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Original Article

Human resource planning for authorized inspection activity

Seung-hee Lee [a,*], Robert Murray Field [b]

[a] Power Generation Division, Korea Hydro & Nuclear Power Co.,Ltd, Gyeongju, Republic of Korea
[b] Department of Nuclear Power Plant Engineering, KEPCO International Nuclear Graduate School (KINGS), Ulsan, Republic of Korea

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ABSTRACT

When newcomer countries consider a nuclear power programme, it is recognized that the most important organizations are the Nuclear Energy Programme Implementing Organization (NEPIO), the regulator, and an operating organization. Concerning the number of construction delays these days, one of the essential organizations is an Authorized Inspection Agency (AIA). According to World Nuclear Industry Status Report, all of the reactors under construction in eight out of the thirteen countries have experienced delays. Globally, the Flamanville 3 project and Sanmen Unit 1 are 6.5 years and 5 years late respectively. One of the major reasons of delay is due to inappropriate manufacturing and inspection on safety class components.

The recommendations are made to develop such an organization: (i) find existing inspection organizations in relevant industries, (ii) contract with expatriates who have experience on nuclear inspection, (iii) develop a legislative framework to authorize the inspection organization with enforcement, (iv) include a contract clause in the BIS for developing the AIA, (v) hold training programmes from vendor country, (vi) during manufacturing and construction, domestic AIA shall be involved.

1. Introduction

The nuclear industry demands a high level of competence from employees due to the complexity of technology and high level of competence required to assure nuclear safety. This naturally leads to the need for effective Human Resource Development (HRD). HRD varies substantially when considering the entire lifecycle of a Nuclear Power Plant (NPP). To be more specific, HRD should be involved from Phases 1 through 5 as identified in accordance with the International Atomic Energy Agency (IAEA) [1].

When newcomer countries consider the first nuclear power programme, it is recognized that the most important organizations are the NEPIO, the regulator, and an owner/operating organization. With these three organizations, and in relation to the number of construction delays these days with NPP construction projects, one of the essential organizations for newcomer countries is considered to be an Authorized Inspection Agency (AIA).

As Technical Support Organization (TSO), the AIA plays a key role in the areas of manufacturing, construction, installation, commissioning, and operation. The AIA is sometimes referred to as a third party inspection organization, an independent inspection body, or an authorized inspection body. In this paper, the general process of HRD for newcomer countries will be addressed. Next the current problems of NPP construction projects will be examined. Specifically, these problems identify the need for early development of the AIA. Finally, recommendations will be made for the development of the AIA.

2. General process of HRD for newcomer countries

At a very early stage, around twelve (12) years before the first fuel loading, it is critical to plan the HRD requirements with a long-term vision [2]. In order to predict the buildup of the workforce and timeline of establishment of relevant organizations for HRD, it needs to be clear which type of contract of an NPP project is expected to be made. For newcomer countries, it is common to accept a turnkey contract. The turnkey contract approach is often used for the first NPP project in the country and also on subsequent projects when the country and owner have no long term plans for a comprehensive localization of the nuclear technology [3].

In the turnkey contract, the main contractor or a consortium takes overall responsibility for design, construction and a startup [4]. Accordingly, the study of HRD for newcomer countries in this

* Corresponding author.
E-mail address: leeshshsh@khnp.co.kr (S.-h. Lee).

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paper will be based on the turnkey contract approach. In this regard, the review can be more focused on the development of the NEPIO, the regulatory body, the Owner/Operator organization, and the AIA rather than the development of architecture engineering companies, construction companies, vendors, and suppliers, etc.

In terms of the three (3) important organizations identified above, the necessary staffing of each organization will change throughout the Phases as illustrated in Fig. 1 [5].

2.1. NEPIO

At the beginning of Phase 1, it is assumed that a newcomer country has determined that it needs additional energy and has considered nuclear power as a possible option to meet its energy demand [6]. The NEPIO will be organized by the government to support planning for launching a nuclear power programme in the country. Through the efforts of the NEPIO, the country will analyze all critical issues that would be involved in introducing nuclear power. At the end of Phase 1, the country is in a position to make a knowledgeable decision on whether or not to deploy nuclear power [6].

In order for the NEPIO to perform its key role, initial resourcing is very important. However, this resourcing could encounter a major challenge in workforce planning, as newcomer countries are unlikely to have all or even many of the needed competencies, particularly those relating to nuclear power.

In this case, HRD could be based on recruits from relevant domestic industries such as other types of power plants, the oil industry, the chemical industry, and so on. Bringing experienced experts from other countries into the various project organizations will also be a good initial strategy while a developing national staff can be placed overseas in the vendor country to gain education or experience.

Ultimately, the NEPIO should: (i) ensure overall coordination and the engagement of all important parties, (ii) compile the information, and (iii) study necessary inputs to produce a knowledgeable policy decision on whether to proceed with nuclear power. At the end of Phase 1, the NEPIO provides comprehensive reports including the prefeasibility study and the nineteen (19) infrastructure issues that are presented by the IAEA.

