LIFE ASSESMENT EXPERIENCE FOR CONTINUED OPERATION OF A CANDU NUCLEAR POWER PLANT IN KOREA

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Abstract

The first pressurized heavy water reactor (PHWR) plant in Korea, Wolsong Unit 1 reaches its 30 years' design lifetime by 2012. As the plant approaches its design life, maintaining a high level of plant safety has become a key issue as well as providing proper aging manahement programs. In this regard, "Wolsong Unit 1 Lifetime Management Study (I)" was conducted to evalutate technical and economic feasibility for the continued operation beyond design life. Korea hydro and nuclear power(KHNP) decided to perform the second phase of the study, "Wolsong Unit 1 Lifetime Management Study (II)" based on the results of the phase 1 study. The project covers an in-depth life assessment for systems, structures and components (SSCs) and establishment of aging management programs for the continued operation. This paper introduces Korean experiences on the process and method of life evaluation and aging management programs for the continued operation of a CANDU nuclear power plant.

1. Introduction

Wolsong Unit 1, the first PHWR in Korea, reaches its 30 years' design lifetime by 2012. As the plant approaches its design life, it is considered important to maintain a high level of plant safety and to provide aging management programs. In this regard, "Wolsong Unit 1 Lifetime Management Study (I)" ('00.07~'03.01) was conducted to assess technical and economic feasibility for the continued operation beyond design life. KHNP decided to perform the second phase of the study, "Wolsong Unit 1 Lifetime Management Study (II)" ('04.12~'07.05) on the basis of the results of the phase 1 study. This study covers an in-depth lifetime evaluation for SSCs and establishment of aging management programs for continued operation.[1]

The second phase of Wolsong unit 1 life management study evaluates technical matters for the continued operation including scoping and screening of SSCs, verification of aging status of the entire facilities through field inspection, in-depth lifetime evaluation, and establishment of aging management programs for SSCs for the extended period of plant operation. The results will be used as an input to aging evaluation part of succeeding periodic safety review (PSR) and as a technical basis for the continued operation license application.
Since rules for the continued operation of PHWR have not yet been provided in Korea, 10CFR54 (License Renewal) of U.S. NRC was applied to perform aging evaluation and management of this study. For main technical references of life evaluation and aging management are NUREG-1800 and 1801[2],[3] and Canadian experiences.[4]

2. Korean regulatory requirements for long term operation

Korean nuclear industry follows the periodic safety review practice. General PSR is reported to regulatory body every 10 years during normal operating period in accordance with IAEA guideline 50-SG-12 of PSR.[5] For the long term operation (LTO) beyond the design life, PSR should review plant safety including the aging management. Figure 1 and 2 represent respectively the contents and the safety enhancement of the intensified PSR for the LTO.

Korean government issued the notice of the MOST, No. 2005-31, the rule of LTO requirements for the PWRs, "Guideline of Technical Criteria for the Continued Operations of Reactors beyond Design Life".[6] The additional requirements for the LTO aging assessment; 39 aging management programs, time limited aging analysis, and operational experiences are to be included in the LTO license application. The requirements for the LTO are basically equitable to the practice of U.S. NRC license renewal.

LTO requirements of Korean PHWRs have not yet been declared but are now under review based on the same technical philosophy applied for the PWR plant. Korean Industry expects that the PHWR LTO rule will incorporate the experiences from PWR regulations and international PHWR practices in the frame work of PSR. Application of lessons learned form PWR regulatory experiences to PHWR plants could be a strong point of Korean nuclear industry.

3. Life assessment of Wolsong Unit 1

The second phase of the plant life management (PLiM) programs was to processed for in-detail life evaluation and provisions of aging management programs (AMPs). Intended functions of SSCs that were designed and required to be maintained for the period of continued operation were confirmed by reviewing functions and design requirements of SSCs using design data and information of systems and structures. In addition, plant history data of tests, operation and maintenance since the first criticality were reviewed and field walk-downs had done to verify current physical condition and aging status of the SSCs. The followings are general methods for the process of life assessment and Figure 3 depicts the process used for the life assessment of Wolsong Unit 1.

