Nuclear Plant Lifetime Management Program of Korean Utility

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ABSTRACT

Twenty-two years have passed since Kori Unit 1, the oldest nuclear power plant in Korea, started to operate in 1978. To mitigate aging phenomena of nuclear power plants (NPPs) operated for a long time, nuclear power plant lifetime management (PLiM) program has comprehensively assessed current physical condition of operating plants by the ways of technical evaluations, performance monitoring, and field tests. The first phase of the program, PLiM (I), which had been done by Korea Electric Power Corporation (KEPCO), concluded in 1996 that it was technically and economically feasible to operate Kori Unit 1 continuously beyond the design life. Based on this result, the subsequent program, PLiM (II) has been performed since 1998. PLiM (II) have focused on evaluating detailed integrity of major structures and components, developing diagnosis techniques, and establishing aging management programs to ensure plant safety and reliability during the latter half of and beyond the design life. KEPCO is to provide aging management programs for Kori Unit 1 to operate up to the optimum life derived from the PLiM assessment. However well-planned PLiM programs are implemented for the continued operation of aged NPPs, structural integrity as well as plant safety have to be met with the current criteria of safety and performance. Systematic periodic safety review (PSR) can be used to verify the plant operating safety incorporating with the PLiM program. This paper introduces overall process of nuclear PLiM program, its relationship with PSR and summarizes the experiences and on-going status of Korean nuclear PLiM program that is supposed to be a good tool of continued operation.

1. INTRODUCTION

Sixteen nuclear power plants (NPPs) are currently operating and four under construction in Korea as shown in Table 1 with two types of reactors; pressurized water reactor (PWR) and pressurized heavy water reactor (PHWR). The oldest PWR plant, Kori Unit 1 has been operated to date for 22 years and the oldest PHWR plant, Wolsung Unit 1 for 17 years. The capacity factor has been maintained well over 84% in last 10 successive years. However, introduction of deregulation and competition in the electricity industry and generation system will certainly give a couple of challenges. First, the competition is getting tougher with bituminous coal plants. Second, the siting for new NPPs and financial funding with of low interest rate for new constructions have become quite difficult comparing with the past. Therefore, it is natural to make efforts to continue operating the older NPPs to compensate the difficulties of new NPP construction[1].

Several programs for the plant lifetime management have been performed to cope with the aging of operating nuclear power pants in Korea[2,3,4,5]. The first phase of Kori Unit 1 lifetime management program identified that the continued operation beyond its design life was technically and economically feasible. Now the second phase has been progressed. Also periodic safety review (PSR) program is adopted per recommendation of the International Atomic Energy Agency, which will be a very useful to assess and ensure the safety of operating plants and contribute to plant lifetime management (PLiM)[6].

Nuclear PLiM is all related technical activities to maintain operating safety and performance of the plants up to the economically optimum life. Nuclear plant safety has not to be affected and degraded by aging phenomena during the whole operating period. NPP aging can be taken account into two parts; the physical aging resulting in deterioration of physical and performance characteristics of systems, structures, and components (SSCs) and the non-physical aging resulting in obsolescence of the plant systems in comparison with current safety concepts, standards and technology[7]. Korean utility deals physical aging with the plant lifetime management and non-physical aging with the periodic safety review (PSR). This paper introduces overall process of nuclear PLiM program rather than technical details, its relationship with PSR and summarizes the experiences and on-going status of Korean nuclear PLiM program that is supposed to be a good tool of continued operation.

2. NUCLEAR PLiM AND PSR

2.1 Safety

Plant safety is the first thing that we should consider in nuclear plant operation and lifetime management. To operate plants safely and prevent plants from failure of their functions, utility implements comprehensive programs, such as preventive maintenance programs, refurbishment of degraded structures and components (SCs), and quality assurance programs of safety systems. In order to maintain the safety level acceptable, plant staffs carry out periodic inspections, in-service performance tests of operating components, and monthly safety diagnosis according to the technical specification of the plant and regulatory guidelines.

However, the plant safety can be affected by the status of system performance that could be dependent on the structural integrity and degradations of the SCs belong to the system. To solve this issue IAEA guides member states to implement PSR as a tool of ensuring a high level of safety throughout plant service life. Reviewing plant safety in every 10 years, PSR can deal with the cumulative effects of plant aging, modification, operating experience, and technology evolutions.

