แบบ ICOP1

รายงานการไปราชการ ประชุม สัมมนา ศึกษา ฝึกอบรม ปฏิบัติการวิจัย ดูงาน ณ ต่างประเทศ และการปฏิบัติงานในองค์การระหว่างประเทศ

ส่วนที่๑ ข้อมูลทั่วไป

๑.๑ ชื่อ-สกุล นายสรัล สูงสว่าง

๑.๒ ตำแหน่ง วิศวกรนิวเคลียร์ปฏิบัติการ

๑.๓ สังกัด กตส.

๑.๔ ชื่อเรื่อง/หลักสูตร

(ภาษาไทย) การฝึกอบรมด้านการพิทักษ์ความปลอดภัยของวัสดุนิวเคลียร์ประจำปี ๒๕๖๑

(ภาษาอังกฤษ) IAEA Safeguards Traineeship Program 2018

เพื่อ ☐ ศึกษา ☑ ฝึกอบรม ☐ ดูงาน

☐ ประชุม / สัมมนา ☐ ปฏิบัติงานวิจัย ☐ ไปปฏิบัติงานในองค์การระหว่าง

แหล่งให้ทุน IAEA

สถานที่ (หน่วยงาน/ประเทศ) IAEA/ออสเตรีย

ระหว่างวันที่ ๕ ก.พ. ๒๕๖๑ ถึง ๓๐ พ.ย. ๒๕๖๑

รวมระยะเวลาการรับทุน ๑๐ เดือน

ส่วนที่ ๒ ข้อมูลที่ได้รับจากการศึกษา ฝึกอบรม ดูงาน ประชุม/สัมมนา ปฏิบัติการวิจัย และการไปปฏิบัติงานในองค์การระหว่างประเทศ (โปรดให้ข้อมูลในเชิงวิชาการ หากมีรายงานแยกต่างหาก)

๒.๑ วัตถุประสงค์

เพื่อนำความรู้และประสบการณ์ที่ได้จากการฝึกอบรมมาประยุกต์ใช้และพัฒนาการพิทักษ์ฯ ในประเทศไทย

๒.๒ เนื้อหา (โดยย่อ)

การฝึกอบรมประกอบด้วยรายละเอียดโดยย่อดังต่อไปนี้

๑. การปูพื้นฐานทางด้าน Nuclear Physics และการป้องกันอันตรายจากรังสี (๔ สัปดาห์)

๒. การศึกษา Nuclear Fuel Cycle จากสถานปฏิบัติการจริงในประเทศเยอรมัน (๑๐ สัปดาห์)

แบบ ICOP1

๓. การจำลอง IAEA Safeguards Inspection ณ สถานปฏิบัติการจริงที่ประเทศฮังการี (๒ สัปดาห์)

๔. วิทยานิพนธ์การประเมินขีดความสามารถทางด้านการพิทักษ์ฯ ของปส. (๑๐ สัปดาห์)

๕. การศึกษาวิจัยเกี่ยวกับ Neutron Coincidence Technique โดยมุ่งเน้นไปที่ Neutron Detector และ Shift register สำหรับประมวลผลจากเครื่องตรวจจับนิวตรอน (๑๐ สัปดาห์)

๒.๓ ประโยชน์ที่ได้รับต่อตนเอง

☐ ต่อตนเอง ได้รับความรู้ความเข้าใจเกี่ยวกับสถานปฏิบัติการทางนิวเคลียร์และระบบด้านการพิทักษ์ฯ ของ IAEA

☐ ต่อหน่วยงาน สามารถปฏิบัติงานได้อย่างมีประสิทธิภาพมากยิ่งขึ้นทั้งทางด้านการตรวจสอบด้านการพิทักษ์ฯ และการทำงานร่วมกับ IAEA

☐ อื่น ๆ(ระบุ) ....

ส่วนที่ ๓ ปัญหา / อุปสรรค

การสื่อสารทางเทคนิคเฉพาะด้านการพิทักษ์ฯ มีความละเอียดอ่อนและก่อให้เกิดความคลาดเคลื่อนได้ง่ายจึงจำเป็นต้องศึกษาเพิ่มเติมในช่วงแรก

ส่วนที่ ๔ ข้อคิดเห็นและข้อเสนอแนะ

การฝึกอบรมในลักษณะนี้ ผู้ฝึกอบรมมีโอกาสได้เข้าไปศึกษาจากสถานปฏิบัติการทางนิวเคลียร์จริง ซึ่งเป็นประสบการณ์ที่มีประโยชน์ยิ่งในการทำความเข้าใจเกี่ยวกับวัฏจักรนิวเคลียร์และจุดสำคัญด้านการพิทักษ์ฯ ในประเทศ

(ลงชื่อ) [signature]

(นายสรัล สูงสว่าง)

วันที่ ๓ ธ.ค. ๖๑

ส่วนที่ ๕ ความคิดเห็นของผู้บังคับบัญชา

เห็นชอบให้นำความรู้ไปใช้ในงานที่เกี่ยวข้อง และให้เสนอแผนจัดทำ ปม. ของปส. เพื่อดำเนินงาน ในปี 2563 ต่อไป.

แบบ ICOP1

(ลงชื่อ)...

(นางสาววิไลวรรณ ตันจ้อย)
(...)
รอง ลปส. รักษาราชการแทน

ตำแหน่ง ผกตส.

วันที่ - 6 ธ.ค. 2561

แบบ ICOP2

แผนงานการนำความรู้จากการประชุม/อบรม ไปใช้ประโยชน์

โดย นายสรัล สูงสว่าง

หน่วยงาน กตส.

ชื่อเรื่อง/หลักสูตร

(ภาษาไทย) การฝึกอบรมด้านการพิทักษ์ความปลอดภัยของวัสดุนิวเคลียร์ ประจำปี ๒๕๖๑

(ภาษาอังกฤษ) IAEA Safeguards Traineeship Program 2018

สถานที่ (หน่วยงาน/ประเทศ) IAEA/ออสเตรีย

องค์ความรู้ที่นำมาใช้

๑. ความรู้ความเข้าใจทางด้านการพิทักษ์ความปลอดภัยของวัสดุนิวเคลียร์

๒. ความรู้ทางเทคนิคด้านการตรวจจับนิวตรอน Neutron Coincidence Technique

แผนการใช้ประโยชน์

หัวข้อการนำความรู้ไปใช้	หน่วยงานที่เกี่ยวข้อง	งบประมาณที่คาดว่าจะใช้	ระยะเวลาดำเนินงาน	ผลลัพธ์/ผลสำเร็จของงาน
การตรวจสอบทางด้านการพิทักษ์ฯ	กตส.		๖ เดือน	ประสิทธิภาพการตรวจสอบเพิ่มขึ้น
ความรู้ทางด้านเทคนิคและเครื่องมือ	กตส.		๖ เดือน	สามารถใช้เครื่องมือที่มีอยู่ได้เต็มประสิทธิภาพยิ่งขึ้น

ลงชื่อ............................

(สรัล สูงสว่าง)

วันที่ ๓ ธ.ค. ๖๑

ลงชื่อ............................

(นางสาววิไลวรรณ ตันจ้อย)

รอง ลปส. รักษาราชการแทน ผกตส.

ผู้บังคับบัญชา

6 ธ.ค. 2561

Traineeship Programme 2018

Thailand SRA Capability Assessment to assure the absence of non-declared Nuclear Material and activities in the State

Trainee: Sarun Soongsawang

Advisor: Susan Pickett

Acknowledgement

1. **Thesis Advisor**

    Susan Pickett
    Safeguard Training Development Officer
    Training Development Team
    International Atomic Energy Agency

2. **Thailand Safeguards Information**

    Boonchawee Srimok
    Senior Nuclear Engineer
    Point of Contact for Safeguards Implementation in Thailand
    Office of Atoms for Peace

3. **SWOT analysis participants**

    Socheth Bith
    Nuclear Safeguards Inspector
    International Atomic Energy Agency

    Prae Neeranatrangsan
    Nuclear Safeguards Inspector
    International Atomic Energy Agency

4. **Training Coordinator**

    Kostadin Dinov
    Safeguard Training Section
    International Atomic Energy Agency

Contents

1 Thesis Statement

Thailand has recently ratified the Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards (referred as AP in this paper) on November 2017 and is now obliged to fulfill many additional requirements for the International Atomic Energy Agency (IAEA). With these additional challenging tasks, the capability of the State Regulatory Agency (SRA) plays a crucial role for the success. In this paper, Thailand SRA capability is assessed by using structured analytical technique to foresee any opportunity and/or issue that may arise along the process of implementation of the AP. In conclusion, recommendations are made to improve the SRA capability to assure the absence of non-declared nuclear material and activities in the State which will expectantly help Thailand to reach the Broader Conclusion (BC) with the agency.

Thailand has been operating a 1.2 MW_{th} research reactor since 1962, with a plan for two new reactors in the near future. It also has several radiotherapy facilities, nuclear therapy facilities, more than 2000 diagnostic radiology facilities, approximately 7000 X-ray units plus 200 Computerized Tomography scanners, and Gammy irradiation centers. Moreover, there are also LINAC[1], Cyclotron, and planned proton therapy center. All these locations and activities have potential to hold nuclear material whether in the form of nuclear fuel, waste, or shielding.

Thailand became the 58th member of IAEA in 1957 and has maintained a good relationship with the IAEA until present. In April 1961, the Thai government proclaimed the enactment of the Atomic Energy for Peace Act (AEP), B.E. 2504 resulting in the establishment of Office of Atomic Energy for Peace, OAEP (later changed to OAP in 2002). OAEP was established in 1961 as the only regulatory body dealing with safety, security and safeguard of nuclear facility and material in Thailand. From then on, OAEP and the OAP (Office of Atoms for Peace) has been, according to its statutory functions, the official agent to regulate nuclear and radiation safety as well as provide recommendations on atomic energy administration to conform with international standards for safety of operators and the public.

Thailand ratified and brought into force the Non-Proliferation Treaty (NPT) in 1972. Subsequently as required by the NPT provision regarding safeguards, it concluded a Comprehensive Safeguards Agreement (CSA) in 1974. Thailand went on and signed the Additional Protocol (AP) in September 2005; however, the AP was not brought into force until

[1] LINAC – Linear Accelerator

November 2017. This long delay was mainly due to the lengthy process to renew the AEP, B.E. 2504. OAP spent many years since 2006 pushing for the new Act and finally succeeded in February 2017. This enable Thailand to ratify for the AP and is now on its way to receive Broader Conclusion with the IAEA.

2 Structured Analytic Technique

Structured Analytic Techniques (also known as Environmental Scanning Techniques) [1]are often introduced to help an organization develop strategy. They are research tools used for perceiving the organization in relation with circumstances now and in the future. Some of these tools also provide a better understanding of internal and external influences which is very important for developing future plan and decision-making processes. A tool that has been widely used in many fields is the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis.