At the beginning of Phase 2, the NEPIO will continue to be very active in taking initiative on the nuclear power programme. At the same time, the other two (2) organizations (i.e., the regulatory body and the Owner/Operating organization), should be fully established and taking increasingly active roles. At the end of Phase 2, the NEPIO staffing can be reduced and separated individuals can then be transferred to the regulatory body, the operating organization, or other project organizations.

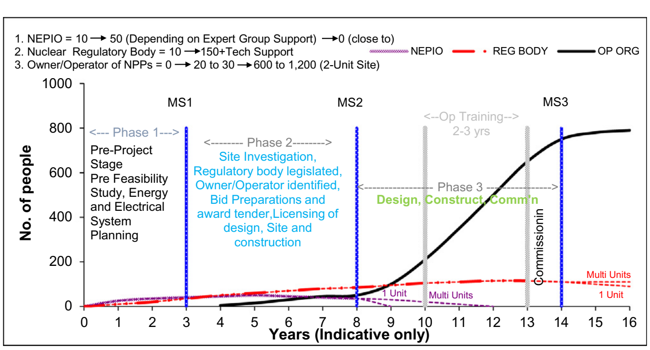

Fig. 1. Typical phasing of resource requirement.

2.2. Regulatory body

The regulatory body should engage experts in specific field of expertise as duties in this organization require significant nuclear power licensing knowledge. For a newcomer country, such staffing represents a tremendous challenge. The number of core staff is expected to be forty to sixty individuals with peak staffing of as many as to 100 to 150 personnel [5]. The role of the regulator during Phase 2 is as follows:

- Legal basis and regulatory processes
- Technical discipline
- Regulatory practice
- Personal and interpersonal competencies

One of the best ways to develop human resource for the regulatory body is to learn from the regulatory body from the foreign country that newcomer countries may have contract with for the NPP project in the near future.

2.3. The owner/operating organization

The Owner/Operator project team needs to manage the specification and contracting of the first NPP during Phase 2. The number of personnel may initially be as few as 30 to 35 personnel as the role of the operating organization is limited in Phase 2. The roles of the operating organization are listed below [5].

- Preparing the Bid Invitation Specification (BIS)
- Preparing the Environmental Impact Assessment Report (EIAR)
- Establishing interfaces with the various national and international bodies associated with safeguards, security, physical protection, the nuclear fuel cycle, and radioactive waste
- Establishing the integrated management system needed to ensure the safe operation of the plant
- Creating the foundations of an appropriate safety culture prior to commencing construction
- Preparing a strategy for dealing with the public
- Starting to prepare emergency plans and procedures

However, the operating organization requires a variety of workforce specialties in the near future. Therefore, HRD for the operating organization should undergo early planning and be reviewed and updated throughout the life of the project.

During Phase 3, the work of the NEPIO will be completed and the staff transferred to other organizations. On the other hand, the regulatory body staff will remain in place to conduct its ongoing role. The organization that will experience the greatest increase in staffing during Phase 3 is the Owner/Operating organization.

2.4. Other Organizations

Since the turnkey contract is commonly considered for the 1st NPP, other organizations, apart from the regulatory body and the operating organization, may not be necessary in contrast to a non-turnkey contract. However, there is the possibility to use local workforce for construction and to have technology transfer from the contractor, particularly if this cooperation is called out in the contract. Construction of the 1st NPP is a mega project for most countries and this project will require careful planning of the workforce during all phases. An example of the overall manpower requirements during the different stages of an NPP project is illustrated below in Fig. 2 [2].

Fig. 2 was originally adapted from the IAEA documents [4]. This figure reflects the current status of NPP construction. From Fig. 2,

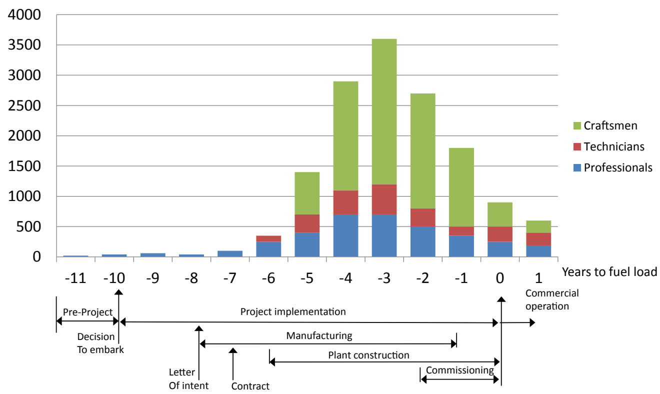

Fig. 2. Manpower loading for a nuclear power project of 1000 MWe PWR plants.

peak of required manpower is approximately 3600 people. In total, ~600 to 700 professionals are expected along with ~500–600 technicians, and ~2000 to 2700 craftsmen.