2.2 Lifetime management and PSR

Proper lifetime management can keep plant safety as the reference level set at the stages of design and construction. PLiM controls, within acceptable limits, aging degradations of the SSCs so that there remain adequate integrity, functions and safety margins in excess of their normal operating requirement. The result of PLiM program can be used as an input to a safety factor of PSR, "management of aging". Other safety factors besides the management of aging are actual physical condition of NPP, safety analysis, equipment qualification, management of aging, safety performance, use of experience from other plants and research findings, procedures, organization and administration, human factors, emergency planning, environmental impact[8].

By performing PSR adequately, utility can confirm the plant safety periodically and through the whole service life of nuclear plants, which also makes it possible to diagnose the current activities of safety enhancement and show the efforts of utility's safety upgrade. Incorporating the results of PLiM program, PSR finally concludes the compliance of current safety level of the plant to the regulatory safety requirements. Current safety practices of the field can be improved, by repeating PSR, for reflecting the experiences and lessons learned from precedent failures, incidents, malfunctions, mitigation, and safety upgrades of other NPPs in the world.

2.3 Depth and scope

All of the plant SSCs, both the passive and the active, is dealt in PSR but PLiM basically focuses on the long lived passive components which are relatively hard to replace and refurbish in normal operation. However, technical depth of engineering PLiM is deeper than PSR because it includes comprehensive evaluations, such as quantitative time limited aging analysis (TLAA), residual life estimation, field test and examination, diagnosis and monitoring, and aging management programs (AMPs). Table 2 classified the scope PLiM in terms of aging management and maintenance with example of SCs. Figure 1 simultaneously tells the scope and depth of evaluating the SCs of PLiM from ones of PSR.

Because most of the SCs excluded from the PLiM are usually short-lived active components, they are scoped into the aging management of PSR, and the engineering level of life evaluation is not complicate and deep as much as that of PLiM. PSR reviews the current physical status and records of maintenance and inspection done to the components in the past. Comparing the review results with current safety standards and practical experiences on- and off-shore in terms of aging and maintenance, utility revises the technical procedures and plans how to improve the system safety and slow down the degradation of SCs for the next 10 years. So the depth of PSR engineering evaluation is shallower but the scope is wider than that of the PLiM.

3. NUCLEAR PLiM PROGRAMS

3.1 Strategy

PLiM has a strong possibility not only to solve the plant aging and maintenance obsolescence but also to provide the vision for continued plant operation beyond the present design life. The primary goal of PLiM is to operate nuclear plants safely and economically for the design life of the plants. If this primary goal is achieved, then the operation of NPPs beyond the original design life will be pursued as the secondary goal up to operate plants up to their optimum life. In order to continue the operation of older NPPs, plant safety and integrity have to be justified technically and reviewed through a regulatory body.

Nuclear PLiM program of Korean utility usually consists of three phases as tabulated in Table 3. In the first phase, a feasibility of the continued operation is evaluated in terms of technical, economical and regulatory aspects to support top manager's decision whether continuing to operate the plant. Once the policy is determined to operate the plant continuously on the basis of the feasibility study, the second phase program works out to evaluate detailed lives of SSCs and to establish aging management programs together with field walk downs, tests, diagnosis and aging inspections. If the license for the continued operation is endorsed by the regulatory body through PSR, the aging management programs are implemented to the field in the step of the third phase with replacing aged components, installing new performance monitoring systems, and improving obsolescent systems in the following outages as scheduled.

3.2 Status

Kori Unit 1 and Wolsung Unit 1 are the leading plants of Korean PLiM program in developing technologies and field applications to the PWR and PHWR plants respectively. PLiM phase I of Kori Unit 1 to see the feasibility of continued operation had been done in 1996 and phase II program was started in 1998, detailed life evaluation and integrity assessment of SSCs to provide AMPs during remaining service life. While performing PLiM study of Kori Unit 1, pressurized thermal shock evaluation for the reactor pressure vessel (RPV) of Kori Unit 1 was completed in 1998 to verify the integrity of the aged RPV which could be the most life limiting component[9].