The SWOT analysis was created by Stanford Research Institute in the 1960s. It was designed to logically analyze data to help understanding of an organization, especially the one with corporate planning failure. From then on, it has been widely used in many organizations as a tool for assessing overall strategic and operational position of an organization. The key element of the SWOT analysis is the investigation of both internal and external environments. By investigating not only on strengths and weaknesses, but also opportunities and threats, SWOT enables the analyst to examine all factors that an organization has complete control over, has limited control, as well as has no control at all. This makes SWOT analysis a radiant technique providing 360-degree systematic examination used as a basis for strategic planning of an organization. The model for a generic organization can be seen in figure below.

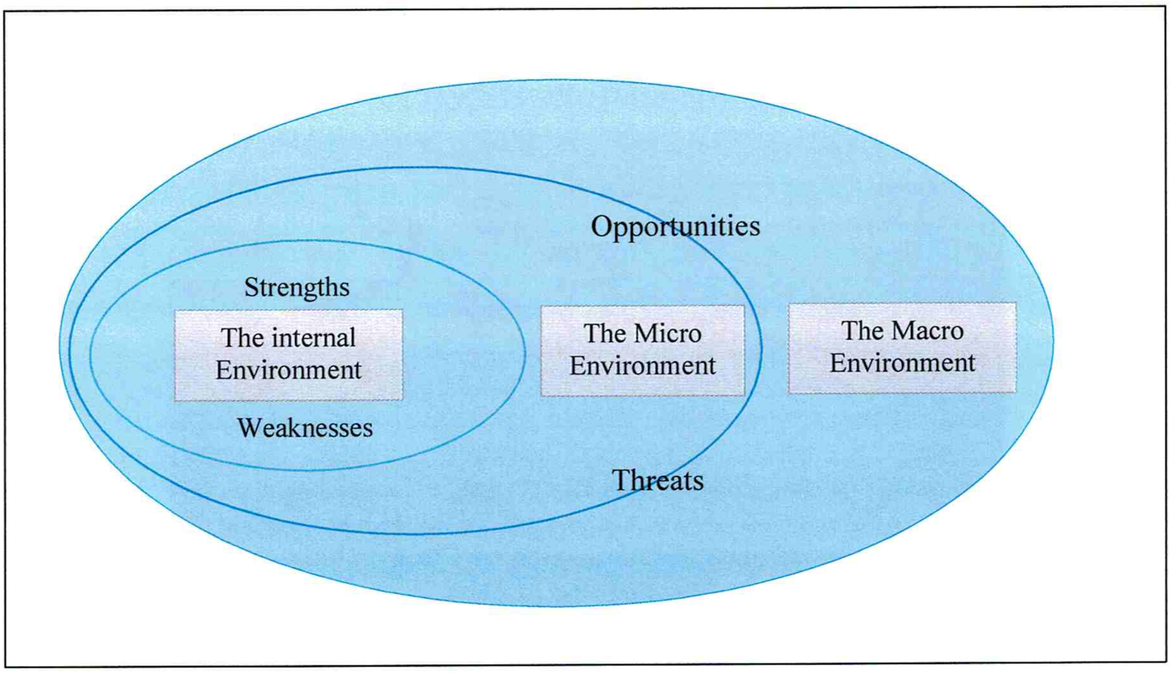

Figure 1: SWOT analysis as Environmental Sampling

There are many strengths of SWOT analysis. It is a combination of brainstorming with logical structure. It analyzes what is positive and negative about an organization and provides an insight and a comprehensive view of the problem. Finally, it produces recommendation which could translate into action plans. Nevertheless, SWOT analysis does have some weaknesses. It requires insight knowledge about the organization and due to its long-term predictive nature, there are many assumptions to be made. Moreover, SWOT analysis is susceptible risk for bias, over subjective, Groupthink in a team setting, and Mirror Imaging. Therefore, it needs to be implemented carefully to obtain useful results.

In this paper, SWOT analysis is selected to assess the capability of OAP. It was conducted in a team setting consists of the following participants: OAP staff, two IAEA inspectors; one of them used to work for a nuclear facility in Thailand, Training consultant and IAEA Safeguards training development officer. At the beginning of the brainstorming session, the objective is clearly defined to be Thailand SRA assessment in term of Safeguards. The session focused on factors influence Safeguards systems, especially AP implementation in Thailand. The presentation regarding OAP was given by Thailand SRA staff (the author). In addition to this, a table on AP implementation was included and every participant was asked to spend five to ten minutes reading it. Thereafter, all participants were asked to write each of their thoughts on a piece of paper and post-it on the corresponding quadrant shown on the figure below. During this 30-minute long session, participants could ask any questions to be clarified. Once everyone was done posting their thoughts on the board, the discussion began.

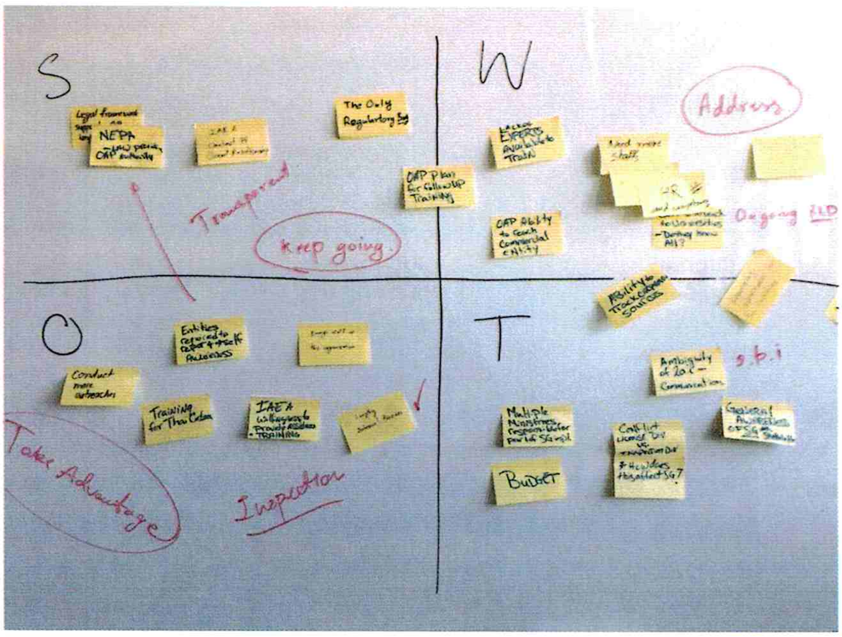

Figure 2: SWOT analysis Brainstorming session result

The idea was to group similar thoughts and to sort them out into 4 quadrants: Strength, Weakness, Opportunities, and Threats. Strength is what SRA is currently good at or doing well. Weakness is the opposite. These two quadrants are mainly internal factors which the organization normally has control over. On the other hand, Opportunities and Threats are usually considered as external factors which the organization has limited control over or no control at all. Again, many questions were asked and clarified during the discussion to reach result all participants agreed on. The detail and the result of SWOT analysis session is discussed in the following chapters.

3 Background

To gain a better understanding of Thailand SRA assessment in this paper, it is crucial to be familiar with the background of two main players in this context: IAEA and Thailand SRA: Office of Atoms for Peace (OAP). In the following section, their roles and responsibilities, the tools they have, and their goals are discussed and used as inputs for SWOT analysis in the following section.

3.1 International Atomic Energy Agency: IAEA

IAEA was inaugurated in 1957; influenced by the U.S. President Eisenhower's "Atoms for Peace" speech during the General Assembly of the United Nation in 1953. According to Article II of the IAEA Statue, IAEA has two main missions. One is to promote uses of nuclear energy for peace around the world. And another is to supervise or to control nuclear energy and its application not to be used in such a way as to further any military purpose. To achieve these missions, especially the second one, IAEA Safeguards system was created and since then has become a crucial tool for verification of States' obligations according to the NPT. In this section, the evolution of IAEA Safeguards system is described for a comprehensive understanding of the current system and the State Level Approach (SLA).

The original design of the Safeguards system is described in documents INFCIRC/26 and later developed into INFCIRC/66: The Agency's Safeguards System (1965) or the so-called Item-Specific Safeguards agreement. The core ideas of this document are to address the following points:

1) Definition of Safeguards

Most of the nuclear facilities could have dual purposes: peaceful or military purpose. To avoid any ambiguity, IAEA requires the States' to declare their intention on peaceful use of items placed under safeguards. IAEA also defines the continuation of safeguards concept which safeguards are applied to all nuclear material used, produced, or processed in the safeguarded facilities. For example, plutonium produced in the reactor would also be subjected to the safeguards.

2) How to implement Safeguards

According to the INFCIRC/66, the implementation of Safeguards must be agreed by concluding a project agreement or Safeguards Agreement (SA) between the State and IAEA. The agreement should specify both the principles and the procedures of the Safeguards implementation.

Although INFCIRC/66 was carefully written and worked fairly well at the beginning, it contains some loopholes. First, items under INFCIRC/66 are considered static and all measures focus only on one specific facility. This results in a narrow view of the State. Moreover, the absence of some definitions and explanations e.g. the lack in explanation of the wording "furthering any military purpose" (INFCIRC/66) or the absence of agreement on non-safeguard nuclear materials and activities.

This was when the first concept of major evolution happened. In 1970s, the new political initiative was introduced. It consisted of one the Nuclear Weapon Free Zones and two, the NPT. Under the NPT, all Non-Nuclear-Weapon State (NNWS) signatory to NPT commit themselves not to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices. They are required under Article III.1 of the NPT, an undertaking by the State to accept safeguards, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within its territory. Therefore, concluding the Safeguards Agreement with the IAEA. Three key states that did not sign the NPT were Israel, Pakistan, and India. Two of these states were later confirmed with nuclear weapons. The detail of the comprehensive safeguards agreement is described in INFCIRC/153 which clearly states that the State shall accept safeguards on "all nuclear material" within its territory. Moreover, INFCIRC/153 also make it clear in paragraph 7 that the "diversion of nuclear material" means the diversion to nuclear weapon or other nuclear explosive devices. This statement basically means that all facilities and location outside facilities under safeguards cannot be used to manufacture nuclear weapon. In order to manufacture one, the State would have to move material to undeclared facilities and the IAEA should be able to detect indications of such activities.

In order to meet its obligation, the IAEA details a number of procedures in part II of the INFCIRC/153. One main concept is by creating Material Balance Areas (MBAs), Key measurement Points (KMPs), conducting verification activities such as Physical Inventory Verification (PIV), as well as requiring the State to create a reporting system through establishing and maintaining the State System of Accounting and Control (SSAC), on all nuclear material[2] declared within the State. IAEA has, in accordance with paragraph 2 of INFCIRC/153 "right and obligation to ensure that safeguards will be applied, in accordance with the terms of the Agreement, on all source or special fissionable material in all peaceful nuclear activities within the territory of the State, under its jurisdiction or carried out under its

[2] All nuclear material – material listed in paragraph 34 of INFCIRC/153

control anywhere, for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices".