Craftsmen consist of welders, heavy equipment operators and many others. Specifically, welders are very important workforce as adequate quality of welding is essential for an NPP construction. Furthermore, welders must be qualified by a relevant organization and be well aware of relevant Codes and Standards. This means that welder should not only train in welding skills but also be knowledgeable of relevant Codes and Standards such as American Society of Mechanical Engineers (ASME) Codes.

Note that unskilled labour and resources for equipment/component manufacturing are not included in Fig. 2 [2] [4].

3. Problem statement

According to the World Nuclear Industry Status Report (2017) [7], reactors under construction in eight (8) out of the thirteen (13) countries have experienced delays, mostly by a year or more. In addition, more than two-thirds of all NPP construction projects (thirty-seven (37) in total) are behind schedule [7]. Such delays are found not only in newcomer countries but also in countries that are expanding existing nuclear power programmes. The reason of the delays varies. However, one of the causes has been attributed to manufacturing defect, which can be minimized by the AI activity.

3.1. Case Study of current NPP construction projects

3.1.1. Flamanville 3

In December 2007, the French company Électricité de France (EDF) began construction of Flamanville 3 (FL3), an NPP with a capacity of 1650 MWe. Since the plant was planned to go into service in 2012, the Flamanville 3 project is currently at least six and half (6.5) years behind schedule and is now expected to start generating power no sooner than May 2019, and is projected to reach full capacity by November 2019 [7].

There are number of causes that led to project delays. However, one of the main reasons is an anomaly discovered in the Reactor Pressure Vessel (RPV). In 2015, the French Nuclear Authority, Autorité de sûreté nucléaire (ASN), revealed that the bottom piece and the head of the FL3 RPV had defects which required detailed investigation [7]. This problem was discovered after the RPV had been installed in the reactor building in January 2014 [8].

Based on information released by ASN, there is a concern related to anomalies in the composition of the steel in the centre of the FL3 EPR vessel closure head and bottom head [9]. These anomalies are linked to the presence of high carbon concentrations which may result in mechanical properties that are not as robust as expected [9]. This may be due to a process for manufacturing the RPV that was not according to technical specification [7]. To be more specific, the technical specification was changed from the technical rules of October 1999 to the Nuclear pressure equipment (ESPN) order of 12 December 2005 in 2005. Subsequently, the ESPN order had been published on 22 January 2006. Hence the licensee and the manufacturer decided that provisions of the referenced order of 12 December 2005 would be applied. However, before technical qualification procedures had been defiend and stabilized, manufacture of the RPV began in 2005. The upper dome was poured on 5 September 2006 and the lower dome on 23 January 2007 [10].

The manufacturer, Areva, wished to use the M140 qualification previously defined in accordance with the RCC-M, which is applied code for design and construction rules for the mechanical components of PWR nuclear islands. The manufacturer was convinced that M140 qualification of the RCC-M would comply with technical qualification requirements of the ESPN order and that the domes would meet the requirements of this order. In this respect, the RPV domes obtained M140 qualification but the conditions necessary for their ESPN technical qualification were not met [10].

During manufacturing of the RPV, the internal inspection body, Areva NP, carried out inspections on the EPR reactor pressure vessel domes and the results did not identify any unacceptable flaws [10]:

- A visual inspection of all the surfaces during the various manufacturing phases
- A dye-penetrant inspection of the inner and outer surfaces of the domes after final machining.
- A volumetric ultrasound inspection after final machining

Nonetheless, there were early warning signs indicating the presence of positive macrosegregations in 2007. High carbon concentration value on the upper dome brought to light when metal chips were sampled in 2007. However, the purpose of the sampling the metal chip was to ensure that the top and bottom sides of the ingot were correctly identified [10].

In order to deal with this issue, the manufacturer and associated engineering group have prepared studies which demonstrate that the mechanical strength of the steel of the RPV is sufficient in all operating situations, including accident situations [8]. In the test programme of mechanical properties of the steel of the RPV lower and closure heads, a third party organization was deletaged by ASN to monitor the programme and ensure that it was essentially carried out by laboratories that are independent of the Areav group [11]. A third party organization, Bureau Veritas Exploitation, is qualified by ASN to perform this type of monitoring [12].

The multinational inspection took place to investigate the cause of the abnomaly in 2016 at the manufacturer of the RPV, Creusot Forge. The inspectors noted that analysis of the causes of the failure to detect the irregularities by the quality system and by the internal inspection body at AREVA NP is essential [10]. ASN has recently accepted that the unit can start up safely, at the end of 2018 as planned. However, ASN will also require that the vessel head be replaced by the end of 2024, which an estimated costs of approximately €100 million (US $114 million) [8] [13].