In 2000 KEPCO started PHWR PLiM program of Wolsung Unit 1 to verify the feasibility of continued operation. Though some generic technologies of PWR PLiM could be used in PHWR, to deal with the inherent degradation mechanisms unique to the PHWR SSCs, technical methodologies of CANDU have to be applied to the plant. Because PLiM evaluation has to address structural integrity and functional performance of the overall plant, all the SCs of CANDU systems has to be technically evaluated plant-specifically using verified techniques currently.

Figure 2 depicts the generic process of nuclear PLiM technical evaluation that is being used in the Korean utility PLiM program. If the feasibility of the continued operation is verified based on the results of the phase I study, utility management lets phase II be started in accordance with the recommendations from the previous study. If a technical issue from the recommendations is shown as so critical that impacts the whole PLiM and PSR program such as the PTS issue of Kori 1 reactor pressure vessel, the issue has to be resolved by an independent program in parallel with or before next phase PLiM program. Phase III implements the AMPs of the phase II to field with the schedule of PSR corrective actions. This general approach of nuclear PLiM program is applicable to both PWR and PHWR typed nuclear power plants.

3.3 Technical Approach

3.3.1 Component Screening

Identification of critical components for aging evaluation is an important step of the PLiM phase I efforts, because it is necessary at the beginning of the PLiM program to ensure the proper focus of nuclear PLiM efforts to allocate resources. The screening process applies safety-related criteria based upon the US license renewal rule (LR) and the maintenance rule (MR), described in 10CFR54 and 10CFR50.65 respectively. Power production (PP) related criteria based on plant availability and other safety requirements are also applied in the screening process. After screening critical SCs as shown in Figure 3, they are to be identified and prioritized to determine their relative importance to the PLiM. Critical components were prioritized utilizing ten attributes selected to assess the impact of component replacement or refurbishment on continued operation like cost of replacement or refurbishment, impact on plant availability, radiation dose, etc.

Most of screened SCs would be long-lived passive SCs that are costly and technically difficult to resolve degradation because it is hard and expensive to replace or there are, sometimes, no precedent experiences. Other long-lived passive components discriminated from the PLiM and active ones of the plant that are relatively easy to replace or refurbish are to be assessed in the viewpoint of preventive maintenance and PSR. PLiM can be thought divided as an area of aging management for the long lived passive SCs and another area of maintenance for active ones as shown in Table 2.

Nuclear PLiM reviews the aging effects of long-lived passive components and establishes aging management program to sustain the integrity and safety of plant components throughout lifetime. Because the integrity of the active components can be maintained by casual or preventive maintenance, they are excluded from the scope of the aging management but have to be properly kept up good performance by optimum preventive maintenance programs. If an active component is considered important for power production and maintenance by field staffs, it could be included in the scope of PLiM program.

3.3.2 Engineering Evaluations

<u>Sub-components</u>

In order to ensure the feasibility of continued operation, it has to be demonstrated that critical sub-components of a SC can maintain reliable service condition for the component through the whole service life. A detailed list of all the sub-components contributing to the intended functions of a SC is provided. Based on the risks and damage histories of the sub-components, critical sub-components affecting the integrity and functions of the SC are selected as items that need aging evaluation.

Screening sub-components is processed through several activities. The first step is to derive the list of all sub-components with the references of FSAR, the equipment specifications, and so on. The second is to characterize the sub-components considering function, geometry and design features. The third selects critical sub-components using screening criteria and groups them, if necessary, to make engineering evaluation convenient. Safety-related, long-lived passive, failure history, availability of repair or simplicity of replacement, and others could be regarded as points of engineering judgement in screening. By the result of taking these steps, the sub-components that need aging assessment and management are to be listed with technical rationales why they are screened as SCs important to the PLiM.

Aging mechanisms

After screening the sub-components, identification of age-related degradation mechanisms (ARDMs) should be performed. The first one is to determine ARDMs that might, generically, affect the integrity of the selected sub-components. Numerous industry and regulatory technical documents, report, and nuclear PLiM experiences are reviewed to provide a technical procedure and evaluation methodology in the process of Figure 3. Identified potential ARDMs with evaluation methods are compiled as a list of aging mechanisms. The list includes a discussion for various aging stressors that cause or exacerbate the ARDMs.