With this INFCIRC/153 system, the IAEA can verify the correctness of the declaration, but lacked all the tool necessary to verify the completeness. INFCIRC/153, like INFCIRC/66 was at that time, based on the facility level approach, which focus only on facilities declared by the State. This made it possible that there might be undeclared nuclear facilities, activities, or material somewhere in the State. IAEA was well aware of this issue but could not push forward a policy to solve it since many States were reluctant to cooperate [2].

Two years after the discovery of Iraq nuclear program, IAEA launched the program 93+2 in response to concern over the effectiveness of the Safeguards system. The goal was to strengthen the efficiency of the safeguards system by first, improve measures that are already include in the context of CSAs. Second was an additional legal tool which in this case is a Model Additional Protocol approved by the Board of Governor later in 1997. To bridge this gap leading toward the completeness of declaration, the Model Additional Protocol (INFCIRC/540) was issued and the state level concept was introduced [2].

In no particular order, the IAEA main objectives now at the State level are

- To detect undeclared nuclear material and activities in the State as a whole (undeclared).
- To detect undeclared production or processing of nuclear material in declared facilities and locations outside facilities (misuse).
- To detect the diversion of declared nuclear material in declared facilities and location outside facilities (diversion).

Objectives misuse and diversion are pursued through comprehensive safeguards agreement mechanisms as described in part II of INFCIRC/153 by evaluating State declarations, accounting report, and the evaluation of activities at facilities and LOFs. However, only for a State in which the provisions of the AP have been implemented does the IAEA have the tools to pursue objective undeclared. This is due to the access to additional information provided by the provisions of the AP. This information is crucial for drawing the broader conclusion that all nuclear material in the State has remained in peaceful activities (GOV/2018/19)[3].

For each facility under safeguards, a detailed safeguards approach is developed in accordance to detection established by the IAEA. The quantity component of these goals focuses on the

[3] The Safeguards Implementation Report for 2017

verification activities needed to assure that 1 significant quantity (SQ) or more of nuclear material has not been diverted over the material balance period. The timeliness component focuses on activities needed for assuring that no abrupt diversion of 1 SQ or more has taken place at the facility within the timeliness period. These goals are defined and served as guidelines for the development of safeguards approach[4] for facilities. Here is when the state level safeguards approach starts coming into play. This state approach encompasses evaluation of all nuclear material, nuclear installation, and nuclear fuel cycle related activities in the State as a whole, by additionally taking into account the acquisition path analysis, the interaction between facilities, technology development, and other State-specific features including the State System of Accounting for and Control (SSAC) of nuclear material [3].

The acquisition path analysis analyzes possible routes which the State can obtain 1 SQ of high enrich uranium or plutonium. By analyzing these paths, IAEA can identify what need to be done by the State in order to complete specific acquisition path. For example, a State with only a research reactor would need hot cell as well as reprocessing facility to complete the plutonium acquisition path. It would also need many researches related to chemical separation, etc. These paths provide the basis for determine what IAEA needs to do. It could be conducting open source research to find out about research or suspicious activities in the State, analyzing satellite images in the area of question or conducting environmental sampling on selected location. If all these measures providing information is still not sufficient for completeness verification of the State declaration, IAEA could conduct a Complementary Access (CA) type of inspection which is enable by the introduction of AP between IAEA and the State. By doing this, IAEA would have adequate information to conclude the completeness and correctness of each individual State declaration. For the State with small risk, the conclusion could also lead to reducing the frequency of routine inspection as well. In the following section of this paper, the competency of Thailand SRA is assessed using SWOT analysis technique and the result is further analyzed by applying the State-level approach in Thailand context to predict the timeline for reaching broader conclusion between IAEA and Thailand.

3.2 Thailand SRA: Office of Atoms for Peace

Prior to the SWOT analysis session, the following information about OAP as Thailand SRA and its current state in term of Safeguards was presented to all participants. As mentioned before in the first chapter, Thailand recently had AP in force on November 17th, 2017. Knowing that

---

[4] Safeguards approach is a set of safeguards measures implemented to meet applicable safeguards objectives

Thailand had ratified for AP since 2005, it surely is a surprise that the entering in force did not happen earlier. One of the most important factors for this long delay was the need for major revision of the Nuclear Energy for Peace Act (NEPA), B.E.2504, so that it could accommodate requirements on the AP. Thailand successfully instituted the new NEPA, B.E.2559 in 2016. The act has been effective since February 2017 with the following provisions related to AP.

- Provision for acquiring information on Article 2.a.(i)
- Provision for Complementary Access
- Provision for enforcement actions
- Delegate the authorities to Secretary General of OAP for certain aspects

There is also another provision for acquiring information on Article 2.a.(ix) by the Draft Act on Trade Control on Weapons of Mass Destruction (TCWMD) related Items which will be effective in early 2019, which will include:

- Provision on Definition of items and technologies related to Weapon of Mass Destruction proliferation, Dual Used Items, as well as controlled activities.
- Provision for regulating the controlled items and activities

The detail of the new NEPA addressing each article in the AP is presented in the following table.

Table 1: The new NEPA section addressing Articles in Model AP INFCIRC/540

Model 540 Article	NEPA Section	Model 540 Article	NEPA Section	Model 540 Article	NEPA Section
2.a.(i)	Sec.89	2.a.(x)	Sec.36 Sec.89	10	Regulations
2.a.(ii)	Sec.36 Sec.38/Para 3	2.b	Sec.80	12	OAP and MOFA collaboration
2.a.(iii)	Sec.6	2.c	Various sections	11	Subject to IAEA and OAP conclusion
2.a.(iv)	Sec.90	4	Sec.107 (1)	13	
2.a.(v)	Sec.36 Sec.51	5	Sec.113	14	Secure Channel and SPD
2.a.(vi)	Sec.36 Sec.88	6	Sec.113	15	Sec.142
2.a.(vii)	Sec.36 Sec.88	7	Subject to IAEA and OAP conclusion	16	Sec.89 Draft TCWMD Act
2.a.(viii)	Sec.36 Sec.51	8		17	Subject to Gov. approval
2.a.(ix)	Draft TCWMD Act	9	Sec.113	18	Regulations

Shortly after the new NEPA became effective in 2017, OAP with assistance from Ministry of Foreign Affair (MOFA) arranged for the AP ratification as well as the first declaration. Information regarding each article were collected. Collaborative IAEA workshops were held with OAP. Many outreach campaigns were conducted. The summary of all activities done for the first declaration can be found on the table below.

Table 2: Current progress and activities by Articles in Model AP INFCIRC/540

Article	Interval	Type of information	Source of information	Detail
2.a.i	1Y	• Fuel cycle related paper/journal • Grants • Annual budget	• Universities • Research Institutes • Ministry of Science and technology • Ministry of Education • Published work • Open sources	• Outreach activities to relevant universities e.g. Chulalongkorn University, Kasetsart University. • Direct contact with afore mentioned Universities • Open source search on papers/journals related to nuclear fuel cycle or annex I of INFCIRC/540 • Requesting for information from Office of the Higher Education Commission? • Annual meeting with all related organizations/stakeholders for updates
2.a.ii	1Y	Per requested by the Agency	• Licensing database • Licensees	
2.a.iii	1Y	• Coordinate • Map • Blue print • Description of building/floor	• Licensing database • Licensees	• Outreach activities to facilities, hospital, private company that have registered their nuclear materials. • Direct contact with relevant parties • Annual meeting with all related organizations/stakeholders for updates
2.a.iv	1Y	Nothing to declare	• Department of Industrial Work	• Annual meeting with all related organizations/stakeholder for updates

Article	Interval	Type of information	Source of information	Detail
2.a.v	1Y	• Analysis report • Production report	• Department of Primary Industries and Mines (DPIM)	• Outreach activities to private mining company and DPIM • Direct contact with relevant parties • Annual meeting with all related organizations/stakeholders for updates
2.a.vi	1Y	• Analysis report • Production report	• Licensing database • Licensees	• The quantity is well below the threshold; however, OAP decided to report it under 2.a.vi(a) as a reference
2.a.vii	1Y	• List of location exempted from safeguard pursuant	• Licenses database • Safeguard database	• Major update has been done on the database prior to the initial declaration • Periodic update from Licensing and safeguard database
2.a.viii	1Y	• Records of relocation • Official documents regarding further processing	• Licenses database • Safeguard database	• Periodic update from Licensing and safeguard database
2.a.ix	3M	• Records of import export according to requested HS code	• Thai Customs	• Currently there is no regulation to support this requirement • Information from Thai Customs are useful but cannot be used to verify if the items are dual use or not

Article	Interval	Type of information	Source of information	Detail
		• Currently there is nothing to declare		• New Export Regulation from Department of Foreign Trade is under review of the parliament
2.a.x	1Y	• National Energy Plan	• Licenses database • Academic journal • EGAT[5]	• Thailand Power Development Plan 2015 (PDP2015) expected 1000 MW NPP by 2035 and another 1000 MW by 2036 • Currently undertaking feasibility study for new RR project • 40 kW RR for Education purposes. Licensee is preparing to apply for construction license • All of this information is either open source since it is included in the national plan or submitted directly by the licensee
2.b.i	1Y	• Currently has no information regarding this topic	• Licenses database	• Outreach activities to all private organizations/companies with capability and related to the field
2.b.ii	1Y	• Currently has no information regarding this topic	•	•

[5] EGAT – Electricity Generating Authority of Thailand

Participants were also provided with more detail of OAP as the only regulatory organization in Thailand for nuclear application. The organization is under Ministry of Science and Technology and serves as a secretariat of the Nuclear Energy for Peace Commission (NEC). Its main role is to make recommendation on regulatory decisions for the Thai NEC regarding nuclear facility, waste facility and spent nuclear fuel. It is also responsible for developing draft regulations and guidelines for anything related to nuclear and radiation application. There are approximately three hundred staff members working in four main divisions and two administrative groups shown below.