From this case, it can be emphasized that competent inspection of safety class components such as the RPV is critical to NPP construction projects. These inspections are generally conducted by inspection organizations such as the AIA or regulatory body. Along these lines, according to ASME QAI-1-2016 [14], one of the duties of Authorized Nuclear Inspector (ANI) is to verify that materials of safety related components comply with applicable code requirements. The methodology and scope of inspection may differ between countries and between AIAs.

In France, ASN as a regulatory body involves all areas of inspection including inspection of manufacturing safety related components. The safety related equipment is classified in three decreasing levels: N1, N2, and N3. These are categorized according to the quantity of radioactivity that could be released in case of failure of the equipment and the importance for safety of this equipment [18].

Generally, ASN carries out an evaluation of the conformity of the EPR reactor's primary and secondary system equipment (vessel, reactor coolant pumps, control rod drive mechanisms, pressurizer, steam generators, as well as some of the pipes, valves and cocks). ASN will often engage the assistance of approved third-party inspection bodies to aid in the evaluation [16].

It is considered that the (equivalent) role of the AIA in France is conducted by both ASN and third-party inspection bodies that are authorized by ASN. As of 2017, five inspection organizations or bodies are currently approved by ASN to assess nuclear pressure equipment (ESPN) conformity. These are Apave SA, Asap, Bureau Veritas, AIB Vincotte International and the EDF users inspection entity [17].

3.1.2. Sanmen

Significant delays have also impacted the AP1000 reactors being constructed at Haiyang and Sanmen in China [7]. Construction of Sanmen Unit 1 began on April 19 in 2009 while construction of the first unit in Haiyang began in September 2009. The original plan for startup of Sanmen Unit 1 was in 2013. This date is currently delayed until 2018. The reasons of such delays are associated with late design changes, component failures, and quality assurance failings [18].

One of the significant events related to quality assurance failings occurred in January 2013 during the final product test of Haiyang Unit 1 Reactor Coolant Pump (RCP). It was discovered that one impeller dropped into the RCP test loop [19].

This RCP impeller was fabricated by Wollaston, one of the subcontractors of manufacturing RCP impeller. Four (4) RCPs produced by Wollaston had already been delivered to the site in Sanmen at the time of the failure. All four (4) RCPs were shipped back to the U.S for impeller replacement causing delays to the Sanmen project.

The primary root cause was assigned as inappropriate manufacturing of RCP impellers with insufficient process control. According to the U.S. NRC Nuclear Safety Review [19], the physical cause of the failure is most likely due to a flaw present in both the cast material and weld overlay applied to the impeller blade.

From investigation conducted by Wollaston, Curtiss-Wright Electro-Mechanical Division (EMD), it was found that unapproved welding procedures were used during manufacture. Furthermore, post-weld heat treatment was inappropriate as more than one post-weld heat treatment cycle was used on impellers when only one post weld heat treatment cycle was authorized by contract documents.

Moreover, a lack of capabilities for penetrant examination was identified as penetrant examinations performed by Wollaston Alloys, Inc. did not identify surface flaws in the casting for specific impellers whereas Curtiss-Wright EMD using the same procedure was able to identify flaws that were dispositioned as unacceptable [20].

The responsibility of manufacturing defect basically lies on the manufacturer. In case of RCP impeller issue, it appeared to be quality issues related to a sub-tier vendor supplying the impeller casting [21]. However, this kind of inappropriate manufacturing process could be discovered and identified by the AIA. The inspection of RCP, which belongs to safety related components, is one of the major tasks for the AIA. In this matter, according to the ASME QAI-1-2016 [22], the AIA shall verify that as follows.

- Welding procedures conform the ASME Code Section III and IX.
- Welders and welding operators are properly qualified and their qualification permits them to use required procedures.
- Required heat treatments have been performed and are properly documented.
- Required non-destructive examinations and tests have been performed by qualified personnel and that the results are properly documented and meet Code requirements.

In response to this matter, the U.S. NRC recommended that such an occurrence would be minimized by proper quality controls and inspections by the manufacturer and by the licensees prior to final installation of the equipment [19].

3.2. Organization development

In spite of the importance of the AIA, there is no recommendation by the IAEA for early development of the AIA in the process of HRD for newcomer countries. Inspection of safety related components was assumed to rely on inspection capabilities of vendors or international inspection organizations contracted by the owner organization of an NPP. Since the development of the AIA differs by country to country depending on local circumstances, the path to the appropriate way of development of such AIA organizations will likewise vary.

For example, the U.S had experience in boiler inspections dating back more than 100 years as related to boiler explosions. This history has led to the development of third party inspection organizations to minimize the potential for such explosion events.

This background naturally led to the development of nuclear inspection organizations as accompanied by insurance company participation.

These days, developed countries have substantial experience in fabricating such pressure vessels using the latest technology. For this reason, third party inspection activities tend to emphasize the review the documents rather than factory inspections. Therefore, a different way of developing an inspection organization should to be applied regarding the situation of newcomer countries.

