

# Development of reutilization system for Nuclear Power Plant Component using Object-Oriented Systems Engineering Method

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**Abstract** : The purpose of this study is to establish a component reutilization system in Nuclear Power Plant (NPP) by Object-Oriented Systems Engineering Method (OOSEM). Unified Modeling Language (UML) is mainly used for OOSEM. Operational Concept (OpsCon), Use cases, Structure Diagrams, and Behavior Diagrams are developed to analyze stakeholders needs, system requirements, logical architecture, and physical architecture. Based on the current decommissioning and purchasing system of the component, some activities from their systems were excepted and additional new activities were developed for a component reutilization system.

**Key Words** : Reutilization, NPP Component, OOSEM, UML, Class diagram

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## 1. Introduction

Kori unit 1 Nuclear Power Plant (NPP) is planned to be decommissioned in 2017 even though new reactor vessel head assembly and emergency diesel generator (EDG) were installed in 2013. In the USA, San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 also were permanently shutdown in 2012, just after the steam generator replacement in 2010 and 2011, respectively. These unexpected shutdown of NPPs makes many components still worth using to be the waste.

Components are normally decommissioned by some proper processes; normally from detaching, pre-decontaminating, dismantling, post-decontaminating, transporting, and finally disposal in Low Level Waste (LLW) disposal facility.

Nowadays, a study on recycling of the metal wastes generated from nuclear facilities was issued[1]. The study introduces the melt decontamination of decommissioning metal wastes as an effective recycling technology for the waste volume reduction. Even steam generator (SG) which is the biggest component and highly contaminated can be partly recycled as clearance level (negligible radioactive level) ingots[2]. These studies define the recycling as the process including wastes melting and reusing of the materials.

Reutilization in this study, which differs from the recycling in previous studies[1][2], means reusing of the used components for their original functions. Reutilization is more economical than recycling because reutilization can not only reduce decommissioning cost for decommissioned NPP owner but also supply useful component for an urgent demand of other NPPs.

In case of sudden failure of a main component

in a NPP, reutilization of the component of the same type from a decommissioned NPP can be one of the options to solve the problem instead of shutting down the NPP and waiting for the new component fabrication. Actually, there was a real case in the USA. Davis-Besse NPP had to be urgently shut down with a serious problem at the reactor vessel head (RVH) in Feb. 2002. FirstEnergy, Davis-Besse NPP owner, could replace the RVH in March 2004 by utilizing the unused, similar design head from the cancelled Midland plant. Considering that new RVH was manufactured and replaced in 2011, FirstEnergy could generate electricity for additional seven years by using RVH on the shelf, and save the revenue loss.

It is evident that each NPP has their specific components which are uncommon and therefore utilizing them is somewhat challengeable. It should, however, be noted that rare important components are not always supplied easily on time and this is the reason why demanders should consider a component reutilization.

On the other hand, reutilizable component owners who are encountered unexpected decommissioning could have an option to reduce decommissioning cost exporting their useful components.

A component reutilization system which was developed from this study provides an alternative for both component demander and reutilizable component owner.

However, no reutilization system has been established for the reusable components from the decommissioned NPPs. The reutilization system consists of all activities and actors for the reutilization which defined before.

In this study, a development for the reutilization

system was conducted by Object Oriented Systems Engineering Method (OOSEM). Based on the current decommissioning and purchasing system of a component, some activities and actors from their systems were excepted and additional new activities and actors were developed for the establishment of the reutilization system.

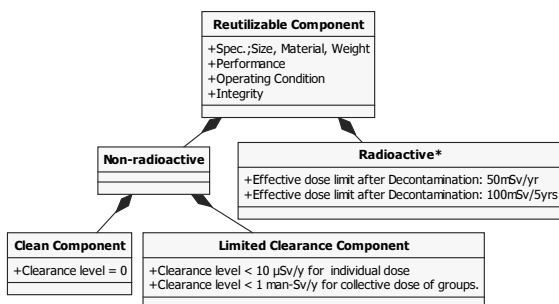
## 2. Methodology

### 2.1 Scope

A component is an assembly of parts which performs independent functions such as pressure vessel, pump, piping, heat exchanger, etc.[3]. In this paper, a component is defined as Figure 1. A component has its unique characteristics such as Specification, Performance, Operating Condition, and Integrity. A component can be classified as Non-radioactive or Radioactive according to its radioactivity. Currently, a component which is classified as Radioactive may not be allowed by the regulation.