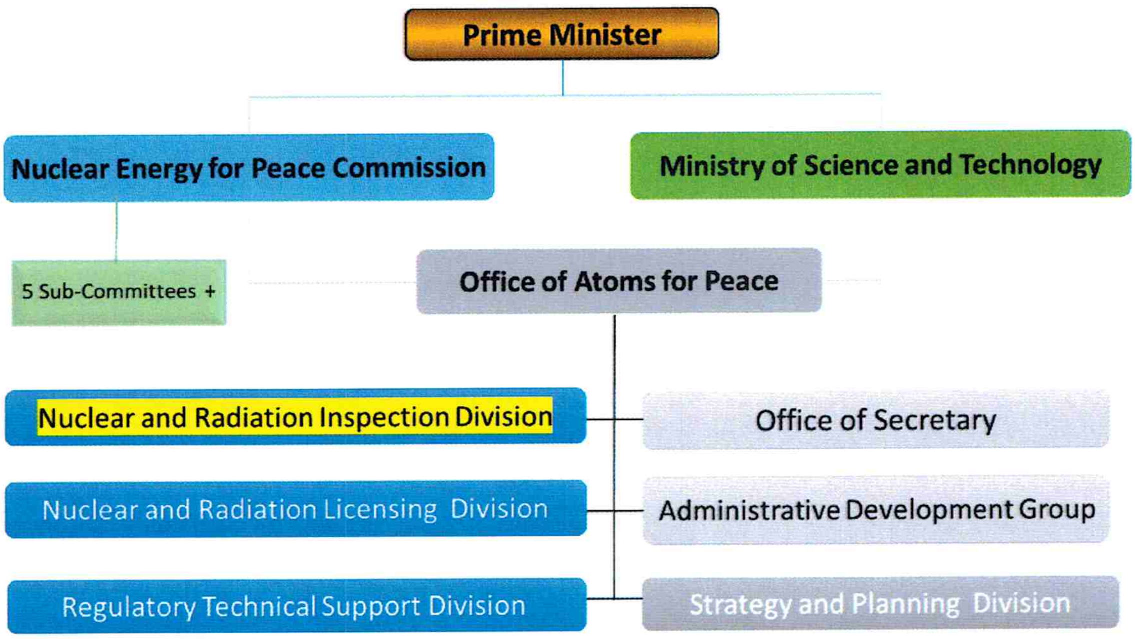

Figure 3: Chart of OAP's Structure

Safeguards responsibility of the office belongs to the Nuclear and Radiation Inspection Division highlighted in the figure above. It consists of four inspection and one Emergency Preparation and Response Section. Those inspection groups are divided by region with Region 1 taking the Northern and Northeastern part of Thailand plus responsibilities in Security and Safeguards as well. The total number of staff in group 1 consists of seven technical and two administrative staff. Among these staff, only three of them have direct responsibilities to Safeguards and one of them had recently transferred out to the other department.

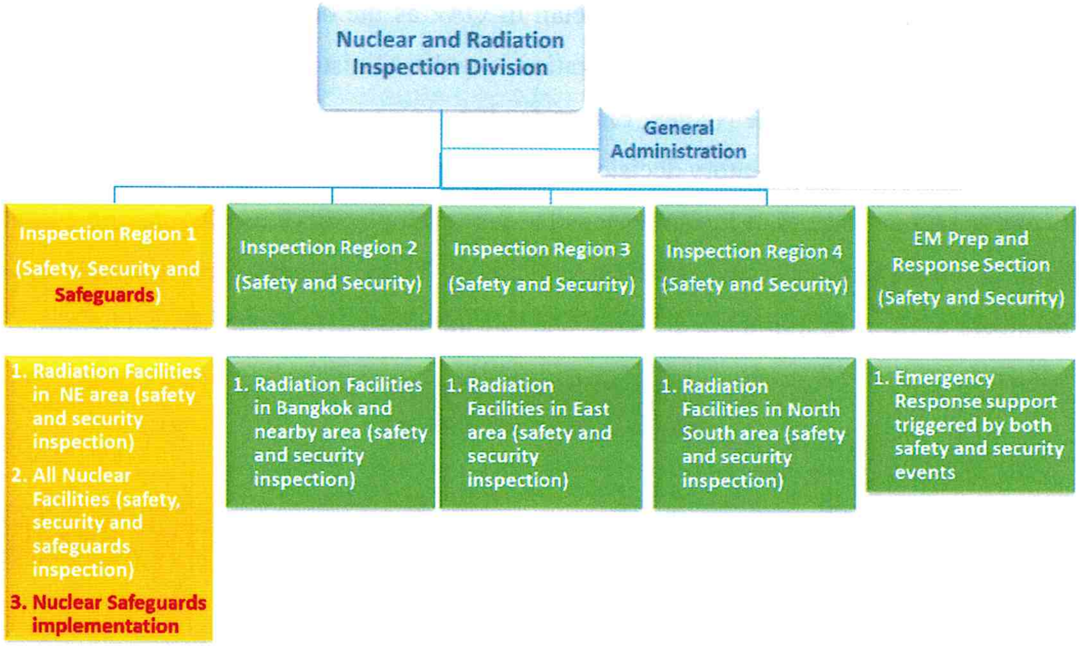

Figure 4: Nuclear and Radiation Inspection Division Structure

4 Assessment of the current Thailand SRA: Office of Atoms for Peace (OAP)

Figure 5: SWOT analysis result

From the SWOT analysis brainstorming session, although there are some strength and many opportunities presented, many weaknesses and threats are there as well. Keep in mind that these results focused on the capability of OAP to fulfill its obligation to the IAEA regarding non-declared nuclear material and activities in Thailand. These SWOT analysis results served as a basis for identifying the gap in OAP's capability especially when assessing it from what activities the IAEA might conduct in the next three to five years.

5 IAEA Activities in Thailand

In order to better outline a strategy for OAP moving forward, it is necessary to think about what the IAEA will do to meet its obligation so that OAP can prepare for what to come.

In summary, there is only one 1.2 MW research reactor in Thailand with a possibility for another two research reactors in the future. Nuclear Power Plant program is mentioned on the National Energy Plan but has not yet received an approval from the government. There is no other facility related to the Nuclear Fuel Cycle (NFC), not even the uranium mined as byproducts. Under this context, two general acquisition path analysis can be considered.

For high enriched uranium (HEU) acquisition path, Thailand would need to build an enrichment facility, secure at least 5,000 kg/year of uranium in the form ready to be enriched such as UF_6 and develop advanced knowledge and skills in this field to finally obtain 25 kg[6] of Highly Enriched Uranium (HEU > 90 percent ^{235}U) or 1 significant quantity (SQ) of Uranium. Although there are some research and development related to this acquisition path such as uranium extraction from sea water, they are all in their early stages and all of them have been reported in 2.a.(i) already. Moreover, the time required, for a country with no enrichment facility such as Thailand to complete this path, would be at least five years. For plutonium acquisition path, Thailand probably need to acquire a bigger reactor (25 MW_{th} or more) since the current one would not have enough fuel or even room for targets to acquire 1 SQ of plutonium. Thailand would also need to acquire more than 8000 kg of undeclared natural uranium feed as well as reprocessing facility capable of retrieving 8 kg of plutonium from the targets [4].

In conclusion, Thailand at its current state has very limited capability of acquiring 1 SQ of Uranium or Plutonium. However, IAEA, under its mandate, should keep monitoring for any indication of undeclared activities that would change the current scenario and enable Thailand to acquire 1 SQ of uranium or plutonium. With the current nuclear fuel cycle situation in Thailand that has both CSA and AP in force, safeguards measures applied by the IAEA could be the following measures:

[6] Number taken from Internal training document: Nuclear Proliferation Rules of Thumb

Table 3: IAEA Safeguard measures

IAEA's Safeguards measures based on CSA	IAEA's Safeguards measures based on AP
o Inspection ▪ Physical Inventory Verification (PIV) ▪ Design Information Verification (DIV) ▪ Non-Destructive Assay ▪ Containments and Surveillances o Environmental Sampling (ES) o Open Sources and Satellite Imagery Analysis o Special Inspection	o Complementary Access o Environmental Sampling

For Thailand, the IAEA would continue its annual inspection while applying some additional safeguards measures now applicable due to the Model Additional Protocol. The following IAEA safeguards measures were predicted to be implemented in the next three to five years, based on current information provided to the IAEA on the first declaration of Model Additional Protocol, to monitor previously discussed acquisition paths.

1. Annual Inspection, conducting PIV and DIV to assure the continuation of information that research reactor is not misused for any undeclared activities
2. Open Sources investigation to cover the research and development in Thailand, especially the one related to undeclared activities. Moreover, IAEA will be looking for any movement of controlled items including technology transfer of these items.
3. Based on information from inspection open sources, and other sources, some CAs will be Conducted for facilities, LOFs, or any location specified by IAEA to assure the consistency between the declaration and information from other sources gathered by the IAEA. For Thailand, the CAs could be at the following places.
   A. Research reactor and its surrounded building declared under 2.a.(iii) especially the isotope production building operated by OAP.
   B. The universities conducting NFC related researches especially the one not declared under 2.a.(i).
   C. The second research facilities with no nuclear material to ensure there is no undeclared activity going on.

D. CA at a potential mining facility to confirm there is no by product or any activity related to uranium mining or byproduct.

4. Monitor import and export especially between ASEAN[7] countries with Free Trade Area. Letter for clarification and conducting CA if needed.

If there is still no indicator after applying all these SG measures, Thailand could be move towards the Broader Conclusion with the IAEA. The mockup timeline of roadmap toward broader conclusion is shown in the following figure.

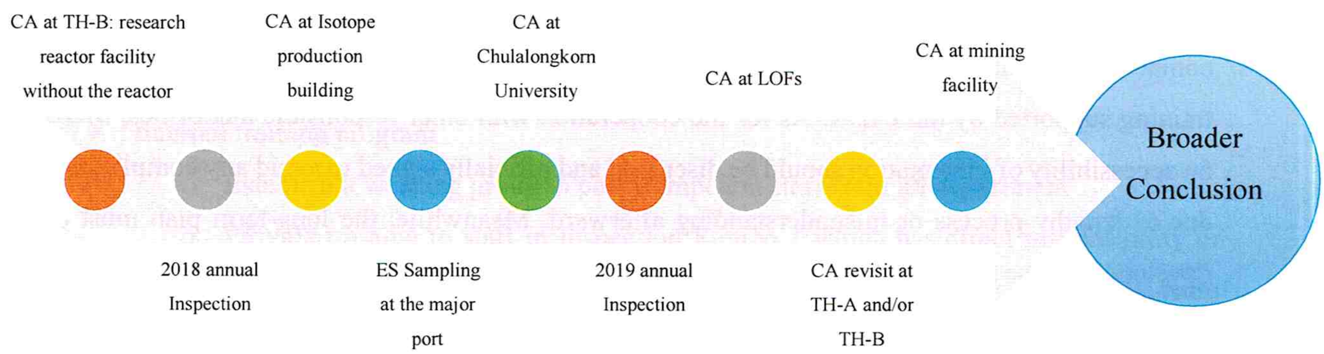

Figure 6: Mockup timeline for the Broader Conclusion between Thailand and the IAEA

According to the mockup timeline, OAP is the key player that has the prime responsibility to facilitate IAEA requests. Therefore, OAP will need to be ready in many aspects. The next section would combine SWOT analysis results with predicted IAEA's activities and timeline to indicate OAP's capabilities gap and develop recommended action plan for OAP.