4. Development of the AIA

4.1. Roles and responsibilities

As defined by the ASME [23], the AIA is an organization that is empowered by an enforcement authority to provide inspection personnel and services as required by ASME Code Sections III and XI. In the nuclear industry, such an AIA plays a major role as an independent inspection organization to ensure nuclear safety by inspecting manufacturing and operation of safety related components. This includes assurance of structural safety or component integrity by performing In Service Inspection (ISI) during the 60 years life of an NPP.

The function of the AIA is to verify that:

- Vendors manufacture safety components according to approved Codes and Standards.
- The constructor constructs the concrete containment according to approved Codes and Standards.
- The operating organization or constructor installs safety class components according to approved Codes and Standards.
- The operating organization repairs or replaces safety class components according to approved Codes and Standards.
- The operating organization regularly inspects safety class components according to approved Codes and Standards.

The AIA is also responsible for performing inspections of ASME pressure equipment Certificate Holders during the manufacturing process [24]. The other responsibility of the AIA is to conduct inspection of installation of safety related components during the NPP construction and to perform ISI during NPP operation.

The AIA involvement related to nuclear power is explicitly required by the relevant Code and Standard. According to ASME B&PV Code Section III NCA-3230, the owner organization is required to obtain a written agreement with the AIA prior to application of owner's certificate. Certificate Holders, which are the manufacturers of safety related components, also need to obtain an agreement with the designated AIA.

4.2. Code requirement for the AIA

Development of the AIA is carried out in associated with relevant Codes and Standards for nuclear power plants in newcomer countries. For example, the ASME code is applied to the AP1000 supplied by the U.S. nuclear industry while the RCC-M code is applied to the EPR from France.

On the other hand, the CAS/CAN code is applicable for CANDU from Canada whereas the PNAE code is applicable to the WWER (VVER) from Russia.

South Korea uses its own Code, designated as KEPIC for the APR1400. Since the ASME B&PV Code is widely used by more than sixty (60) countries, development of the AIA in this paper is illustrated for the case of ASME code jurisdiction.

According to the ASME QAI-1-2016 [22], AIA qualifications can be broken down in more detail in accordance with applicable ASME Section III Divisions.

- AIA for ASME BPVC Section III, Division 1, 3, and 5
- AIA for ASME BPVC Section III, Division 2
- AIA for ASME BPVC Section XI

Note that the ASME B&PV Code Section III Division 5, which is for construction rules for high temperature reactors, and is not directly related with this paper. This Code section is excluded from further discussion. Applicability of the relevant ASME Code sections mentioned above is referred in Fig. 3 below [24].

The scope of the items from each division is listed below [23]:

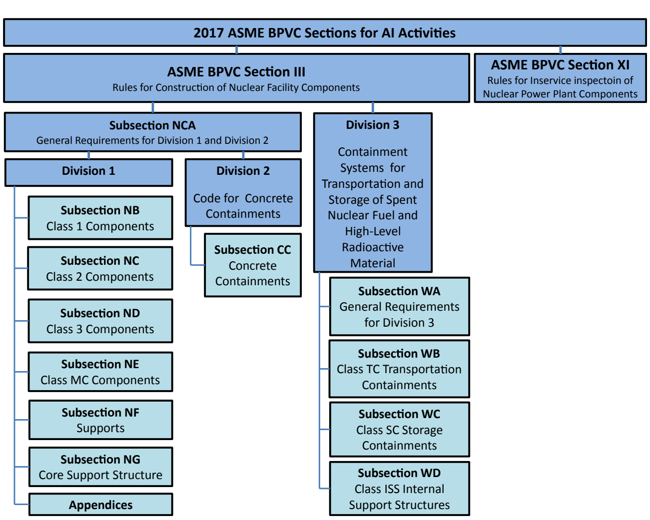

Fig. 3. 2017 ASME B&PV code for AI activities.

- Division 1: Metallic vessels, heat exchanger, storage tank, piping system, pumps, valves, core support structures, supports, and similar items.
- Division 2: Concrete containment vessels.
- Division 3: Metallic containment systems for storage or transportation of spent fuel and high level radioactive materials and waste.

Table 1 illustrates examples of NPP components for each Code subsection. From Table 1, the scope of components requiring AIA inspections is identified [25].

In terms of qualification of the three areas addressed by AIAs, general qualification requirements are similar whereas only the applicable Codes are different for each AIA qualification. The AIA shall be organized under one of the following organizational structures [22].

- A jurisdiction that has adopted and does administer relevant Section and Division of ASME Codes.
- An insurance company that has been licensed or registered by the appropriate authority of country.
- A company in the business of providing "third party" inspection services with in a jurisdiction, which government recognition to perform
- Inspection and design reviews for boilers and pressure vessels.