Then the next step is to identify those ARDMs that are applicable to the specific sub-components being evaluated. To assess aging effects of ARDM to the components and to find the relationship of them the matrix of ARDMs and sub-components is tabulated. At this point, material characteristics, operating environments, maintenance history, etc. of the specific sub-components are being considered for making the matrix. Potential ARDMs will be listed with technical rationales and be used to manage the aging of each SCs.

Life evaluations

The main purpose of the life evaluation is to assess whether the integrity of sub-components are maintained, the aging phenomena occur or advance, and there is a sufficient margin for the integrity of component during operating period. The procedure of the life evaluation is divided into three tasks; pre-evaluation, quantitative qualitative evaluations in detail, and integrated life evaluation. The pre-evaluation usually done in PLiM phase I is summarized as followings; (1) review of design documents including design stress reports, design specifications, certificate of material test report (CMTR), geometric drawings, etc., (2) review of failure history and maintenance, and (3) determine whether the review results satisfy design acceptance criteria.

For the results of life evaluations are normally reviewed by the objective regulatory bodies to justify continued operation of a plant, aging mechanisms not applicable to a component have to be justified why they are not addressed in the life assessment of it. The quantitative detailed evaluations are usually performed when the results of pre-evaluations do not meet the acceptance criteria of structural integrity. The qualitative evaluations most part of PLiM phase II life assessment are performed by investigating the following activities; review of operating condition and maintenance history, evaluation of plant specific aging effects, and determination of whether the result of aging evaluation satisfies operating acceptance criteria.

In the integrated life evaluation, residual lives of SCs are determined by reflecting the results of site walk down, examinations, monitoring or tests as well as detailed evaluation performed. These are integrated into the activities of establishing aging management programs (AMPs) of SCs to keep plant at the required level of safety and integrity up to the optimum life of utility PLiM program. Figure 4 shows the process of detailed life evaluation in PLiM program

Aging management programs

Aging management programs provide utility timely detection and mitigation of significant aging effects of NPPs to ensure their integrity and functional capability and to contribute to the safe and reliable plant continued operation. From the integrated life evaluation, long-lived passive components may need to have AMPs to sustain their intended functions against aging. Most suitable AMP to a component will be determined based on the result of sub-component aging evaluation and understanding current aging status of a component. To develop proper AMPs, existing one in the fields and other experiences of domestic and offshore NPPs have to be reviewed. Unless a proper AMP is found for the aged component, there would be required to plan an R&D to resolve, control, or monitor degradations caused by specific aging phenomena.

For the aging management of SCs, existing programs in field are surveyed including in-service inspections and surveillance test experiences as well as operations, technical support, and external programs like R&Ds. Existing AMPs are usually well mitigate the aging effects occurring in operating plants. When, however, a new degradation mechanism is revealed by engineering evaluation or existing programs are not sufficient to control the aging mechanisms, additional AMPs would be implemented to the field as one of the PSR corrective action items. While planning AMPs of a nuclear plant, it is important to consider an economic aspect of decisions on the type and implementing time of the aging management actions for the competitiveness of nuclear power operation.

3.3.3 Performance Monitoring and Field Tests

System performance monitoring

Even though the lifetime management program assures the integrity and safety of SSCs, aging progress and current status of long operated NPPs have to be monitored and any symptom of system function failure be checked up periodically in normal operation to prevent plants from being degraded. Field walk down, aging monitoring, system performance diagnosis and in-situ tests are necessary to verify the current status of plant conditions, which should be monitored nevertheless the plant is well maintained to the level of safety required to put the plant in service. These activities support the technical life evaluation of the major SCs to understand correctly current physical aging and also can be used as AMPs for continued operation utilizing the existing ones.

Currently available monitoring systems for each degradation mechanism were identified by considering not only the monitoring systems of newer domestic NPPs but also additional new systems, such as radiation embrittlement monitoring of reactor pressure vessel material, fatigue and transient monitoring, and a cable condition monitoring system. Monitoring systems and tools developed for the aging management of Korean NPPs are listed in Table 4.