Component reutilization in this study means that a component dismantled from a decommissioned NPP can be reutilized in any other NPP, operating or under new construction.

Decommissioning system is previously described, and purchasing system for a component normally falls into three categories: <Supply>, <Install>



[Figure 1] Definition of a reutilizable component

and <Inspection>. Firstly, a component may be supplied by a vendor and then installed in a NPP. After installation, component inspection is done by inspectors. Decommissioning system and purchasing system are illustrated in Figure 5 as packages.

In this study, some activities for the component reutilization will be adopted from the decommissioning and purchasing systems. Unnecessary activities such as dismantle, dispose, and supply are excepted. Additionally, a new activity is developed for the component reutilization.

### 2.2 Assumption

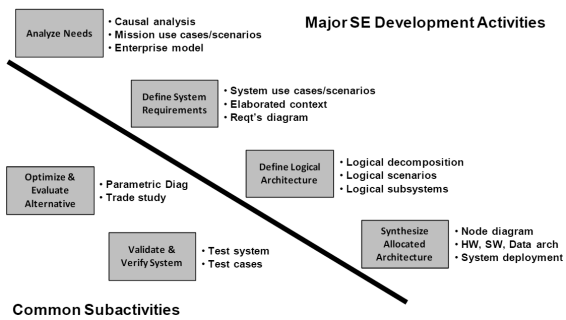
Reutilization of radioactivated components such as steam generator, reactor coolant pump, and fuel handler are assumed to be allowed in this paper though current regulation does not clearly allow it. All things related to a radioactivated component are star marked in all Unified Modeling Language (UML) diagrams of this paper.

A reutilizable component is assumed to be prepared by decommissioned NPP owner waiting for a requirement from a demander who wants to use the component.

All actors in UML diagrams are assumed to have abilities for their activities. For example, transporter is assumed to have an available transportation for the reutilizable component.

### 2.3 OOSEM

OOSEM integrates object-oriented concepts with model-based and traditional SE methods to help architect flexible and extensible systems that accommodate evolving technologies and changing requirements. Object-oriented concepts



[Figure 2] OOSEM activities [4]

that are leveraged in OOSEM include classes in UML and objects, along with the concepts of encapsulation and inheritance[4]. OOSEM activities are illustrated in Figure 2; upper four activities and lower Validate & Verify (V&V) subactivity were described in chapter 2.5. As a test case for V&V, polar crane utilization system was developed. Polar crane can be a representative test case because it is a Non-radioactive component, so that there is no current regulation issue regarding radioactive control.

## 2.4 UML

In the 1990s, a new modeling language that incorporated object-oriented concept was formalized: the UML[5]. UML 2 provides system designers with 14 different diagrams to show different system characteristics. They are divided into two groups: Structural Diagrams and Behavior Diagrams. Structural Diagrams show the static structure of the objects in a system. That is, they depict those elements in a specification that are irrespective of time. On the other hand, behavior diagrams show the dynamic behavior of the objects in a system, including their methods, collaborations, activities, and state histories. The dynamic behavior of a system can be described as a series of changes to the system over time.

In this study, following UML 2 diagrams were used: Class, Component, Deployment, Activity, Use Case, State Machine, and Sequence diagrams.

All diagrams are developed by StarUML Ver. 2.7.0 which applies UML 2.

## 2.5 OOSEM using UML

OOSEM proceeded through following 5 steps.

### 2.5.1 Step 1: Analyze Stakeholder Needs

This activity supports analysis of both the “as-is” and the “to-be” enterprise. OOSEM specifies the mission requirements for the “to-be” enterprise to reflect customer and other stakeholder needs. This paper developed Operational Concept (OpsCon) and Mission Use Case in this step. OpsCon is an Operational Concept articulates a vision for what the system is, a statement of mission requirements, and a description of how the system will be used.