Another important qualification for the AIA is to have no commercial interest in, or to be independent of any part of an organization having direct commercial interest in, the products to be inspected [22]. Hence, the judgment or the results of work are not influenced by other than professional aspects. The AIA of an insurance company and a company providing third party inspections shall also maintain liability insurance.

From this fact, the government of newcomer countries must determine in which way the AIA will be established. This also relates to legislation and regulation of the nuclear power programme that newcomer countries will develop.

4.3. Process of becoming the AIA and the ANI in the United States

The AIA is authorized to conduct inspection activities after being issued both a certificate of accreditation from the ASME and a

Table 1
Examples of NPP components for each subsection.

Subsection	Example of Components
NB - Class 1 Components	• Reactor Pressure Vessel • Pressurizer Vessel • Steam Generators • Reactor Coolant Pumps and Piping • Line Valves, Safety Valves
NC - Class 2 Components	• Emergency Core Cooling • Post-Accident Heat Removal • Post-Accident Fission Product Removal
ND - Class 3 Components	• Cooling Water Systems • Auxiliary Feedwater Systems
NE - Class MC Components	• Containment Vessel • Penetration Assemblies
NF - Supports	• Plate and Shell Type • Linear Type • Standard Supports
NG - Core Support Structures	• Core Support Structures • Reactor Vessel Internals

certificate of acceptance from the National Board (NB). Both parties are involved in the certification of the AIA. Qualification of the AIA was addressed earlier in Section 4.2. Specific requirements for the certificate are slightly differentiated among three AIAs. However, the general process is to obtain the certificate in similar manners. Fig. 4 illustrates general process of becoming an accredited AIA in the U.S [22]. [26].

In order to play a role as the AIA, employment of inspectors and inspector supervisors is necessary. According to the NB [27], qualification of inspectors and supervisors in each area, which are ANI, ANII, and ANI for Concrete, is different as it requires different background and levels of experience and knowledge. The process of becoming a commissioned and endorsed ANI is illustrated in Fig. 5 below.

5. Case study of the AIA development in South Korea

As of 2018, KHNP operates twenty-three (23) NPP units. Further three (3) units are under construction with one unit (Kori Unit 1) permanently shut down, another unit (Wolsung Unit 1) being planned for permanently shut down.

In 2009 South Korea became one of the countries to exports nuclear power technology. Since the first commercial operation of Kori Unit 1 in 1978, there has not been significant accident in operating NPPs. This demonstrates that the Korean safety management system has worked sufficiently. Further, one of the contributions for nuclear safety is definitely the role of the AIA.

5.1. History of development of the AIA in South Korea

In early 1970, South Korea started the nuclear power programme with a turnkey project. The first authorized nuclear inspection activities were performed by foreign companies, namely Hartford Steam Boiler (HSB) and Bureau Veritas (BV) [28]. These two companies performed services as third party inspection organizations. However, these companies did not have enforcement authority as an AIA in South Korea. Since then, HSB had carried out a number of manufacturing inspections of safety related components for seven (7) NPP units in South Korea.

Beginning in 1985, AI activities were carried out by the Korean regulatory body. The nuclear safety centre headquartered at the Korea Atomic Energy Research Institute (KAERI) performed inspections in the roles as the nominal AIA. In 1990, the regulatory body was separated from the existing KAERI organization and

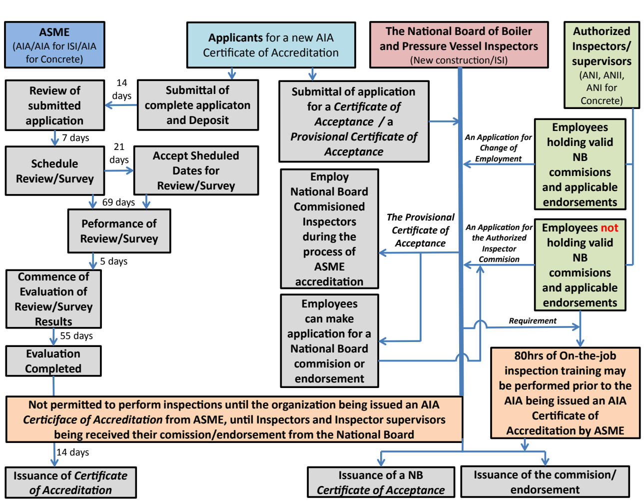

Fig. 4. Process of obtaining certificate of the AIA

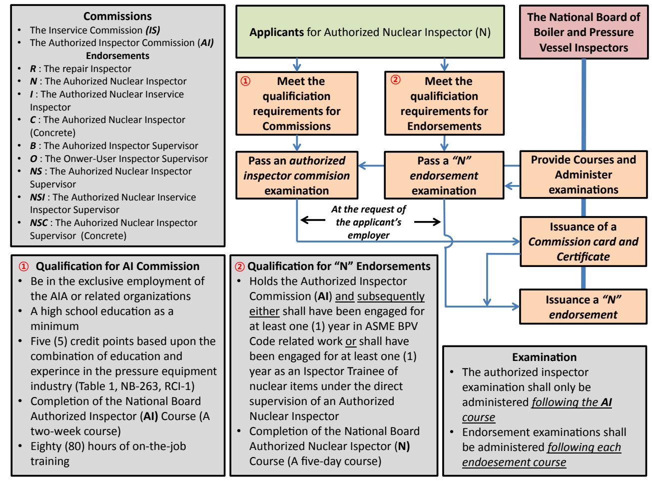

Fig. 5. Process of the ANI commission/endorsement.

