nrc-approves-first-us-small-modular-reactor-design (9-12-20).
19. See "Pakistan Warns India's Kashmir Move Could Lead to 'Nuclear War' if World Does Not Act," https://www.newsweek.com/sayed-bukhari-fears-nuclear-war-over-kashmir-1460033 (9-18-20).
20. See "IAEA Conducts Training Course on Protecting Nuclear Facilities from Cyber-Attacks." https://www.iaea.org/newscenter/news/iaea-conducts-training-course-on-protecting-nuclear-facilities-from-cyber-attacks (9-17-20).
21. See *Journal of Nuclear Materials Management*, Vol. 47, No. 3, pp. 26-29,

"Taking the Long View in a Time of Great Uncertainty: The New NNSA Strategic Vision to Modernize the U.S. Nuclear Stockpile."

22. See "U.K. Lobbies U.S. to Support Controversial New Nuclear Warheads." https://www.theguardian.com/world/2020/aug/01/uk-trident-missile-warhead-w93-us-lobby (9-14-20) .
23. See https://en.wikipedia.org/wiki/Budapest_Memorandum_on_Security_Assurances (9-12-20).
24. See "COVID-19: The Current Economic Status of Countries Around the World." https://www.weforum.org/agenda/2020/08/global-imbalances-and-the-covid-19-crisis/ (9-14-20).
25. See "How Worried Should You Be About the Federal Deficit and Debt?" https://www.brookings.edu/policy2020/votervital/how-worried-should-you-be-about-the-federal-deficit-and-debt/ (9-12-20).
26. See https://energycommerce.house.gov/sites/democrats.energycommerce.house.gov/files/documents/Bill-HR8159ih.pdf?utm_medium=email&utm_source=-FYI&dm_i=1ZJN,712J7,E2AE76,SCPO1,1 (9-18-20).
27. See "Pentagon to Get More Control Over Nuclear Weapons Funding Under Senate Proposal." https://www.defensenews.com/smr/nuclear-arsenal/2020/06/30/pentagon-to-increase-control-over-nuclear-weapons-funding-under-senate-proposal/ (9-12-20) .
28. See "Trump Administration Discussed Conducting First U.S. Nuclear Test in Decades." https://www.washingtonpost.com/national-security/trump-administration-discussed-conducting-first-us-nuclear-test-in-decades/2020/05/22/a805c904-9c5b-11ea-b60c-3be060a4f8e1_story.html (9-12-20).
29. The discussion of nuclear testing has been an issue of public discussion for decades, because of events such as the India and Pakistan tests in 1998, a series of nuclear tests performed by North Korea in recent years, and speculation that both Russia and China have been surreptitiously conducting small, undetectable tests as part of their own nuclear modernization programs. These discussions intensified following the revelation of the discussions at the White House in May. Some pertinent references for the reader include:
    - An article in *Arms Control Today* on the history of nuclear testing by Frank Von Hippel. "The Decision to End U.S. Nuclear Testing." https://sgs.princeton.edu/sites/default/files/2020-01/vonhippel-2019.pdf (9-14-20).
    - An article in the *LANL National Security Science* magazine by John Hopkins, former head of the Los Alamos Nuclear Test Division, and Weapons Test Director for the Laboratory for many years, on the difficulties associated with a resumption of nuclear testing, and why it may be necessary to test again. See "Nuclear Test Readiness. What is needed? Why?" https://www.lanl.gov/discover/publications/national-security-science/2016-december/_assets/docs/NSS-DECEMBER2016.pdf (9-14-20).
    - A letter in *Science* magazine authored by approximately 70 notable scientists requesting that the U.S. Government desist from plans to conduct nuclear tests and presenting the arguments for the ratification of the CTBT. See https://science.sciencemag.org/content/369/6501/262.2 (9-14-20).
    - An article on actions being taken in Congress to restrict the authority to resume nuclear testing. "Lead Dems Back Bill to Ban Live Nuclear Tests." https://www.defensenews.com/congress/2020/06/04/lead-dems-back-bill-to-ban-live-nuclear-tests/ (9-14-20).

Book Review

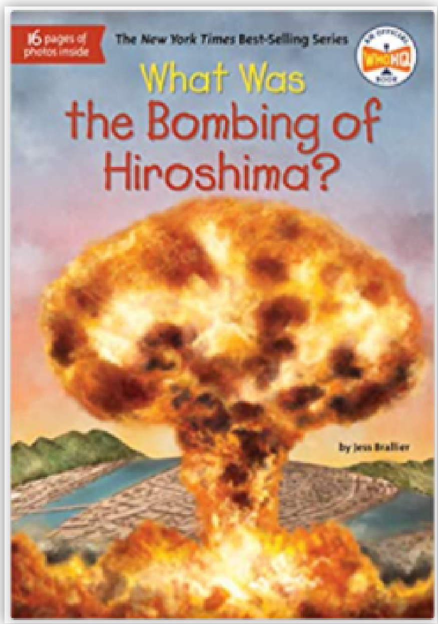
Mark L. Maiello, PhD
Book Review Editor

What Was the Bombing of Hiroshima?