Field test and inspections

Field data earned by inspections, examinations, or tests are used as input of technical evaluation when the collected data are not sufficient to perform engineering. For example, the ferrite content of material is a dominant factor in analyzing thermal embrittlement of reactor coolant system (RCS) piping made of cast austenite stainless steel. Whereas the ferrite content data in the CMTR of RCS piping of Kori Unit 1 was high so that it was resulted to have high susceptibility of thermal embrittlement. So field test to get the actual ferrite contents of the pipe was performed with a surface ferrite tester of during outage, and the field data could justify the susceptibility of thermal embrittlement was low.

Another typical one of the field inspections for nuclear PLiM can be the aging diagnosis of the buried commodities and structures which seems to be low priority in normal plant operations and maintenance. To diagnosis aging of the buried commodities and structures procedures of field walk down was developed for Kori Unit 1. The procedure deals with structures of steel and concrete and buried commodities. In performing walk down and reviewing the status of aging visual inspection technique was mainly used by PLiM technical staffs. PLiM usually recommends to perform field tests and aging management with others of cable aging diagnosis, field test of vibration and thinning integrity for main steam and feed water piping, thermal stratification test of pressurizer surge line, and leak detection of branch lines connected to RCS piping.

3.4 PLiM Database

In order to carry out nuclear PLiM program effectively it is very important to collect and keep the records of component design, manufacturing, operation, maintenance, replacement, and betterment histories. For the case of old plants, besides them, it is also required to survey the status of back-fit implementation, experience of technical procedure changes, and safety upgrades to evaluate non-physical aging. As a prerequisite to the evaluation of the plant aging status, a voluminous amount of plant design and field data, accumulated since plant construction, should be surveyed and reviewed. This is an essential process of PLiM and performed on the plant-specific basis, which would require tremendous amount of resources for reproducing useful data from the raw.

Followings are examples of necessary data for the PLiM technical evaluation, they could be general methodology and technical references, engineering procedures, operating transient history and experiences, component design specification and manufacturing data, maintenance practices and experiences, in-service inspection and surveillance data, results and procedures of life evaluation, aging management program and its implementation schedule, and the contents of related R&Ds.

All the information and data produced by life assessment and economic evaluation in PLiM program have to be kept in PLiM database, which has to be so well organized that aging management related parties can share and use it to verify plant integrity objectively. The database should be updated periodically by PLiM coordinator and be input with newly produced data throughout plant service lifetime. PLiMDB was developed to facilitate the database that is operating on Web site in order to share PLiM data with related personnel or organizations and to utilize it further in public acceptance.

4. CONCLUSIONS

Continued operation of an existing nuclear power plant through a proper lifetime management can help utility resolve the increasing domestic power demand avoiding huge investment for new NPP constructions. The nuclear PLiM is at present one of the most important tasks in the Korean nuclear programs as Kori Unit 1 becomes aged. PSR supplements the PLiM engineering evaluations of structural integrity and system functions with reviewing current status of operating NPPs in comparison with current safety standards. This paper introduced the relationship between PLiM and PSR in terms of purpose, scope, and depth.

To explain Korean nuclear PLiM program of utility, PLiM strategy, on-going status, and technical approach were introduced. The technical approach dealt with overall process and items to be considered in nuclear PLiM based on lessons learned and experiences of Kori Unit 1 and Wolsung Unit 1 PLiM programs. The general sequence of technical evaluation in nuclear PLiM was in turn explained. That is to screen SSCs important to PLiM, to perform engineering evaluations, and to do system performance monitoring and field tests. The engineering evaluation consists of screening sub-components, identifying aging mechanisms, life evaluations, and establishing aging management programs for aged SCs. All the data collected and results from PLiM program has to be stored and kept in systematic database in that related parties of nuclear industry can share and use it to verify plant safety and integrity objectively.

Korean utility was fortunately ready to apply PSR to operating domestic NPPs because nuclear PLiM program has been carried out last decade. We believe that well-harmonized PLiM program with implementing PSR is so useful for utility to diagnosis system performance and integrity of SCs and to keep plant safety at the level of regulatory requirements. Another contribution of PLiM to nuclear utility is expected to reduce the financial burden of new plant construction and to increase industrial competitiveness of nuclear power production. Furthermore, continued operation of NPPs by PLiM evaluation shall be one of countermeasures to mitigate greenhouse effect of carbon dioxide.