[7] Association of Southeast Asian Nations

8 Appendix

State's responsibilities	Capability gaps	Action Plan
Based on SWOT analysis result, the concerns regarding the quality of the reports under CSA and AP are mainly due to the lack of Safeguards awareness from stakeholders and lack of coordination between government authorities. OAP, as Thailand SRA, could address these issues by clearly stating reporting responsibility in the Act and regulations. Continue with Outreach activities for universities and other research and development entities and establish information channels between responsible authorities. These measures should gradually create safeguard awareness among the stakeholders which would eventually enhance the correctness and completeness of the report/declaration.	According to this analysis result, the main gap for OAP is the limited number of staff responsible for Safeguards in OAP. Since it requires more trained staff who have adequate understanding of the safeguards system to be more pro-active in outreach activities. For information from other responsible authorities, it is currently obtained by requesting through official letter one at a time. This is not an effective way to obtain information since there might be some delay issue.	To fulfill this gap, OAP top level management must be committed to make changes. By moving toward concluding agreements with all relevant entities regarding the flow of information, the following action plan should be implemented. • Establish working group of competent staff by pooling human resources from all department in OAP. This should temporary solve the lack of staff issue for accomplishing more outreach activities. • Carefully plan and integrate outreach activities to other routine activities such as safety and security inspection for cost effective purpose while waiting for solid plan to be put in place and secure sustainable budget. • Utilize the established working group in cooperate with the legal team to start looking into opportunities for establishing Memorandum of Understanding (MOU) with all relevant parties. • Organize all information using technology to enhance tracking capability for orphan sources.

For OAP to accommodate and facilitate obligation towards the IAEA, the weakness and threat regarding the lengthy process and insufficient budget shall be addressed. OAP should take this opportunity to scrap out unnecessary processes and emerge with a new and effective internal system.	Currently, there is no solid plan for safeguards activities in the next 3-5 years. Hence the uncertainty of budget for long-term activities. As for the internal system, the process for any official letter can take a long time while some requests from the IAEA, such as CA, must be facilitated within 24 to 48 hours. There is a specific solution for CA, but the overall system is still ineffective.	To fully achieve this goal, OAP need to have a solid plan for the next 3-5 years. The plan should have a clear objective and the following items must be prepared • Detail of outreach activities including number of staff needed as well as budget for cost effective implementation. • Prepare the proposal to shorten the internal processes. This can be done by creating templates for specific scenarios such as annual inspection and CA. Then start applying this approach to more scenario until it covers all internal processes.
Since there are many Ministries responsible for DUIs, obtaining this information require integrated procedure with other Ministries and other responsible authorities. To avoid any miscommunication or delay, an agreement between all responsible entities shall be established. Then, follow by setting up specific channel for sending and retrieving information as well as develop and record all relevant procedures.	The new legislation on DUIs item from MOFA is postponed for couple more months. Although OAP is working on creating an agreement for obtaining information, nothing is official until the MOU is signed and integrated procedure is established.	The solution to this gap is already mentioned earlier as part of information acquiring process. However, beside securing budget and signing MUO, there are some other preparations need to be done by the OAP • Secure channels must be established since some of this information could be confidential or private. • Information flow and format should be discussed among relevant parties and agrees on for consistency of the information. • Procurement of hardware and software related to information transfer.

		• Conduct cooperate training and workshop among parties to exchange knowledge and experience.
Staff competency is a common weakness in many areas from the result of SWOT analysis and need to be addressed for sustainability of the whole safeguards system in Thailand. OAP must utilize its current trained staff to train others while trying to obtain or request additional training from International community such as the IAEA.	There are only limited number of staff under the safeguards group in OAP. Moreover, only two of them are adequately trained and has direct responsibilities for safeguards. The rest are either looking after safety of nuclear and radioactive facilities or security. Hiring new governmental offices also has many limitations and is not practical. Outsourcing or hiring civil worker has no sustainability especially all newcomer would need a series of training to understand safeguards system.	This generic gap for an organization can be filled by the following actions: • Start training the rest of qualified staff in Inspection Region 1 • Establish working group for safeguards purpose by pooling resources from all divisions and departments. • Develop quality assurance for all safeguard's procedures and rules as part of the knowledge management system. This can be done applying ISO-9001 on Inspection Division. • Request support from the IAEA, e.g. workshop, on-the-job training, expert mission, etc.

9 References

[1] IAEA, "Information Analysis Environmental Scanning," in *Master IAEA Analysis Course Book.*

[2] V. Bytchkov, "IAEA Safeguards System: Conceptual Evolution," 2013.

[3] IAEA Department of Safeguards, Section of Safeguards Training, Fuel Fabrication: IAEA Manual on the Nuclear Fuel Cycle, Vienna, 2011.

[4] T. Alice, "Pu-breeding feasibility in irradiation channels of research reactors," *Nuclear Engineering and Design vol. 241,* pp. 476-483, 2011.

[5] "https://cnpp.iaea.org/countryprofiles/Thailand/Thailand.htm," 24 October 2018. [Online].

[6] "http://oap.go.th/en/about-us/about-us," 9 September 2018. [Online].

[7] "https://www.iaea.org/about/governance/list-of-member-states," 8 November 2018. [Online].

[8] "https://www.tint.or.th/index.php/th/2013-07-30-15-08-10?id=801," 9 September 2018. [Online].

[9] "https://www.iaea.org/topics/non-proliferation-treaty," 24 October 2018. [Online].

[10] IAEA, Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corrected), Vienna, 1997.

[11] IAEA, The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), Vienna, 1972.

[12] IAEA, "INFCIRC/241," 19 November 1976. [Online].

[13] IAEA, "INFCIRC/241/Add.1," 22 November 2017. [Online].

Traineeship Programme 2018

Uses of Neutron Coincidence Technique in Safeguards

Comparison of JSR-12 and JSR-15

Trainee: Sarun Soongsawang

Advisor: Peter Santi

Contents

I. Rationale

It is essential that all nuclear materials are accounted in any state under Nuclear Proliferation Treaty to assure the diversion of nuclear material is not taking place. There are many techniques used by International Atomic Energy Agency (IAEA) to quantify nuclear material including Non-Destructive Assay (NDA). Most of the NDA techniques utilize the fact that all nuclear material in the fuel cycle emit neutrons and specific gamma rays and process the detected signals to obtain the information of nuclear materials. These NDA techniques allow the agency inspector to measure and verify nuclear materials at the site accurately without altering the materials. Among these techniques, neutron detection has been widely used in the field of Safeguards due to its ability to measure mass of the nuclear material items when the isotopic compositions of the items are known. It is done by measuring the rate of coincidence or time correlated neutrons that are emitted from the sample. Then map these measurements onto the calibrated curves to obtain the mass of nuclear materials in the samples. However, this technique requires a remarkably precise method of counting neutrons. Hence, all devices related to neutron coincidence counting must be thoroughly calibrated and tested before they are used in the field.

The primary objective for this practical task is to ensure that measurements from two shift registers, JSR-12 and JSR-15, show no significant difference by comparing results from both of them. These shift registers process signal from neutron detectors to quantify the mass of nuclear materials and it is important to ensure that they are working properly and consistently. In this experiment, two types of neutron detectors and two model of shift registers will be studied and tested using signals both from a Neutron Pulse Simulator (NPS) and from actual nuclear materials. The results will be compared, and the differences will be analyzed.

Since nuclear material verifications rely heavily on this technique as well as other NDA techniques, an inspector conducting measurement must be aware of equipment as well as their limitation and condition. All equipment shall be checked and calibrated thoroughly before deploying to the fields. Moreover, inspectors on the field need to know their equipment inside out, which perfectly fit the objective of the practical exercise in this report.

II. Neutron Coincidence technique

As mention in the previous section, mass measurements of nuclear material can be achieved by counting the number of real coincidence neutrons emitting from nuclear fission reaction since fission rate is directly proportion to the nuclear material mass in the sample. These real coincident neutrons are neutrons created at the same time by the result of nuclear fission reaction and later detected by the detectors almost at the same time. However, what is detected could also be accidental coincidence neutrons happen by the combination of neutrons origin such as alpha-n reaction, background, and the fission reaction. Therefore, we need to distinguish between the real coincidence neutrons from nuclear fission reactions and accidental coincidence neutrons from other origin. We can achieve this by understanding the unique characteristic of neutron radiation.

Neutron radiation

All nuclear materials under safeguards emit neutrons as well as gamma rays. For most cases, gammy rays have higher emission rate unless it is shielded or contained in the thick wall. Isotopes emit gamma-rays at specific energies. By measuring the full energy of the gamma-ray one can associate the measured gamma-ray to a specific isotope that omitted it. For small sample with known geometry, signal from gamma rays can also be used to obtain quantitative information of the sample such as mass. However, most samples are too dense and experience the phenomena called self-shielding which would inhibit this technique to obtain accurate quantitative measurement.

Neutrons detection technique on the other hand does not retain information on the isotope that produce it. However, this technique does not have problem with self-shielding phenomena since neutrons can easily penetrate through dense materials. This is because neutron is neutral and has no interaction with the electrons in an atom. Moreover, neutrons scatter with heavy nuclei very elastically without losing energy due to the difference in masses. Hence, heavy materials can hardly slow down neutrons let alone absorb them due to small interaction probability at higher energy level. So, one can say that neutrons assay blindly counts the number of emitted neutrons without knowing its origin, whether they are from nuclear fission or other reactions. Yet, there is a distinct characteristic of neutrons emitted from nuclear fission.

For nuclear materials, neutrons are mainly produced by either spontaneous fission, induced fission, or alpha-n reaction. Each type of production will yield differently in emission rate, number of neutrons produced per reaction, distinctive time, etc. Some of these characteristics are the cores of neutron coincident technique used to obtain mass information of the samples measured if the samples' composition is known.

Spontaneous fission rate depends strongly on the number of protons and neutrons within the nucleus. The even-even isotopes such as Pu-238 and Pu-240 are typically thousands of times higher than even-odd isotope such as U-235 and Pu-239. On contrary, fission of even-odd isotopes can be easily induced when bombarded with low-energy neutrons. Based on these spontaneous fission and induced fission yield rate properties of nuclear materials, two type of counting detectors are developed: the passive and active counting detectors. The active counting requires an interrogation source to induce the nuclear fission in Uranium items while the passive counting is for Plutonium items. Although there are two types of nuclear fission, there are some common properties between them: the number of neutrons emitted per fission which is likely to be 2 neutrons or more. From the figure below, we can see that the probability of number of neutrons emitted to be more than 1 is around 0.8 or 80 percent. This characteristic is the unique signature of nuclear fission when comparing to neutrons produced from other reaction such as the alpha-n reaction which only emits 1 neutron per reaction. This property of fission neutrons enables the quantification of nuclear material masses.