By Jess Brallier

Soft cover, 122 pages, ISBN 978-1-524-792657

Penguin Workshop, New York, 2020



Nuclear Deterrence

Lawrence Freedman

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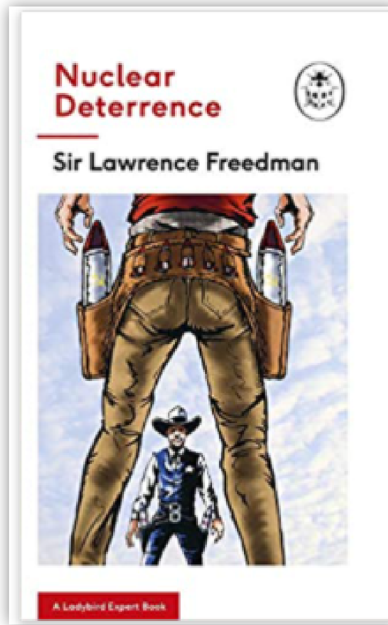
Penguin Random House, UK, 2018



It's not like authors don't try to reach lay people and young readers in particular on the subject of nuclear weapons. They do. The question is, do young and older readers care? If you ask a colleague of mine, Alex Wellerstein, Director of the Program in Science and Technology Studies at Steven's Institute of Technology in New Jersey, he'll tell you it's not the first thing on his student's minds. They know of nuclear weapons, but that concern pales in comparison to the basic desire of finding a well-paying job–something their parents paid good money to Stevens to "assure."

If you ask my peers–now in their 60s–they may heave a sigh of reluctant acceptance, maybe even expend the effort to shake their heads and with a heavy air of resignation, indicate by gesture and/or brief remarks that the current state of nuclear affairs is somewhat bleak. Treaties are going by the wayside, norms are being eroded, and the weapons are still with us. Things are a bit grim.

Much like any technological subject and the concept of beauty, interest lies in the mind or eyes of the beholder, but interest can also be created by an outside influence. One way to catalyze this reaction is through books.

Here we have two recently published books that attempt to explain to their intended audiences about the atomic bombing of Hiroshima and the concept of nuclear deterrence. Perhaps of more importance are the audiences they are intended for. *What Was the Bombing of Hiroshima?* is aimed at a very young age group–perhaps starting in the eight to 12 year-old range. *Nuclear Deterrence* finds its audience beginning with young adults. Yes, authors keep trying to bring nuclear weapons to the night stand despite the many distractions of contemporary life–especially the distractions of young people–that frustrate such attempts. I think they know that interest is largely self-generating but occasionally (perhaps frequently), it needs a spark for proper ignition.

What Was the Bombing of Hiroshima? is part of the popular series of *What Was* history picture-books begun in 2002 that now number more than 250 titles. (www.whowasbookseries.com/books/) Unlike most that feature a bobble head caricature on the cover of a selected figure from the past, this title is quite rightly adorned with a mushroom cloud roiling above the city. That's a clue to the approach here. There aren't many punches pulled. The text is forthright but it's set at the right temperature for its audience. This was war, it was terrible, and we made a horrific weapon that was used to end the war. The message seems to be that the reader should be frightened of the bomb, but not the book telling its story. The sentences are short. The tone is matter of fact and direct. There is no hyperbole. The text appears to be accurate. Boom–kids will love it.

The author, Jess Brallier, who also wrote *Who Was Albert Einstein?* for this series, specializes in educational publications for young readers. His expertise is on full display here. The value is in the context he provides. How did the bomb develop? Why did we want it? Why were Germany and Japan our enemies? Context is everything. To accomplish this, the 106 pages of text are presented in 11 chapters and a bibliography. The history spanned includes the development of Japanese culture from the samurai period to the forced opening of the country by U.S. Commodore Matthew Perry in 1853. The rise of Nazi-controlled Germany and the attack on Pearl Harbor follow in easily digestible bites. The start of the Manhattan Project is then described. And there you have it–the essential historical context grounds the reader for what follows. From here, chapters on bomb development and the bombing itself follow. The destruction, death, and injuries are described with an unwavering objectivity. Yes, it is "sanitized" to an extent, but the picture painted isn't comforting and the young reader will keep reading. Burns, radiation sickness, fires, people trying to help each other, people trying to escape–it's all there. Truman's decision to use the bomb is placed in the traditional framework: the saving of one million American lives and as many Japanese or more in Operation Downfall justified use of the bombs. A brief discussion of all the second guessing to use the bomb is also included. The picture would not be complete without mentioning the aftermath, the recovery and the subsequent peace movement spawned by the Hiroshima bombing. The poignant and sad tale of Sadako Sasaki, who attempted to make 1000 paper cranes to fulfill her wish to live brings home the personal tragedies of Hiroshima–especially those of young people. Sadako died of leukemia at age 12. Despite the sadness of this story, the book ends hopefully with the message that people care about controlling and even banning nuclear weapons.