- Data collection and review of design, manufacture and installation documents and plant operation and maintenance history
- Determination of physical or functional boundary for SSCs
- Grouping and screening of sub-components within the scopes
- Aging analysis for the screened groups and sub-components
- Technical recommendations and management programs based on the aging evaluation results

Besides reviewing design or operation data, they performed a number of on-site tests with various expertise; visual inspections, wall-thinning measurements, heat exchanger performance tests, cables environment temperature measurements, and chemical ingredient analysis for soils in order to verify current physical condition of the SSCs. All the results of the PLiM programs are incorporated to a part of PSR, aging management, to confirm the overall plant safety periodically.

3.1. Screening

SSCs for LTO aging assessment are screened by the criteria of 10CFR54.[7] Screened SSCs are bounded as long-lived passive structures and components of safety related systems and non-safety systems that can affect the safe shutdown functions when they are failed. The CANDU safety definition in the plant design guide document is adopted to review safety related systems. Long-lived passive components are screened from the component master list and the structure aging management system of the plant. Screened structures and components (SCs) are usually primary and auxiliary systems and parts of secondary systems defined as safety related.

SSCs were screened in two steps, screening systems in the level of plant and structures, components, and groups in the level of the screened systems. 81 out of 130 systems and structures were screened and those selected have importance to the LTO in terms of basic subject index (BSI) numbers of Wolsong unit 1. The contents of life assessment reports for 46 systems and 8 common components/groups are as follows.

- Data collection: design, operation, inspecton, and maintenance
- Condition assessment: field walk-down and diagnosis, interviews
- Aging review: aging mechanisms, aging effects, screen time limited aging analysis (TLAAs)
- Residual life evaluation: in-detail aging assessments, TLAAs
- Aging management programs

3.2. Field inspection and diagnosis

To evaluate integrity and residual life of the screened SCs, it is necessary to verify their current aging status in the field using visual inspection method. Besides visual inspections, field diagnosis tests such as pipe thickness measurement, material property test, environment temperature measurement for cable aging assessment, performance tests, corrosion circumstances analysis of soil for buried commodity, and etc. are carried out. Most of recommends from the visual inspections can be fixed by the field normal maintenance but some aged SCs are to have additional maintenance plans for aging management.

5 times of field walk-downs and visual inspections had been performed from 2004 to 2006 to verify the aging status of SSCs of the plant. Degraded structures and components were listed up and informed to the field staffs for the replacement or improvement planning. Field walk-down and tests included wall thickness measurement of the buried pipes of emergency feedwater, fire and service water systems, inspection of carbon steel pressure vessels, heat exchanger performance test, installation of thermo-grapher for aging evaluation of power cables, and chemical ingredient analysis of soil. Figure 4 shows the inspection of buried commodity in the field. All the test results were used as input to the aging and life evaluation of SSCs.

Condition assessment were conducted to determine which SCs require an extended maintenance outage for replacement or repair and to decide which replacements or repairs may be made during normal maintenance outages. Basic information of the condition assessment can be obtained from the results of field walk-down, plant documents including design, construction, operation, inspection, and maintenance history, and other experiences of plant aging management.The assessment will also identify changes which are necessary to address issues that are related to equipment obsolescences, aging effects, and degradation.

3.3. Life assessment in detail

To conduct detailed life assessments of SCs, aging related degradation mechanisms (ARDMs) are identified and the aging effects of the ARDMs are reviewed by evaluating the design and material data of the SC with the operational and environmental conditions of the systems. Qualitative life evaluation as aging management reviews (AMR) of 10CFR54 as well as the quantitative life evaluation as the TLAA are carried out in the aging assessments. The life of a system is defined as the shortest life of a SC within the system boundary.

3.3.1. Aging mechanisms

For the aging evaluation of the screened SCs, aging mechanisms of the sub-components were reviewed using the aging mechnisms in the ASME Section III App. W that describes aging mechanism in operating nuclear plants,[8] American Concrete Institutes codes for structures,[9],[10] and Canadian practices introduced in the IAEA TECDOCs.[11],[12] In oder to select exact aging mechanisms for the sub-components, followings should be examined thoroughly and technically.

- Understanding of the aging mechanisms in operating nuclear power plants
- Susceptible operating environments that can cause aging degradation.
- Functions, materials, design, fabrications, and operating conditions of the sub-components
- Review technical documents and reports of experiences for degradation happened worldwide
- Select proper aging mechanisms for each sub-components based on above information

3.3.2. Review aging effects

Degradation tendency of the sub-components was evaluated for each aging mechanism derived from the information of design characteristics and operating environments. Material characteristics and properties are normally taken from the certificated material test report (CMTR) and the final safety analysis report (FSAR). Operating evironments could be working fluid, temperature, pressure, humidity, water chemistry, radioactive fluence, etc. Aging mechanisms to be evaluated for the SCs life evaluation were reviewed in this step with strategies for tecchnical aging evaluation and necessary data for the assessment. Table 1 shows a review example of aging effects of a heat exchanger.