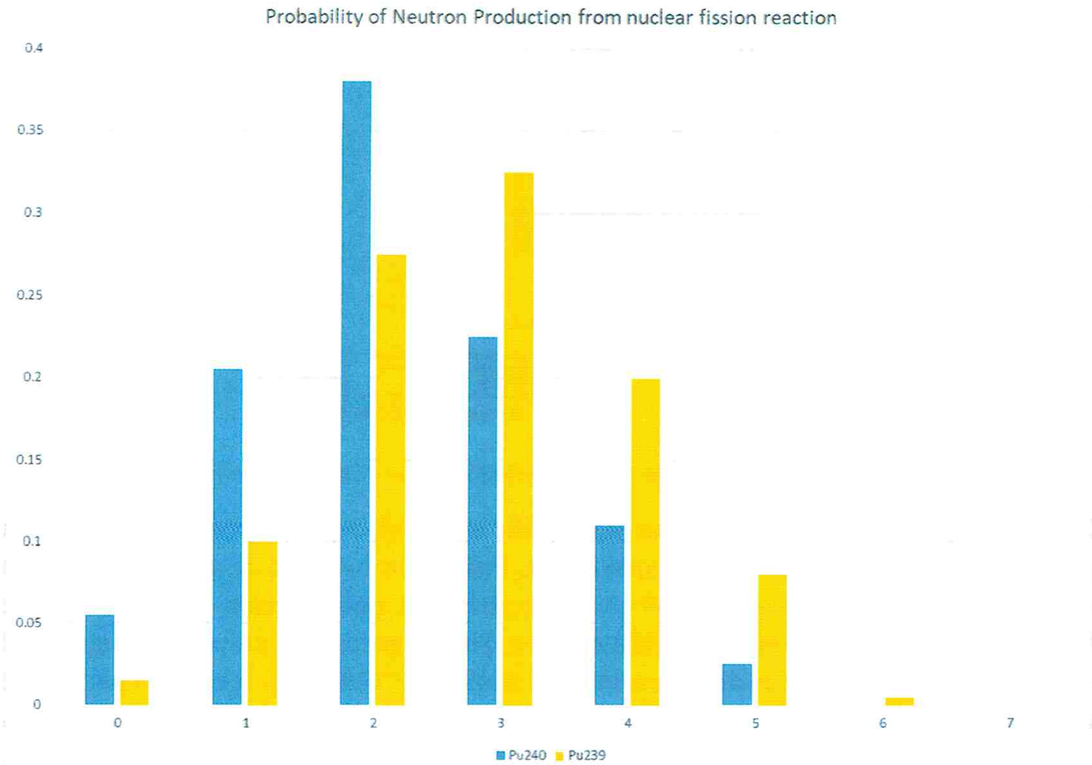

Figure 1: Probability of Neutron Production in nuclear materials

Neutrons Coincident Counting

Neutron Coincident Counting technique utilizes the distinct characteristic of neutrons multiplicity distribution[1] for nuclear fission that in average more than two neutrons will be produced at the same time (Doubles – also counted as 2 Singles). While neutrons produced by other means most of the time will produce only 1 neutron (Single). This counting technique's goal is to differentiate between the Single and the real Doubles which can be accomplished by the shift register.

Neutron detector and Shift register

The detectors used by the agency are ^{3}He based counters requiring moderation of neutrons due to the neutron absorption cross-section property of ^{3}He being too low for fast neutrons. The items are placed in the well surrounded by moderator and counter tubes as we can see in figure 2. Nuclear fission reaction produces multiples neutrons at the same time. These neutrons will take different random path through the moderator located inside the detector

[1] Multiplicity Distribution is the distribution of the number of neutrons emitted in nuclear fission reaction

and finally detected at different times. A coincident event is defined as the detection of two neutrons within specified time interval. These coincident events could be results from neutrons produced by fission reactions (real coincidences) or from two random neutrons produced by different means (accidental coincidences). For each neutron detected in the counter tubes, the detector will generate a pulse signal. All pulse signal will be streamed into the Pulse processing Electronics called the shift register.

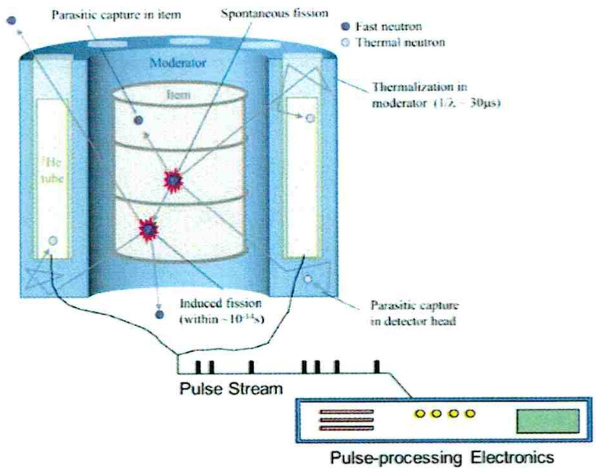

Figure 2: Schematic Diagram of a Neutron Coincidence Counting System

The shift register is the device used to process the electronic signals from neutron detector and logically decides if it is coincidental or not. Furthermore, it also be able to distinguish between the real and the accidental counting rate. The pulse stream generated by the detector will be passed through the shift register. Shift register then process the signal and statistically counts real coincident events and accidental coincident events. This can be done by applying the concept of die-away time and Rossi-Alpha distribution. Die-away time is the average lifetime of neutrons in the detectors before they either get detected, absorbed, or escape from the detector. A real coincident event can only happen within 4 die-away times; while accidental coincidences are totally random. Rossi-Alpha distribution, shown in the figure below, is a histogram of all detection times between all neutron. From the figure, the region on the left denoted with R and A is when neutrons are detected coincidentally within specified time interval. This could be from either Real or Accidental coincidences. The area on the right of the figure denoted with A is when neutrons are detected with time differences more than Long delay (which is 1024 μs for this experiment). Hence, these detections are not the results of nuclear fissions, but purely the contribution of accidental coincidences. By choosing an appropriate limit of detection time G (Gate width), the shift register can count number of coincidences in R+A and A regions, then calculate the real coincidences as an output based on the difference between what was counted in the R+A region and what was counted in the A region.

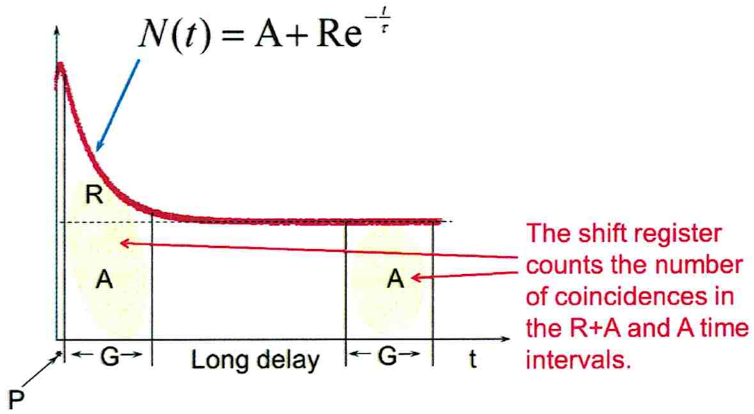

Figure 3: Rossi-Alpha distribution

The reason the shift register works is because neutrons created from the same fission event will be detected by the counter close together in time. The early gate (noted as R+A) detect both real coincidences and accidental coincidences whereas the delayed gate can only detect accidental coincidences since the neutron that triggered the gate could not have been created from the same event as those detected in the far gate. The real coincidences are shown on the shift register as Doubles and the total neutrons detected shown as Singles. This double count is what we are looking for since it is directly proportion to the mass of nuclear material in the sample. Miscounting the double would also means wrong measurement of mass as well. Therefore, the shift-register must be extensively tested to ensure it is counting correctly before we can hand it over to inspectors.

III. Comparison between shift register

For many years, IAEA inspectors has been using the shift register model JSR-12. It is accurate, sturdy, and very reliable. Still, JSR-12 has been around for approximately 20 years. As technology advances, older electronics must be replaced with up-to-date technology so that it is sustainable. JSR-15 is the new model that has been digitized and equipped with some new features such as the ability to count triple coincidence events. However, there has been some observed cases of mismatched results between the two models when used with a Neutron Pulse Simulator (NPS) for training purposes. To ascertain whether the two shift registers produce the same counting rates, a series of measurements were undertaken to determine if using the new shift register produced the same results as the older model.

Step 1: Measurements using signal from NPS

Since we have limited access to the actual nuclear material, we started the experiment utilizing the equipment called Neutrons Pulse Simulator (NPS). What NPS does is statistically generate pulse stream signal from pre-recorded data and feed it into the shift register. There are many pre-recorded pulse streams to choose; ranging from Pure Plutonium sample to Uranium oxide with variation of masses. The main goals for this part of the experiment was first to observe differences in Doubles counting between two shift registers. Second was to be familiar with equipment and to establish measurement procedures for the following steps. For each comparison, we controlled the following parameters to make sure that the only influence for Doubles counting rate was from the shift register.

- Isotopic composition and mass of the sample
- Measurement time – the same for each sample
- All measuring parameter of the shift register
- Background level of neutrons
- All parameter on the software (INCC)

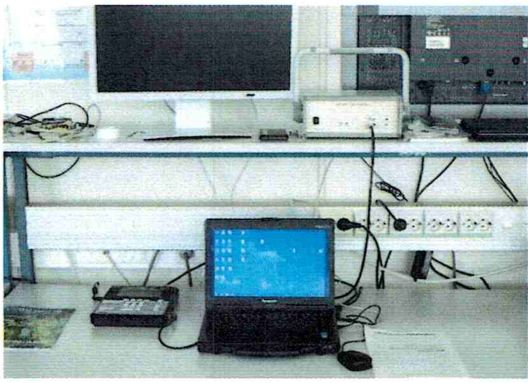

Figure 4: Setup for NPS

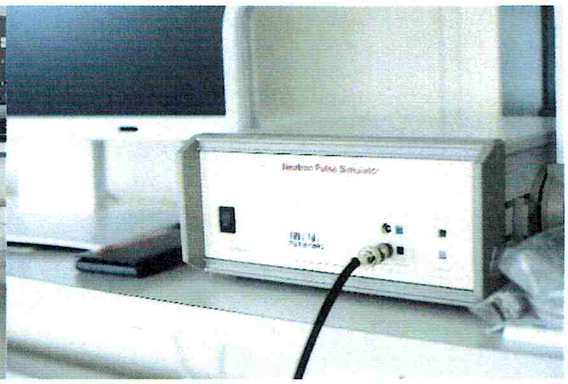

Figure 5: NPS

The figure above shows the NPS is connected to the shift register as a signal input. It is also connected to the computer running the NPS interface software. The shift register is then connected to the computer running INCC software uses for outputting results. The results from the first set of pulse streams are shown on the first table. The stream signals consist of pure plutonium material with variation in mass. The second table is the result from various stream signals of impure plutonium sample. Finally, we could observe the pattern of difference between double counting from two shift-register.