established as the Korea Institute of Nuclear Safety (KINS). KINS performed three categorized inspections: (i) manufacturing inspection, (ii) pre-service inspections, and (iii) regular inspections. Those three inspections were designated by Korean nuclear law. However, in order to inspect welding integrity of pressure vessels, it was not sufficient to oversee just with pre-service inspection (PSI) or ISI. Instead, inspectors needed to stay in the field to monitor welding integrity for a certain period of time. For that reason, KINS also used to perform on-site insepction for construction before Hanul Unit 3 and 4.

To adapt the duty to the workforce, this eventually led to transfer authority of inspection to another government organization, the Korea Institute of Machinery and Materials (KIMM) in 1993. It was enable to enhance the independence of regulator and inspection diversity.

Beginning in 1997, the Korea Electric Power Industry Code (KEPIC), whose role is to provide services of Korean Code and Standard, started the qualification certification program. Since that time, KIMM was certified by KEPIC as an AIA. Now a subsidiary of KIMM, Korea Institute of Materials Science (KIMS), has performed authorized nuclear inspections since 2007.

The first construction inspection of by a South Korean AIA was implemented on Hanul Units 3 and 4 in 1993. Other inspection activities such as PSI, ISI, and Manufacturing inspection were simultaneously performed by a South Korean AIA since 1993.

As of 2018, the current status of the AIA certified by the KEPIC is indicated below in Table 2 [29]. From Table 2, it is recognized that international inspection organizations have participated as certified AIAs in South Korea.

5.2. Strategy for the early development of the AIA in South Korea

After KIMM was accredited as an AIA by the Ministry of Science and Technology in 1993, substantial inspection activities were performed. Before accreditation of an AIA, KIMM had relevant experience in associated industries. They had conducted a number of welding technology supports for nuclear components through international technology cooperation with TUV for fifteen (15) years. TUV is a well-known organization for the technical service and was found in 1866 in Germany. KIMM also performed damage evaluations, aging measurements, and safety analysis of oil plants.

In order to develop capability of human resources in KIMM, number of strategies had to be applied to the organization as follows [28]:

Table 2
AIAs certified by KEPIC in South Korea.

Agency	Type	No. of people (including all MN,MI,SN)	No. of people			Total No. of people in the Agency
			[a]MN	[b]MI	[c]SN	
Korea Institute of Materials Science	The ANI (including The ANI supervisor)	76	28	24	24	37
The Hartford Steam Boiler Inspection and Insurance Company of Connecticut, Korea Branch Office	The ANI (including The ANI supervisor)	12	12	–	–	12
Lloyd's Register Asia	The ANI (including The ANI supervisor)	31	15	14	2	20
ABS Consulting	The ANI (including The ANI supervisor)	5	5	–	–	5
Korea Authorized inspection and research institute	The ANI (including The ANI supervisor)	8	8	–	–	8

[a] MN: Nuclear Mechanical Components.
[b] MI: In service Inspection.
[c] SN: Nuclear Structure.

- Internal Activities
  - o Seminars and educational sessions to share knowledge, technical expertise, knowhow, and experience
  - o Invitation of domestic and international experts outside of organization
  - o Development of educational materials and technical publications
  - o Publication of Case Studies based on field experience
  - o Technical lecture
  - o Public hearings with other organizations
- External Activities
  - o International education and training
  - o Thesis publication and presentations
  - o Involvement on relevant technical committees

One of the effective methods for significant development of such organization is to study cases of existing organizations in developed countries. Cases of the organizations in the U.S, Germany, France, Sweden, Canada, and Japan were investigated by KIMM [28]. As a result, KIMM reached various agreements (Memorandum of Understanding (MOU) and Letter of Understanding (LOU)) with Japan Power Engineering and with the Japan Inspection Corporation (JAPEIC). They cooperated with welding and Non-Destructive Testing technology for AI activities through MOUs and collaborated in technology development of AI including the development of quality assurance systems through LOUs. Furthermore, KIMM had MOUs with the Technical Standards and Safety Authority (TSSA) in Canada. They agreed to conduct activities to enhance the safety of pressure vessels as well as to the sharing of information related to qualification [28]. Using international agreements, KIMM was able to develop capabilities on equal to or exceeding international standards.