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Table 1 Profile of Nuclear Power Plants in Korea

Plants		Reactor types	NSSS suppliers	Capacity (MWe)	Year of Commercial Operation	Capacity Factor in 1999 (%)
Kori	#1	PWR	Westinghouse	587	1978	85.2
	#2	〃	〃	650	1983	97.1
	#3	〃	〃	950	1985	90.5
	#4	〃	〃	950	1986	89.0
Wolsung	#1	CANDU	AECL	678	1983	82.8
	#2	〃	〃	700	1997	90.8
	#3	〃	KHIC	700	1998	82.0
	#4	〃	〃	700	1999	103.0
Yong-gwang	#1	PWR	Westinghouse	950	1986	84.5
	#2	〃	〃	950	1987	84.3
	#3	〃	KHIC	1,000	1995	89.1
	#4	〃	〃	1,000	1996	91.8
	#5	〃		1,000	-	construction
	#6	〃		1,000	-	〃

Plants		Reactor types	NSSS suppliers	Capacity (MWe)	Year of Com. Operation	apacity Fctr in 1999 (%)
Ulchin	#1	PWR	Framatome	950	1988	89.4
	#2	〃	Framatome	950	1989	97.9
	#3	〃	KHIC	1,000	1998	83.5
	#4	〃	〃	1,000	1999	88.2
	#5	〃	〃	1,000	-	construction
	#6	〃	〃	1,000	-	〃
Sum		-	-	17,715	-	86.2

Table 2 Scope of PLiM with example of major structures and components

	Work Scope	Classifi-cation	Structures and Components
Plant Lifetime Manage-ment	Aging Manag-ement	Long lived passive compo-nents	Reactor pressure vessel, Reactor pressure vessel internals, Steam generator, Pressurizer, Reactor coolant pipe, Nuclear fuel channel, Pressure tube, Supports, Containment building, Concrete and steel structures, Cable, Pressure vessels, Heat exchangers, RC pump bodies, and so on.
	Mainte-nance	Short lived active compo-nents	Control rod, Control rod drive mechanism, Pumps, Fans, Valves, Motors, Heat exchange tubes, Heaters, Turbines, Generator, Diesel generator, Air Compressor, Instrumentation and control systems, Electrical systems, Filters, Moisture separators, Nuclear fuel facilities, and so on.

Table 3 Phases of nuclear PLiM program

Phases	Period	Contents
Phase I	2-3 years	- Feasibility study of the continued operation - Evaluation the feasibility in terms of technology, economy and license
Phase II	3-4 years	- Detail life evaluation and provision of aging management program - Comprehensive safety evaluation and license acquirement
Phase III	7-8 years	- Implementation of the aging management program and components replacements for the continued operation

Table 4 Monitoring Systems developed in the PLiM of Kori Unit 1.

Monitoring Systems	Aging Mechanisms	Components or Systems
Cable Aging Tester (CAT)	Jacket Hardening	Cables
Environment Temperature Monitor (TEM)	Environment Temperature	
Transient Auto Counting System (TACS)	Fatigue	Pressure Boundary Components
Monitoring Inherent System Performance (MISP)	Intended Function	General Systems
Component Performance Analysis for IST (CoPAIST),	Operating Function	IST related Components
Ex-vessel Neutron Dosimeter (END)	Neutron Embrittlement	Reactor Pressure Vessel
Detection for Isolation Valves Internal Leak (DIVIL)	Thermal Stratification by Internal Leak	Pressure Boundary Valves