Table 1: Results for Plutonium signals

List of samples		Run time	Pu mass	Single JSR-12	Single JSR-15	Double JSR-12	Double JSR-15	Diff (%)	σ (%)
Pure Pu Oxide	HPUOX0050	20	50.004	2365.977	2367.476	187.722	196.205	4.519	0.860
	HPUOX0150	20	150.110	7166.294	7127.811	573.228	601.946	5.010	0.786
	HPUOX0300	20	299.997	14301.391	14305.503	1200.829	1265.334	5.372	0.737
	HPUOX0600	20	600.003	28863.731	28872.684	2586.193	2731.669	5.625	0.616
	HPUOX0900	20	900.000	43691.856	43706.758	4228.948	4445.086	5.111	0.576
Impure Pu Oxide	HIMOX0059	50	59.797	5976.455	5973.407	91.907	96.341	4.824	2.287
	HIMOX0149	20	149.096	5116.643	5155.888	324.551	338.080	4.169	0.964
	HIMOX0298	20	298.420	10340.510	10323.116	681.924	707.449	3.743	0.835
	HIMOX0613	20	613.304	22134.800	22128.113	1620.790	1695.931	4.636	0.713
	HIMOX0857	20	857.896	44647.824	44647.140	3853.912	4071.140	5.637	0.669

At the first glance, we could clearly see that both shift registers detected almost identical counts of single neutrons. However, the numbers of doubles counted were statistically different from one another with JSR-15 always yielding higher doubles count rate. Statistically these differences were considered significant since they are more than three times greater than the standard deviation of the calculated error.

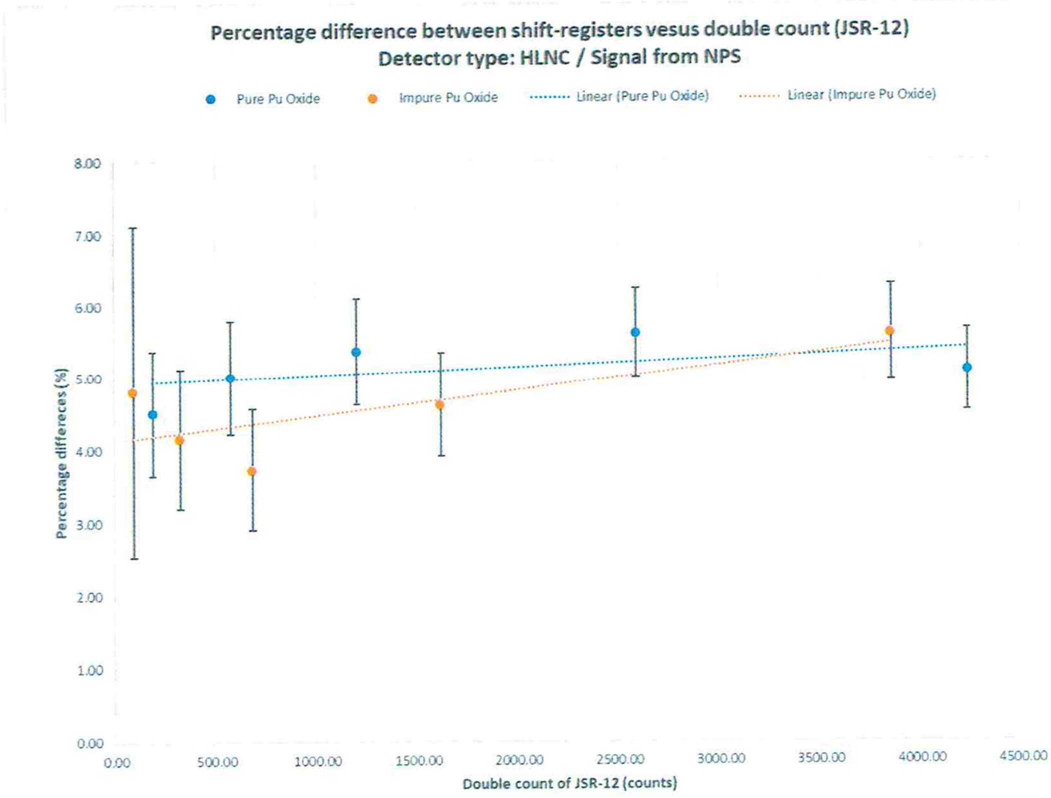

Figure 6: Percentage difference b/w shift registers vs Doubles (JSR-12) using HLNC detector

From the plot above, we could detect positive correlation in the differences which were hovering around 4 to 5 percent of the total doubles count from JSR-12 in the case of Pure Pu Oxide signals. For Impure Pu Oxide signals, although the pattern of the difference is less clear, which might due to the different level of impurity in each of the samples, the measurements also yielded significant differences base on statistical errors of the data.

We went on and continued comparing two shift registers with another scenario. The NPS was again used to generate stream signals from Uranium samples. The INCC software was now set to Active Well Coincident Counting (AWCC) mode. All other parameters for shift registers were the same; however, we increased measuring time to 60 minutes to minimize uncertainties. The results were on the following table.

Table 2: Results for Uranium signals

List of samples		Run time	U mass	Single JSR-12	Single JSR-15	Double JSR-12	Double JSR-12	Diff (%)	σ (%)
Pure U Oxide	AUMT0050	60	50.000	5741.498	5762.112	5.918	7.217	21.950	26.176
	AUMT0100	60	10.000	5741.498	5781.308	13.269	15.738	18.607	11.247
	AUMT0250	60	250.000	5746.780	5747.958	32.892	34.963	6.296	4.947
	AUMT0500	60	500.000	5856.530	5856.415	67.428	69.692	3.358	2.360
	AUMT0800	40	800.000	5984.946	5988.007	112.339	114.992	2.362	1.913
Bulk U Oxide	AUOX0050	60	50.000	5741.498	5791.104	20.619	22.394	8.609	7.834
	AUOX0100	60	100.000	5743.688	5843.201	29.941	32.443	8.356	5.307
	AUOX0200	60	200.000	5843.017	5943.829	48.638	52.996	8.960	3.213
	AUOX0300	60	300.000	5939.886	6038.010	65.343	69.881	6.945	2.701
	AUOX0500	60	500.000	6121.457	6221.903	98.898	105.435	6.610	1.723
	AUOX0800	60	800.000	6378.197	6474.888	148.606	155.629	4.726	1.275
	AUOX1000	60	1000.000	6534.025	6630.385	177.679	186.018	4.693	1.116

Here the differences were surprisingly inconsistent. For some sample such as AUOX0500, the difference was seemingly significant with the number greater than three times the Standard Deviation (SD) of error. However, for some samples especially the one with smaller mass of Uranium, the differences were not significant since the SDs were relatively large.

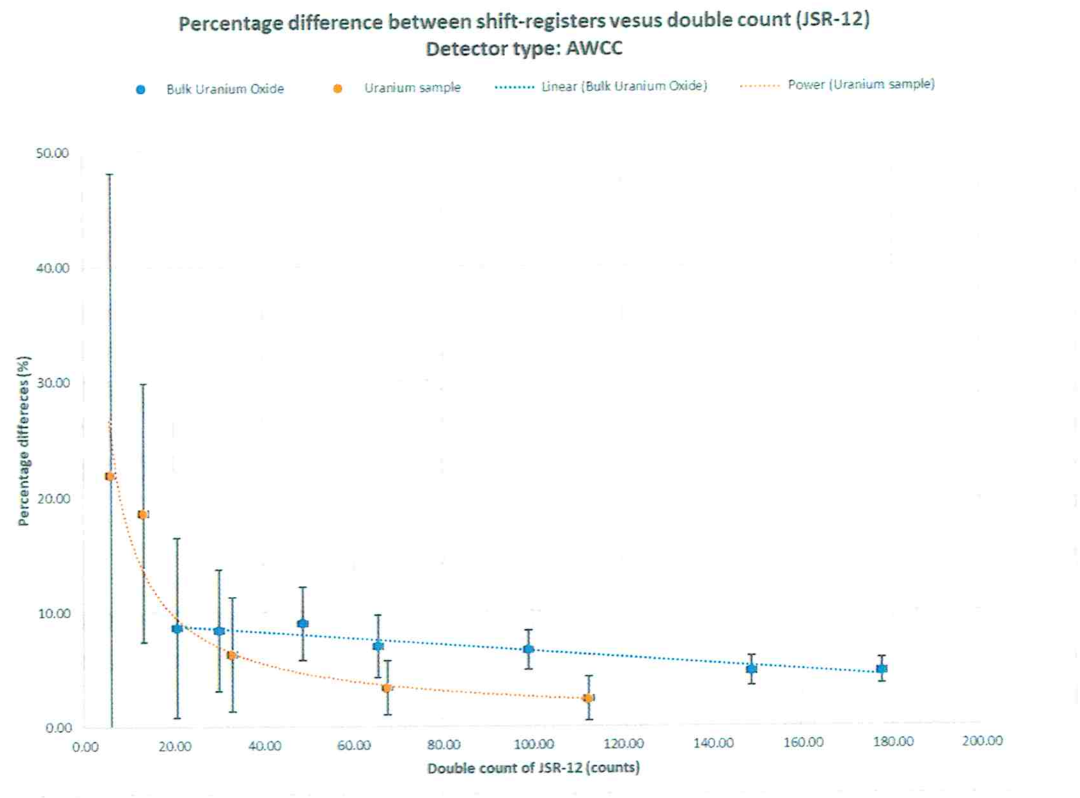

Figure 7: Percentage difference b/w shift registers vs Doubles (JSR-12) using AWCC detector

From the graph, the pattern was quite clear for bulk Uranium oxide samples. This was not the case for the Uranium samples due to the spike of percentage differences on the left side of the graph. We were not certain what caused these inconclusive results, but it was time to move onto the next step which is the measurement of actual nuclear materials.