Aging assessment items as of the TLAAs were identified using the definitions of the TLAAs explained in the regulatory requirement of the LTO. For the CANDU nuclear power plants, additional TLAAs should be considered for quantitative aging assessment. Life assessment of reactor assembly and fuel channels could be included in PHWR’s LTO applications as additional TLAAs instead of neutron embrittlement evaluation of reactor vessel of the PWR’s.

3.3.3. Life assessment

Once the aging effects review was done, the SSCs were evaluated whether they would maintain the intended functions and design integrities for the period of the LTO in technical manners. The intended fuctions should not be influenced by the aging effects during plant life time. After reviewing all the plant data records since the first reactor criticality, the lifetimes for which the SCs would remain sustainable were assessed by the method of the qualitative AMR and the quantitative TLAA. Many of aging assessments are normally qualitative based on worldwide aging experiences reported up to date. The TLAAs are reletively small items but takes lots of resources in engineering and scientific investigations.

AMR compares the material and operational status of a component in a plant with ones in others plants. If component aging databases of other plants do not mention any aging phenomena under the same material, design, operation history and environments, the components can be considered sustainable to the time of other plants' operations. However, the integity of the components needs to be monitored during the period of the LTO operation. Quantitative TLAA analyzes remaining life of SCs according to the well defined engineering procedures approved by code and standard organizations. Sometimes scientific research and technical development can be asked to confirm a trend of a specific aging or an unclear area of material degradation.

Table 2 summarizes an example of a component life assessment for corrossion degradation in terms of sub-components. Table 3 and 4 shows briefly the results of life assessment of a system and a component group respectively. The technical recommendaions in the life assessment results were to be the bottom of the aging management programs.

3.4. Aging management programs

Many recommendations from detailed life assessment of the PLiM phase II will be implemented through AMPs for the LTO operation. The AMPs are provided for the plant to maintain the intended functions of the SSCs during the continued operation period by refurbishment, replacement, design modification, performance monitoring, upgrading, and etc. Current maintenance activities listed by reviewing the plant working procedures are compared with other AMPs of on- and off-shore nuclear power plants.

New AMPs for the LTO of the plant are recommended to mitigate the recommendations deriveded from the detailed life evaluation. Figure 5 explains the process of reviewing AMPs for a nuclear power plant. Generic AMPs for LTO are well introduced in the GALL report but the CANDU plant specific ones have to be found out by the utility for continued operation.
AMP items can be referred to the ones of GALL (generic aging lessons learned) report of NUREG-1801. The AMPs listed in the GALL report have to be investigated thoroughly for the applicability and appropriateness for the CANDU plant and to find out additional AMP items because of the differences of plant design and configurations. Followings could be regarded as CANDU unique AMPs for the LTO application. Table 5 is an example of system AMPs that shows how the AMPs are related with the AMP regulatory requirements.

- Reactor assembly
- Fuel channels
- Feeders
- Non-metallic liner of containment building

4. Conclusions

PLiM and continued operation of operating NPPs beyond design life is one the hottest issue in Korean nuclear industry. Comprehensive and integrated PLiM program makes it possible to achieve safe, cost-effective, and reliable operation. It anticipates that PLiM programs will provide a good way of maintaining long-time operated NPPs and contribute to reducing the amount of CO_2 emission in Korea.

One-through process of detailed life assessment for a CANDU nuclear power plant has introduced the comprehensive experiences of PLiM project in Korea. For the long-term operation beyond the design life, PSR should evaluate plant safety including the aging assessments and AMPs applicable to the continued operation period.

Korean government noticed LTO requirements for the PWR plants in 2005 under the umbrella of PSR rule. PHWR requirements has not been declared yet but will be soon issued based on the same technical philosophy as the PWR's. Application of Korean lessons learned form PWR experiences of plant life management to CANDU nuclear power plants could be a strong point of nuclear industry worldwide in the future.