This book is replete with black and white line drawings of important historical figures, survivors, maps of Japan, invasion routes, newspaper headlines, and other illustrations such as those of the Enola Gay. If that is not enough, young readers can refer to thirteen black and white photographs that include images of Emperor Hirohito, President Truman, Little Boy, and Hiroshima Peace Memorial Park. Throughout, text boxes bring to light important facts that supply background for the historical narrative. Sadako's story is told this way as is that of journalist and author John Hersey, scientist Marie Curie, and the nuclear accidents at Chernobyl, Three Mile Island, and Fukushima. A five-page timeline at the end of the book puts the period of World War II into perspective. This is an outstanding book that may indeed encourage interest in nuclear history, weaponry, and policy. Why not start them young?

Nuclear Deterrence was designed as a quick introduction to the subject matter for an older audience beginning with the advanced high school age group. Printed in Italy, it is a beautiful little hard cover book with color illustrations on every facing page. It too is part of a series (number 31 in the Ladybird Expert series) which is now up to 39 short volumes (www.penguin.co.uk/series/explady/the-ladybird-expert-series.1.html). Many of the illustrations are allegorical but a smattering of informative images is included to provide technical clarity. This is a monograph: there are no chapter divisions. Freedman, Emeritus Professor of War Studies at King's College London, writes eloquently and readably about the development of nuclear weapons, the threat to civilization they pose, and how mutual deterrence has developed as a preventative to their use. There is a British perspective to the book but it is not a hindrance. It is part history book and part policy text. It has to be because, again, context is everything. How deterrence became a strategy is important for understanding why and how deterrence has worked.

A brief history of the atomic bomb, its development and use opens the discussion. A very concise but understandable explanation of fission and fusion supported by one of the color technical illustrations is nicely executed. The emphasis here, besides the destructive power of nuclear weapons, is placed on the insidious effects of radiation from fallout and the downrange health effects. No cancer statistics or a deep dive into the science of the bombs is provided or is necessary. This is an introduction for the curious–a book designed for those with an itch that needs a good scratch. Remarkably, it's all done using only 250 words per page.

Freedman then ventures into a history of the Cold War–the birthplace of nuclear deterrence. As weapons numbers grew on both sides, it became apparent that if nuclear war were ever waged, there could be no winner. The balance of terror was defined: the two scorpions in a bottle are poised to kill but only at the risk of each other's life. What of first strike capability? Just like a Western showdown, everything depends on firing first and being accurate. Would nuclear powers hang their hats on that contingency or would they perhaps attempt a diplomatic solution?

From here, it is a well-constructed and informative narrative that includes the Berlin crisis, the concepts of mutually-assured destruction, U.S. "extended deterrence" to allies and the development of tactical nuclear weapons to enhance conventional forces. The story continues with the influence of popular culture on nuclear policy. The movies *Fail Safe*, *Dr. Strangelove,* and *On the Beach* put varied and frightening nuclear crises into palatable form for mass consumption and highlighted the public anxiety about the widespread destruction and socially destabilizing consequences of their use. Thus the anti-nuclear movement arose and, alongside it, the Strategic Arms Limitations Talks. Freedman concludes with mentions of the Nuclear Proliferation Treaty and the weapons programs of Israel, Iran, and China. The assistance of A.Q. Khan to the North Korean acquisition of nuclear weapons explains how the status of even small nations can be elevated by the acquisition of nuclear weapons. Unfortunately, many things that we cannot easily solve, such as the COVID-19 pandemic, do not "go away" spontaneously. Instead, nuclear weapons persisted because they continued to confer an air of importance on nations, geopolitical leverage, and a place at the world bargaining table. They even gave rise to the potential for nuclear terrorism. So here we are at two minutes to midnight, according to the Doomsday Clock, still relying on deterrence to save the peace.

It is no mean feat to have written this book–which covers a complicated technical and policy subject with order, intelligence, and clarity. Perhaps the limitation of 52 pages was an incentive. Often, given less, some authors can do more.

These two books, and indeed the series of books each is part of, are the legacy of older introductory series. The *Golden Guides* of the late 50s, 60s, and 70s (Western Publishing) and reprised in the early 2000s by St. Martin's Press and the associated Golden Field Guides, come to mind (https://us.macmillan.com/series/agoldenguidefromstmartinspress/). For many a baby boomer, these books were gateways to science, hobbies, and an appreciation of the natural world. Perhaps they may even have helped launch careers. The legacy of such outreach to primary, secondary, and high school students, as well as adults, continues. I draw your attention to the *Very Short Introduction* series aimed at adult audiences that cover varied topics in the arts, science, literature, philosophy, history, language, and the human condition (https://global.oup.com/academic/content/series/v/very-short-introductions-vsi/?cc=us&lang=en&). It now lists at least 710 titles.

For the wonder that these series, old and new, have inspired, the hours of pleasure that they have brought to their readers, and the spark of purpose that they may have kindled in some, their authors and publishers are thanked. What more could you ask of good books?

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