Step 2: Measurements of small Cf-252 sources

Figure 8: Setup shift register with HLNC detector

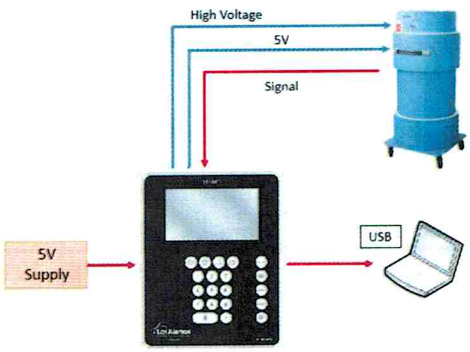

Figure 9: Setup diagram of the system

The figure above shows the setup of equipment used for measurements of small Cf-252 sources available in the training laboratory. Instead of NPS, the detector is connected to the shift register through the 3-heads cable. Nuclear materials will be placed inside of the detector. The measurement assumptions were all the same; however, the results were drastically different from what we anticipated.

Table 3: Results for Cf-252 in Training Laboratory

List of samples		Run time	Single JSR-12	Single JSR-15	Double JSR-12	Double JSR-15	Diff (%)	σ (%)
INVS	Black	20	203.206	220.082	61.118	62.049	1.523	0.819
	E8-282	20	8356.243	8364.417	2529.043	2545.497	0.638	1.245
HLNC	Black	20	105.308	106.423	20.049	20.177	0.651	0.270
	E8-282	20	4412.893	4417.319	833.121	838.653	0.664	0.303

From the table, we observed marginal difference of double counting between two shift registers and the numbers were relatively small compare to statistical error from the devices. For most cases, the difference were around 0.6 percent with statistical error of almost 1.0 percent. With these results, we started speculating that there might not be significant difference of double neutron counting between the two shift registers in question.

Step 3: Measurements of actual nuclear materials in Seibersdorf

To confirm this speculation, we ran the following tests on actual materials at the IAEA Nuclear Material Laboratory in Seibersdorf. The list and properties of materials are provided on the table below.

Table 4: List of nuclear materials for measurements

	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
CBNM 93	0.01	93.43	6.29	0.22	0.04	0.10
CBNM 84	0.07	84.40	14.16	1.02	0.35	0.22
CBNM 70	0.85	73.42	18.25	5.42	2.05	1.16
CBNM 61	1.21	62.66	25.35	6.64	4.15	1.44

The plan was to measure each individual sample and combination of samples if time permitted. We ended up with around 10 set of measurements and the results were on the table below.

Table 5: Results for actual nuclear materials with HLNC detector

List of samples Detector: INVS		Run time	Single JSR-12	Single JSR-15	Double JSR-12	Double JSR-15	Diff (%)	σ (%)
Cf	Cf-048.08	20	12092.676	12105.094	2279.538	2286.043	0.285	0.349
	Combined	20	23422.392	23435.432	4383.507	4420.708	0.849	0.336
	Combined*	18	23309.166	23331.488	4302.034	4319.799	0.413	0.349
Pu	CBNM-Pu61	20	727.526	730.677	46.683	46.630	0.114	0.958

Table 6: Results for actual nuclear materials using AWCC detector

List of samples Detector: AWCC		Run time	Single JSR-12	Single JSR-15	Double JSR-12	Double JSR-15	Diff (%)	σ (%)
Pu	CBNM-Pu700-2	20	609.734	612.068	33.768	33.624	0.426	1.284
	Combined Pu (T)	15	906.083	909.284	49.131	48.969	0.330	1.238
	Combined all 4 Pu	30	1885.119	1891.272	112.322	113.853	1.363	0.851
Cf	Combined Cf (T)	15	24832.930	24830.811	3585.686	3581.272	0.123	0.396
	Combined Cf (T)	30	31212.659	31241.622	5607.941	5628.758	0.371	0.311

As we can see from the highlighted cell on the table, all the differences were less than 1 percent and well below one time the standard deviation of error. Hence, we can confidently conclude that the difference of double count from two shift-register were insignificant and mainly due to uncertainty of the devices.

Disregarding type of materials, we rearranged the table and sort all data by the number of double counts. We plotted all data onto the graph to see if there was any correlation between the number of double counts and difference between two shift registers. The trendline and calculated correlation factor suggested no influence from number of double counts on differences between two shift registers.

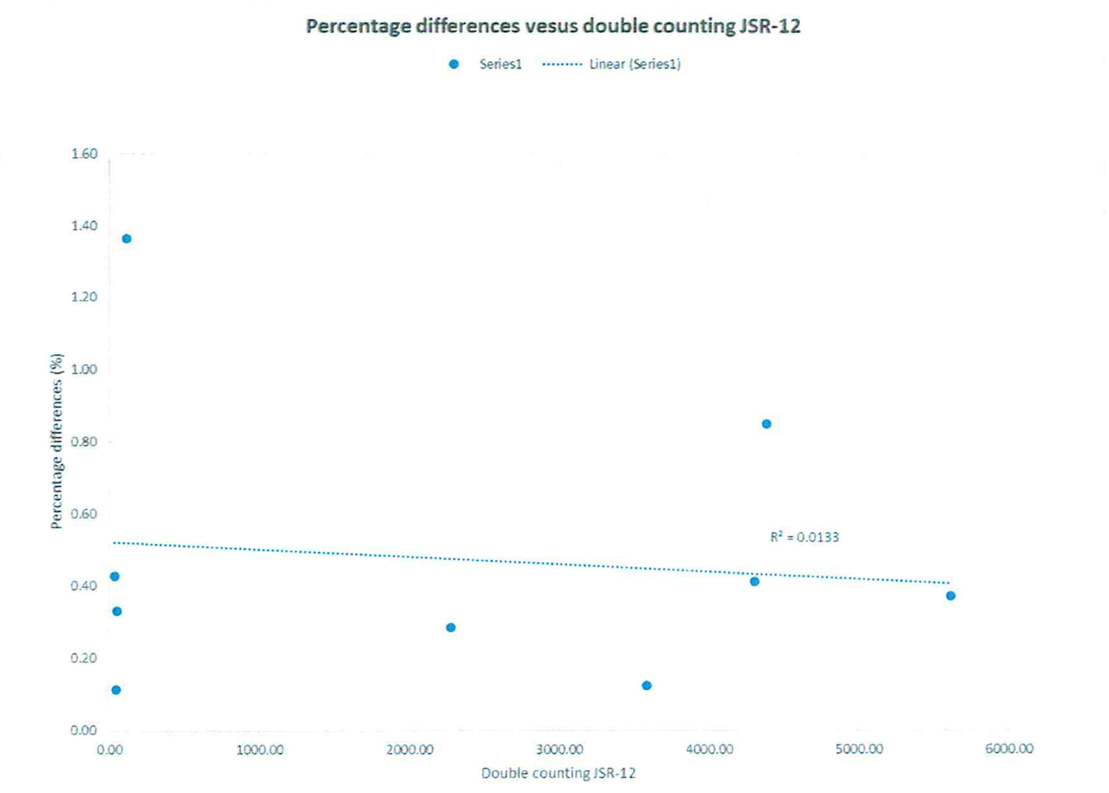

Figure 10: Correlation between Percentage differences vs Doubles JSR-12 disregarding type of detectors/materials

At this point, we started to think that the problem might not lie within the shift registers, but rather in the NPS. To understanding this problem and find out more which of the two shift register give more accurate output when used with NPS, we decided to record the pulse stream from the NPS using the device called Pulse Train Recorder model PTR-32 and processed by the software called Pulse Train Reader (PTR32HV). This device and software have been widely used by many research institutes such as KFKI in Hungary. The results from PTR32HV were compared with results from JSR-12 and JSR-15 on the table below.

Table 7: Results from JSR-12, JSR-15, and PTR-32 using NPS

List of items and type of detector	mass (g)	time (s)	PTR-32 Single	PTR-32 Double	JSR-12 double	JSR-15 double	Diff from JSR-12	Diff from JSR-15
HLNC Pure Pu02	50	20	2627.44	195.50	187.72	196.21	3.98	0.36
HLNC Pure Pu02	150	20	7368.83	603.49	573.23	601.95	5.01	0.26
HLNC Pure Pu02	300	20	14528.15	1253.53	1200.83	1265.33	4.20	0.94
HLNC Pure Pu02	600	20	28999.23	2727.03	2586.19	2731.67	5.16	0.17
HLNC Pure Pu02	900	20	43648.24	4396.11	4228.95	4445.09	3.80	1.11
HLNC Impure Pu	60	20	6226.37	97.08	91.91	96.34	5.33	0.76
HLNC Impure Pu	149	20	5366.10	339.03	324.55	338.08	4.27	0.28
HLNC Impure Pu	298	20	10569.52	707.19	681.92	707.45	3.57	0.04
HLNC Impure Pu	613	20	22309.51	1706.47	1620.79	1695.93	5.02	0.62
HLNC Impure Pu	858	20	44597.91	4031.29	3853.91	4071.14	4.40	0.99

The results from the PTR-32 is much closer to the results from JSR-15 than JSR-12 which implied that the JSR-15 has been working as intended with no significant difference to JSR-12 when using with actual samples. However, the problem could lie within the way JSR-12 processes the signal from NPS.

IV. Conclusion

In addition to the objective of learning more about neutron detection and NDA equipment IAEA inspectors use on the field. We embarked our practical exercise with the aim to verify if there are any difference in the results between two models of the shift-register. The first batch of data was generated using NPS as sources and the results show significant difference between two shift registers. However, the results from measuring actual samples both in the training laboratory and Seibersdorf showed very small and insignificant difference. To ensure this, the third instrument was introduced by using the device called pulse train recorder to record signals from NPS and evaluated them using PTR-32 software. The results were in line with the new model, JSR-15. Therefore, we can conclude that there is no significant difference between double counting from JSR-12 and JSR-15. Furthermore, there is statistically significant difference between double counting when the signals are generated from NPS. Hence, it is recommended to take the result from this only for training purpose but not for research and development.

V. References

[1] N. Ensslin, "The Origin of Neutron Radiation," in *Passive Nondestructive Assay of Nuclear Materials*, Washington, 1991, p. 337.

[2] P. Rinard, "Neutron Interaction with Matter," in *Passive Nondestructive Assay of Nuclear Materials*, Washington, 1991, p. 357.

[3] M. T. S. D. S. B. C. R. F. a. M. R. N. W. H. Geist, "Calibrating and training of neutron based NDA techniques with less SNM Standards".

[4] B. Geist, *Introductory Course on Agency Safeguards (ICAS 64) Module 6a: SG NDA Measurement Techniques,* International Atomic Energy Agency.

[5] P. Santi, *Session 2.2 Principles of Neutron Coincidence Counting,* IAEA, 2017.

[6] P. Santi, *Session 2.3 Passive Neutron Coincidence Counting of Plutonium (HLNC, INVS),* IAEA, 2017.

[7] P. Santi, *Session 2.6 Active Neutron Coincidence Counting of Uranium using AWCC,* IAEA, 2017.

[8] T. S. IAEA, *Job Aid for HLNC,* 2016.

[9] Training Section IAEA, *Job Aid for INCC with AWCC and UNCL,* 2016.