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[10] ACI, "Existing Nuclear Power Safety Related Concrete Structures," 1996

[11] IAEA, "Nuclear Power Plant Life Management Process; Guidelines and Practices for Heavy Water Reactors," IAEA TECDOC-1503, June 2006

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Table 1. Review agigng effects

Comp.	Sub-comp.	Material/Environment	Analysis	Aging Mechanism Note 1)				
				A2	A3	A4	A6	C14
Heat Exchangers	Tubes	Ti/Sea Wtr(IS), Demin Wtr(OS)	○Corrosion resistive Ti ○MIC/Fouling inside for sea wtr ○Fretting btwn tubes and tube plate	-	-	-	○	○
	Shell	SS/Dem Wtr(IS), Air(OS)	○Gen Corr by leaking of sea wtr	○	-	-	-	-
	Tube Plate	SS/Demin Wtr	○Fitting, crevice corr. for demin wtr ○Fretting btwnn tubes and tube plate	-	○	○	○	-
	Channel	SS(Ti clad)/Sea Wtr	○Fitting, crevice corr. for demin wtr ○Fretting btwnn tubes and tube plate	-	○	○	○	-
	Supports	CS/Air	○Gen corrosion for CS	○	-	-	-	-
Pumps	Pr Bndry	SS/Demin Wtr	○Fitting, crevice corr. for demin wtr	-	○	○	-	-
	Supports	CS/Air	○Gen corrosion for CS	○	-	-	-	-
Valves	Vv Body	SS/Demin Wtr	○Fitting, crevice corr. for demin wtr	-	○	○	-	-
Ion Exchanger & Filters	Body, Flng, Nz	SS/Demin Wtr	○Fitting, crevice corr. for demin wtr	-	○	○	-	-
	Supports	CS/Air	○Gen corrosion for CS	○	-	-	-	-
Pipes & Supports	Pipes	SS/Dem Wtr(IS), Air(OS)	○Fitting, crevice corr. for demin wtr	-	○	○	-	-
	Supports	CS/Air	○Gen corrosion for CS	○	-	-	-	-

[Note 1] A2 : Gen Corrosion, A3 : Pitting, A4 : Crevice Cor, A6 : MIC/Fouling, C14 : Erosion/Fretting

Table 2. An example of life assessment

Aging -SCs	Data	Aging Effect/Degradation	Assessments
Corr-RCP01	❍ Material: A351 Type CF8M CASS ❍ Des. T.: 650°F ❍ Des. Pr.: 2485psig	Aging Effects ❍ Loss of material Degradation ❍ CS comp. (IS corr.) ❍ Bolts (OS Corr.)	❍ No experiences in RCS piping ❍ Low inside corrosion of austenitic stainless steel for the protective film on the surface ❍ Good Water chemistry control of RCS. Low fluid velocity relatively. No bolting connection ❍ No findings from site walkdown and inspections ❍ Modified water chemistry and boron leak detection program would be proper for the LTO ❍ Justify a modified AMP item
Corr-RCP02	❍ Material: A351 Type CF8M CASS ❍ Des. T.: 650°F ❍ Des. Pr.: 2485psig	Aging Effects ❍ Loss of material Degradation ❍ CS comp. (IS corr.) ❍ Bolts (OS Corr.)	❍ No experiences in RCS piping ❍ Low inside corrosion of austenitic stainless steel for the protective film on the surface ❍ Good Water chemistry control of RCS. Low fluid velocity relatively. No bolting connection ❍ No findings from site walkdown and inspections ❍ Modified water chemistry and boron leak detection program would be proper for the LTO ❍ Justify a modified AMP item
Corr-RCP03	❍ Material: A351 Type CF8M CASS ❍ Des. T.: 650°F ❍ Des. Pr.: 2485psig	Aging Effects ❍ Loss of material Degradation ❍ CS comp. (IS corr.) ❍ Bolts (OS Corr.)	❍ No experiences in RCS piping ❍ Low inside corrosion of austenitic stainless steel for the protective film on the surface ❍ Good Water chemistry control of RCS. Low fluid velocity relatively. No bolting connection ❍ No findings from site walkdown and inspections ❍ Modified water chemistry and boron leak detection program would be proper for the LTO ❍ Justify a modified AMP item