### 2.5.2 Step 2: Analyze System Requirements

This activity specifies the system requirements that support the mission requirements. This paper developed System Use Case and Capability in this step. Capability is the ability to achieve a desired effect under specified performance standards and conditions through combinations of ways and means activities and resources to perform a set of activities. The Operational Concept and the Use Cases require Capabilities in order to be implementable.

### 2.5.3 Step 3: Define Logical Architecture

This activity includes decomposing and partitioning the system into logical elements. This paper developed Structural and Behavior Diagrams such as Class Diagram, Activity Diagram, Sequence

Diagram, and State machine Diagram in this step.

### 2.5.4 Step 4: Synthesize Candidate Physical Architectures

Logical elements are allocated to physical elements. This paper developed Component Diagram and Deployment Diagram in this step.

### 2.5.5 Step 5: Validate and Verify System

As one of the common subactivities, this activity verifies that the system design satisfies its requirements and validates that those requirements meet the stakeholder needs.

As previously described before, polar crane was chosen for a test case. Class Diagram of a polar crane in Figure 14 is a representative reutilization system design and Use Case in Figure 5 is the requirements of the system. Operational Concept in Figure 3 is the stakeholder needs for the validation.

### 2.6 Limitation

Since the reutilization of radioactivated component has not been tried by nuclear industry, there is no prior reference. However, this study includes reutilization of radioactivated components because of their potential benefits. Alternatively, existing regulations for safety such as the effective dose limit for radiation workers are considered.

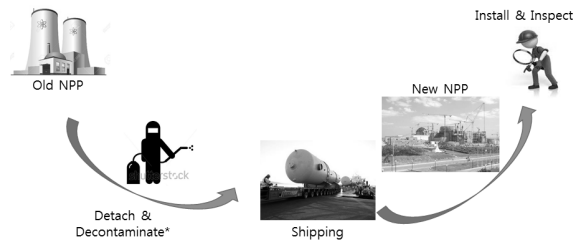
Though the main issue of the component reutilization is the cost benefit, actual calculation is excluded from this study. Studying the cost estimates of NPP plants, it was clear that there is no standard methodology for categorizing the costs of decommissioning. Also, publically available decommissioning cost information for some plants does not include a breakdown of the costs, and even the breakdown of

costs is considered to be confidential[6].

## 3. Developments and Results

### 3.1 Step 1: Analyze Stakeholder Needs

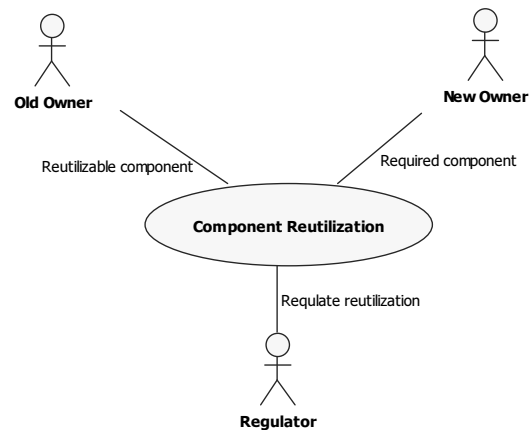
In this step, OpsCon and Mission Use Case are developed as Figure 3 and 4, respectively.