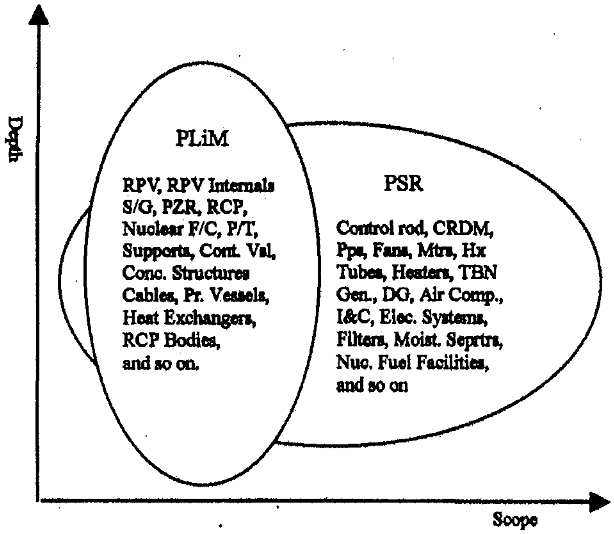

Figure 1 The Scope and Depth of PLiM and PSR

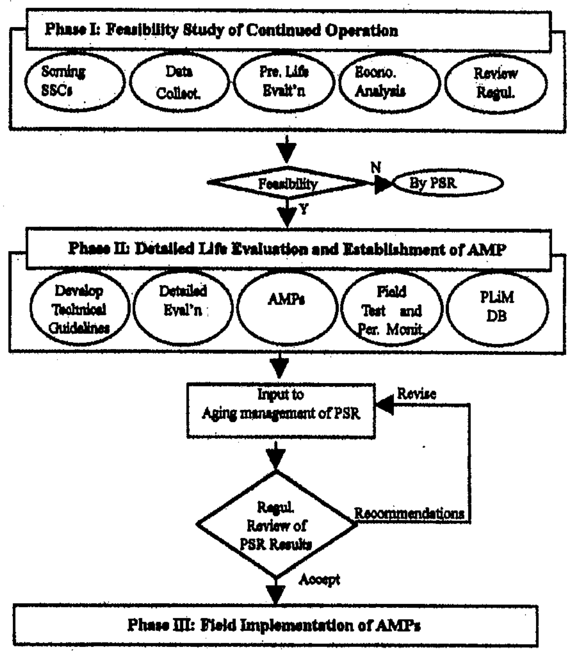

Figure 2 Generic Process of Nuclear PLiM Program in Korea

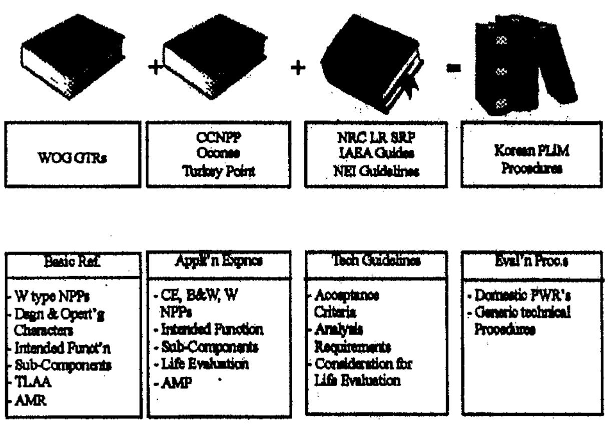

Figure 3 Developing Technical Procedure and Evaluation Methodology

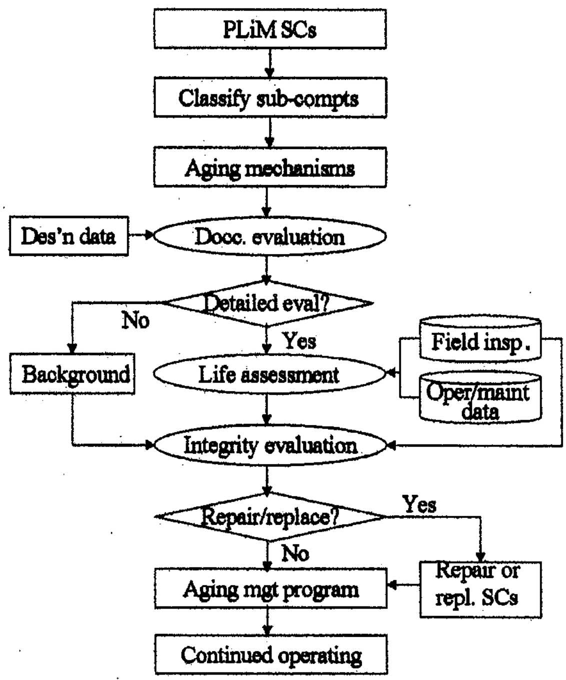

Figure 4 Detailed Life Evaluation of SCs