Table 3. A result of a system life assessment

BSI	System	Cmpts	Assessment Results
33350	Purification Circuit	Purification Hx, Purification Cooler, Ion Exchanger, Vvs, Piping and Supports	◆Aging Mechanisms : SCC, general cor., fouling, FAC ◆Aging Assessment : Hx fouling O.K., TLAA (fatigue) and FAC no limit to LTO ◆Recommendations : Mgt of closed cooling circuit sys, water chemistry, ISI and FAC ➢ Transient counting for fatigue control ➢ Provide Hx. performance test procedure ➢ Mitigate thermal stratified piping
33410	Shutdown Cooling System	Shutdown Clg Pp, Shutdown Clg Hx, Vvs, Piping and Supports	◆Aging Mechanisms : SCC, general cor., pitting, crevice cor., fouling, FAC ◆Aging Assessment : Hx fouling O.K., TLAA (fatigue) and FAC no limit to LTO ◆Recommendations : Mgt of closed cooling circuit sys, water chemistry, ISI and FAC ➢ Transient counting for fatigue control ➢ Provide Hx. performance test procedure ➢ Mitigate thermal stratified piping

Table 4. A result of a compont group life assessment

Cmpt Group	Major Sub-cmpts	Assessment Results
Valves	Valve body and bonnet in pressure boundary	◆Scope : Valves of 29 systems (gate, globe, ball, diaphragm, butterfly, check) ◆Aging Mechanisms : erosion/erosion-corrosion, FAC, thermal embrittlement, fatigue ◆Aging assessment ▪ erosion/erosion-corrosion, FAC : Vvs on thin thickness piping ➢ Inspection by NSAC-202L-R3 (VT, RT) ▪ thermal embrittlement : 63332-PCV5, PCV6 ➢ ASME Section XI IWB Table 2500-1 ▪ fatigue : no limit to LTO ◆Recommendations ➢ Vv insp. plan for those on thin thickness piping ➢ ISI plan for thermal embrittlement suspicious Vvs (63332-PCV5, PCV6)

Table 5. An example of system AMPs

BSI	System	Cmpts	AMPs	MOST Notice of AMP
33310 33320	Pressure and Volume Control System	PZR, Degasser cooler, Degasser Condenser, Pps, Vvs, Piping and Supports	◆Performance test of degasser clr ◆ISI for themal embrittlement suspicious Vvs (63332-PCV5, PCV6) ❖Fatigue monitoring system ❖maintenance program for the bolts of man-way and supports	◆1. ISI of safety class 1,2,3 components ◆2 .Supports ISI ◆7. Chemistry control ◆23. Closed cool'g wtr sys. ❖CASS therm. Embrit. ❖15. Bolt tight integrity
33350	Purification Circuit	Purif. Hx, Purif. cooler, Ion exch, tower, Vvs	◆Perf. test of Purif. Hx and Purif. cooler ◆Thermal stratification piping mgt (piping line 3335-18, 19) ❖Fatigue monitoring system	◆7. Chemistry control ◆23. Closed cool'g wtr sys.