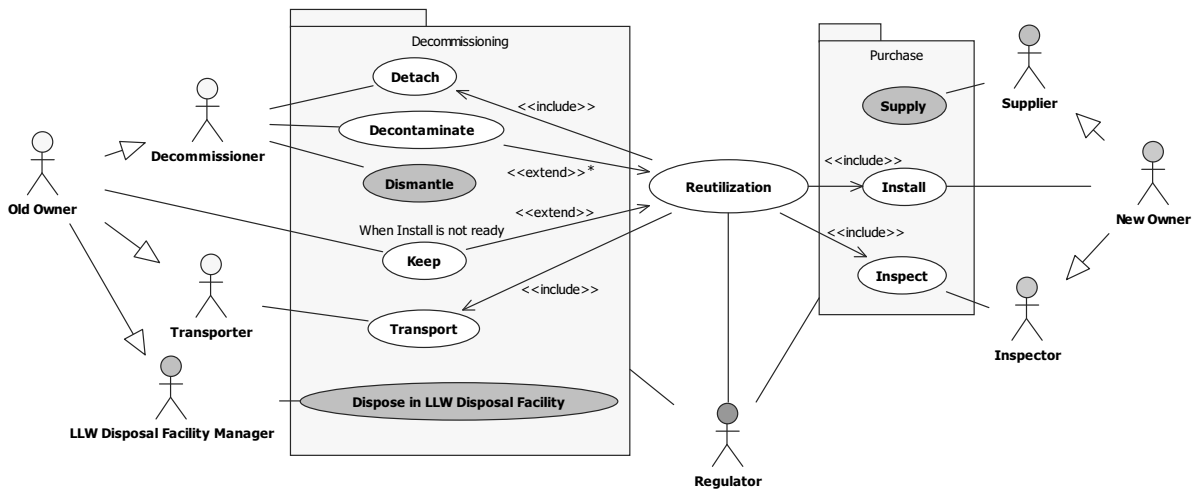
[Figure 3] Operational Concept

OpsCon is described as follows;

- Decommissioned plant owner (Old Owner) wants to reduce decommissioning work exporting reutilizable components.
- Demander (New Owner) wants to reduce purchase work importing the required component.
- The regulator checks the safety of the reutilization system.
- The component to be reutilized is detached,



[Figure 4] Mission Use Case



[Figure 5] System Use Case

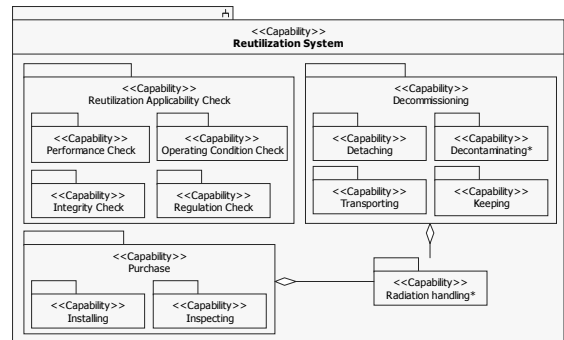
decontaminated, and transported from the old owner, installed and inspected in the new owner.

Figure 4 shows there are three main actors who interact with the component reutilization system. Old owner supply a reutilizable component, New owner demands a required component, and Regulator checks whole reutilization process. Detailed component reutilization system functions are described in the System Use Case.

### 3.2 Step 2: Analyze System Requirements

In this step, System Use Case and Capability are developed as Figure 5 and 6, respectively.

Component reutilization system includes <Detach> and <Transport> from Decommissioning system. <Decontaminate> extends to the component reutilization system when the reutilizable component is radioactivated and <Keep> extends to the component reutilization system when Install is not ready. Component reutilization system also includes <Install> and <Inspection> from Purchase. Decommissioner and Transporter are Sub-actors of Old Owner and Inspector is