5.3. The current role of the AIA in South Korea nuclear industry

KIMS is one of the most active ANI organizations in the nuclear industry in South Korea. ANI activities can be categorized into three activities: (i) manufacturing, (ii) construction, and (iii) in-service inspections. Regarding current NPP construction in South Korea, KIMS is involved in manufacturing and construction inspections for Shin Kori Units 4 and Shin Hanul Units 1 and 2. Moreover, KIMS is currently carrying out inspections during installation and construction of nuclear components and concrete containments for the UAE Barakah projects, Units 1 through to 4. Since there are twenty-three (23) NPPs in operation in South Korea, KIMS also performs PSI/ISI and Repair/Replacement Activities (RRA) oversight for those operating NPPs [30].

Apart from inspection activities, KIMS also provides training services related to welding technology, repair/replacement activities, and manufacturing/construction technology of safety related components. Through these types of activities, KIMS contributes to the improvement of competence and capacity of human resources in the nuclear industry.

6. Conclusions/recommendations

Development of the AIA is a key element to ensure nuclear safety during the lifetime of an NPP. It is also a Code requirement for the owner organization to contract with an AIA in order to obtain the owner's certificate for NPP construction projects in accordance with ASME Code. There are also many benefits which can be accrued by developing the AIA organization, including improvement of relevant industry competence and capacity, the development of relevant legislative framework, and so forth.

It may also be economically beneficial when considering future NPP projects as construction inspection costs are estimated at approximately four (4) million US dollars according to the NPP construction project of Shin Kori unit 5 and 6 in South Korea [31].

As shown in Table 2, inspection organizations do not require many employees. However, with certain key and highly trained and experienced individuals, the AIA can contribute beyond its numbers to the success of the project.

In particular, given the current status NPP projects, appropriate AI activities can become critical to prevent NPP construction delays and cost overruns (e.g., Flamanville 3). Therefore, for newcomer countries, early development of the AIA is a recommended area for HRD.

The recommendations in this paper are made to develop such an organization in the short to intermediate term using the following approach.

- It is recommended to find existing inspection organizations in relevant industries in the newcomer country as it is relatively easy to start off with existing human resources.
- It is advised that expatriates who have experience and certificate on nuclear inspection be engaged. Since there is not a significant level of new NPP construction in developed countries, many individuals with experience and expertise may be available. The relationship between the vendor and newcomer countries should also be considered. For example, Saudi Arabia, one of the countries that has announced the intent to build new NPPs, has a good relationship with South Korea through a number of construction projects spanning many years.
- A legislative framework to authorize the inspection organization with enforcement need to be developed and passed. Qualification process is also to be developed considering local

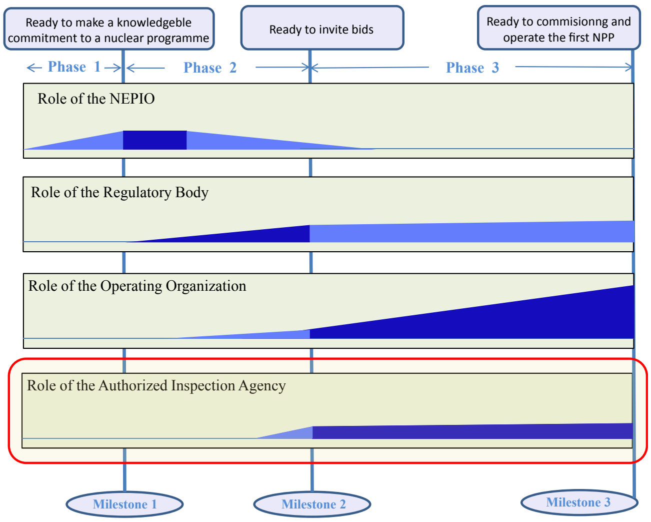

Fig. 6. Role of the organizations in each phases.

circumstances in newcomer country. It will be easy to benchmark qualification process from vendor country.

- In a turnkey contract for an NPP construction project, a contract clause for developing the AIA in the newcomer country should be included in the BIS.
- Training programmes provided by the AIA of the vendor country can be effective. The programme should start after signing the contract.
- During manufacturing and construction, involvement of domestic AIA personnel from the newcomer country is advised. Generally, inspection of manufacturing and construction will be performed by the AIA of the vendor country. The AIA of newcomer country should be involved so that the AIA of newcomer country can have experience and ensure future NPP safety based on proven experience. In particular, on-the-job inspection training is recommended. Trainees will work side-by-side with an Authorized Inspector in an applied Code shop/field site. The role of trainee is to observe, take notes, and learn the inspection process.

Regarding the recommendations above, the starting point of development of the AIA for newcomer countries is illustrated in Fig. 6 below.

In this paper, the importance of early development of the AIA was emphasized. In addition, effective ways to develop human resources for the AIA were suggested. Developing such an organization of a few numbers of experts can contribute toward ensuring a high level of safety to the nuclear industry as well as to successful completion of NPP construction projects.

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