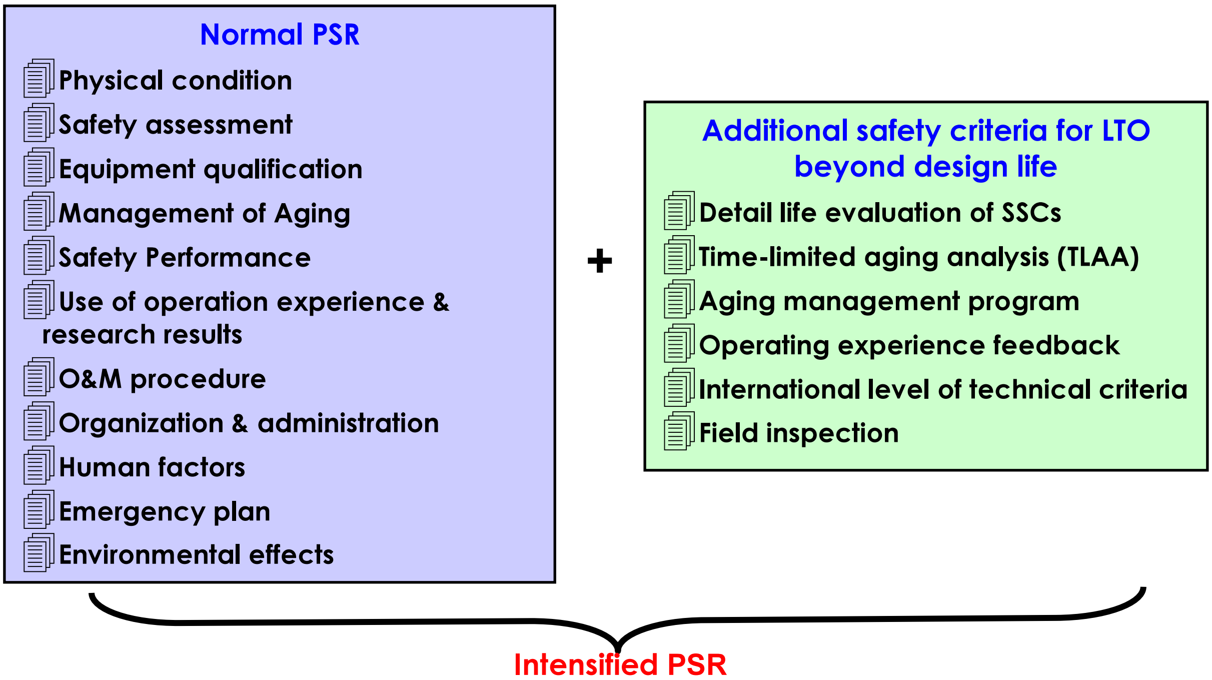

Fig. 1. Contents of the intensified PSR for the LTO

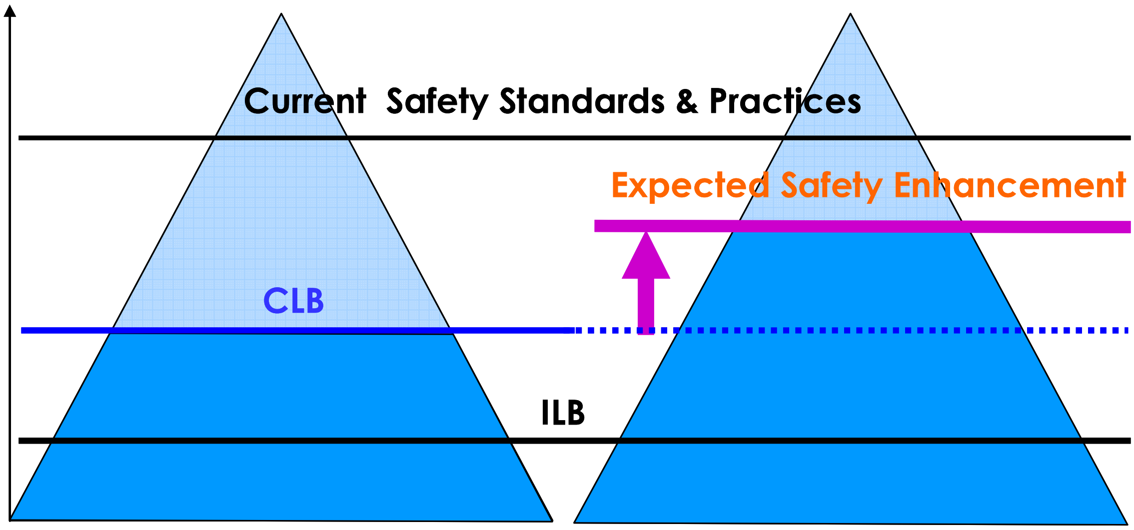

FIG. 2. Safety Enhancement of the intensified PSR for the LTO