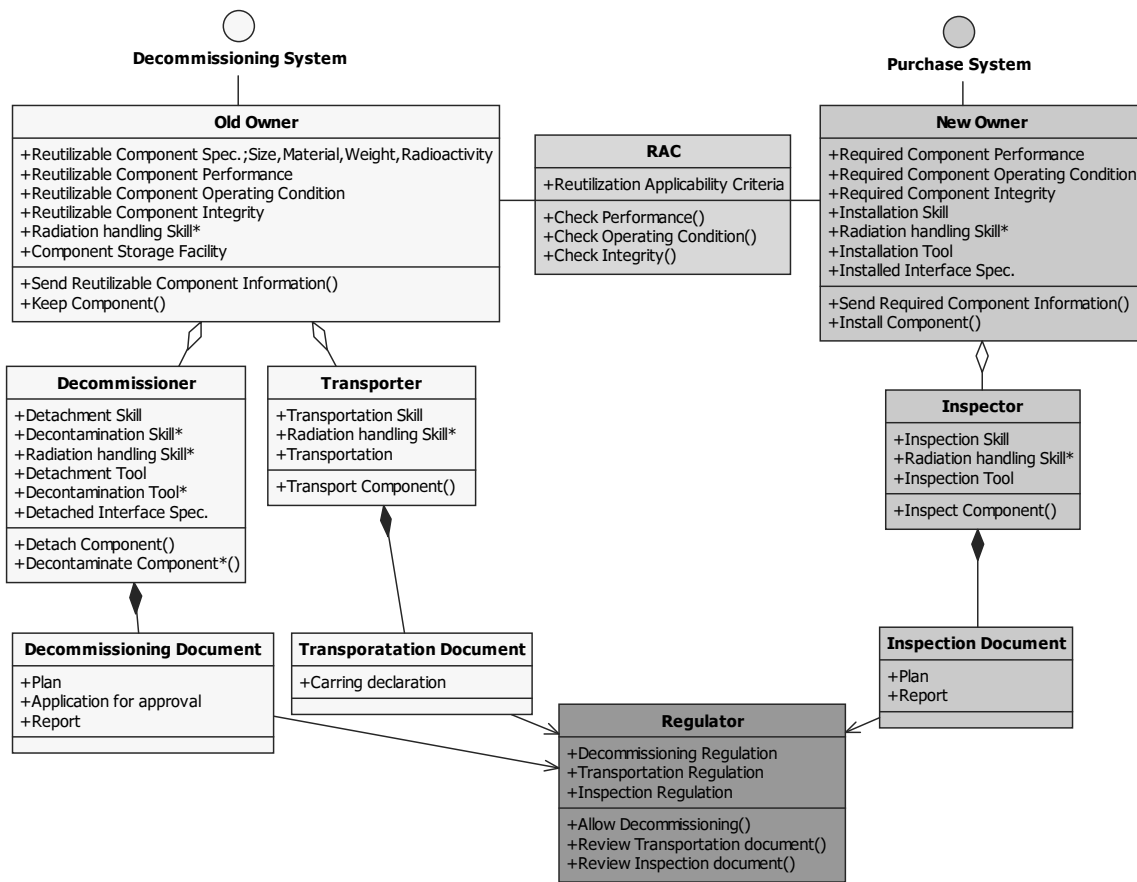
[Figure 6] Capability

a sub-actor of New Owner. Old Owner, New Owner, Regulator, and all Sub-actors are classes in Step 3 Class Diagram.

Capability shows the ability to achieve a component reutilization. Basically, there are three capabilities; reutilization applicability check, decommissioning, and purchase. Radiation handling works when the reutilizable component is radio-active. All capabilities are matched with System Use Case and OpsCon.

### 3.3 Step 3: Define Logical Architecture

Class, Activity, Sequence, and State Machine Diagrams are developed in this step as Figure 7, 8, 9, and 10, respectively.