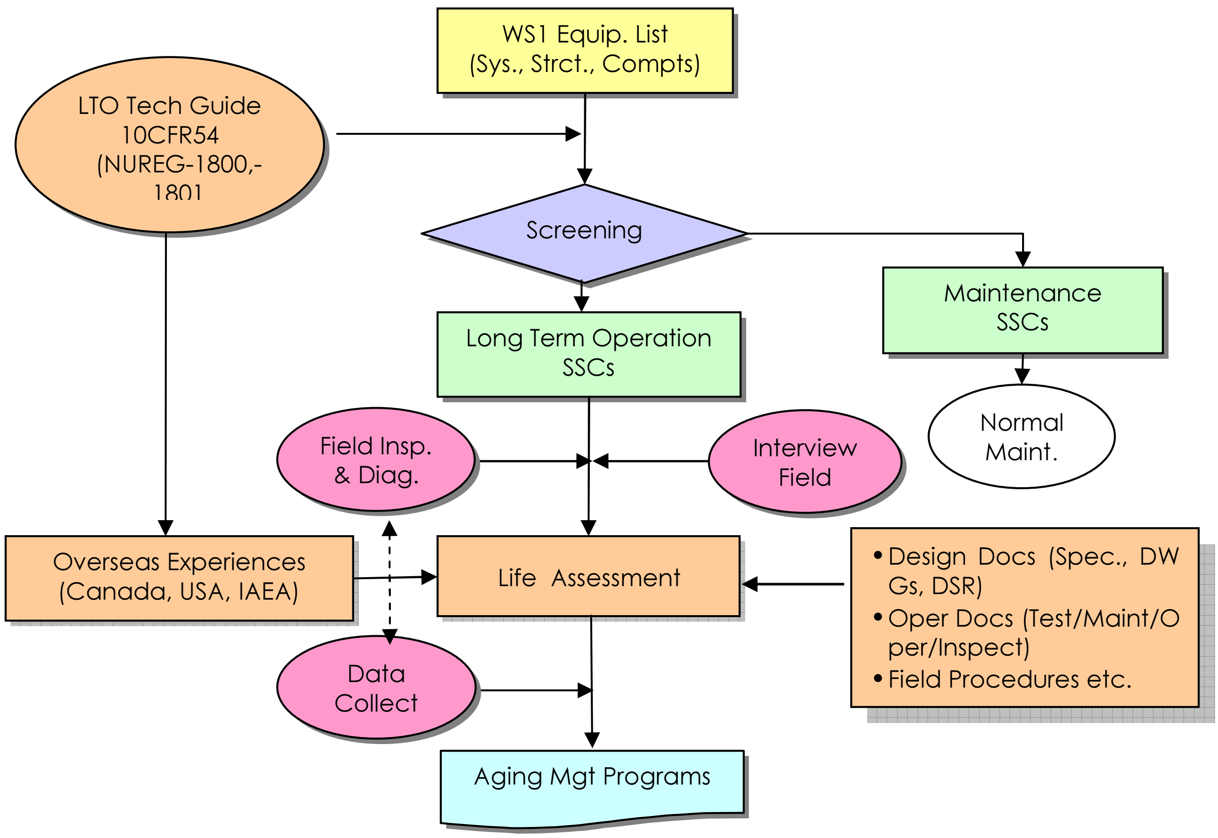

FIG. 3. In-detail life assessment of sructures and components

FIG. 4. Buried commodity inspection in the field

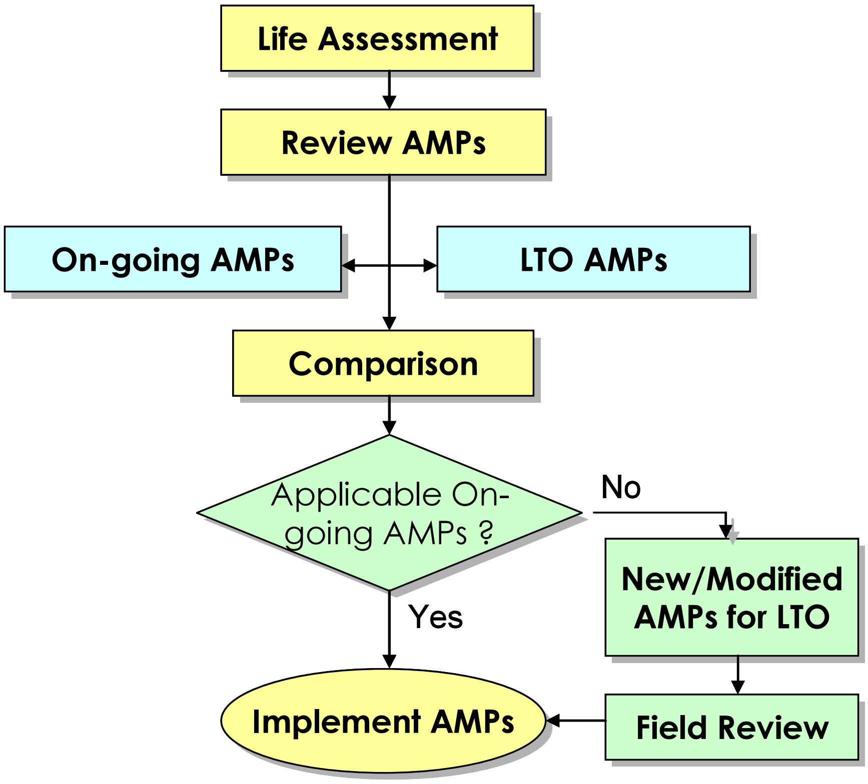

FIG. 5. Review of aging management programs