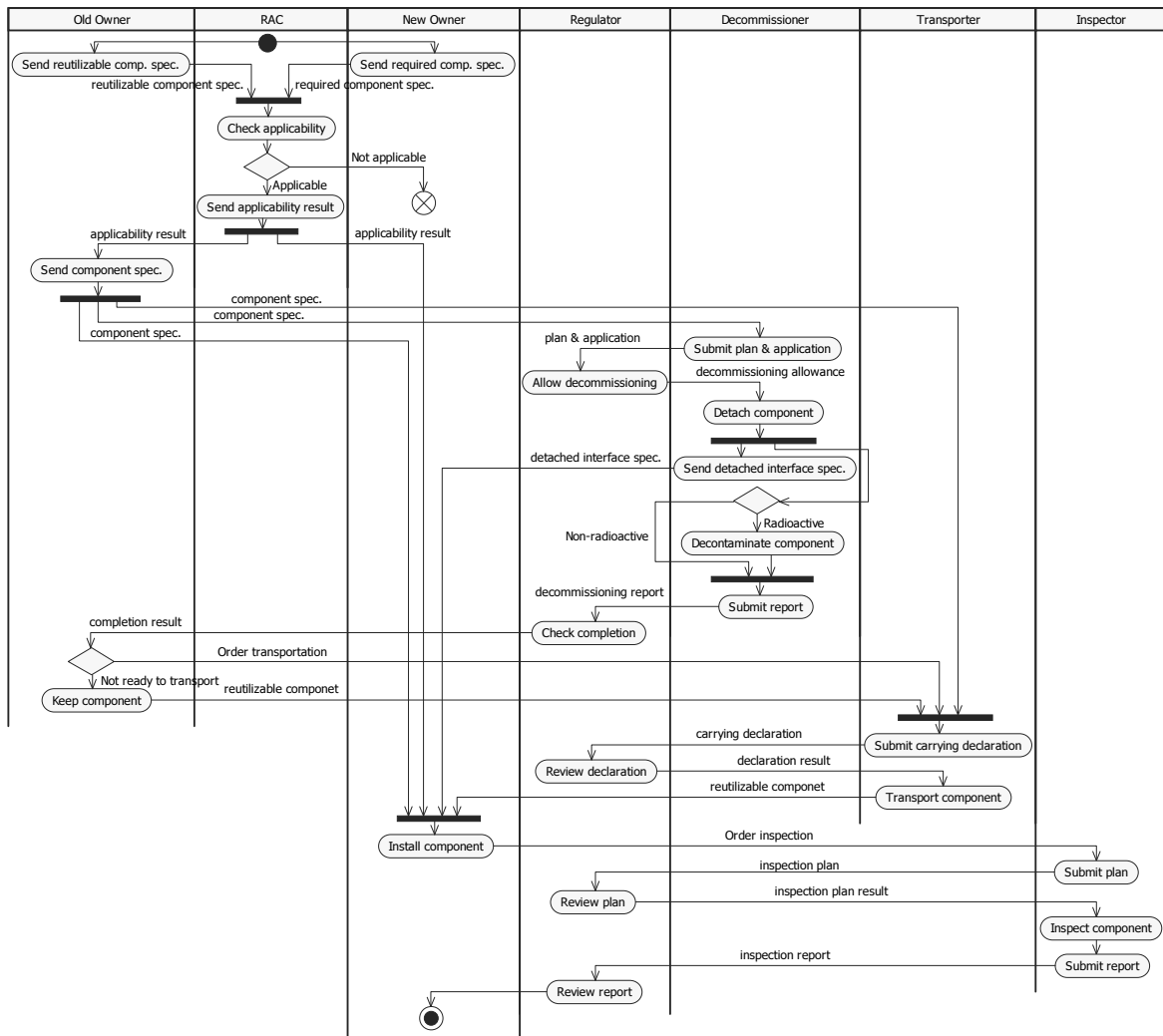


[Figure 7] Class Diagram

In Figure 7, Old Owner sends a reutilizable component characteristics such as specification, performance, operating condition, and integrity to a reutilization applicability checker (RAC). RAC checks the applicability comparing with a reutilizable component characteristics and required component characteristics. Old Owner keeps a reutilizable component in a Component Storage Facility until the install is ready. Decommissioner detaches a reutilizable component and decontaminates when the reutilizable component is radioactive. Transporter moves a reutilizable component to the New Owner's NPP. New Owner installs and Inspector inspects the component. Decommissioner, Transporter, New Owner, Inspector have their own skills and tools to

perform their work successfully. Classes need radiation skill for a radioactive component. Regulator reviews Decommissioning, Transportation, and Inspection Documents which are submitted by Decommissioner, Transporter, and Inspector according to the regulation.

Figure 8 shows an Activity Diagram of a component reutilization system. Each swim lane represents a class in the Class Diagram. When the reutilization is applicable, the Old Owner sends a reutilizable component specification to the New Owner, Decommissioner, and Transporter to conduct their work. After the component detach, Decommissioner sends the detached interface specification to New Owner so that a reutilizable component is installed. Regulator



[Figure 8] Activity Diagram

allows decommissioning reviewing the plan & application documents and checks the decommissioning completion reviewing the report. Inspector submits the plan and report to the regulator before and after the inspection.

In Figure 9, Sequence Diagram, Each lifeline shows an instance of the Classes and corresponds to the swim lanes of the activity diagram. The sequence of message exchange matches those shown on the Activity Diagram. This sequence represents a radioactive component reutilization.

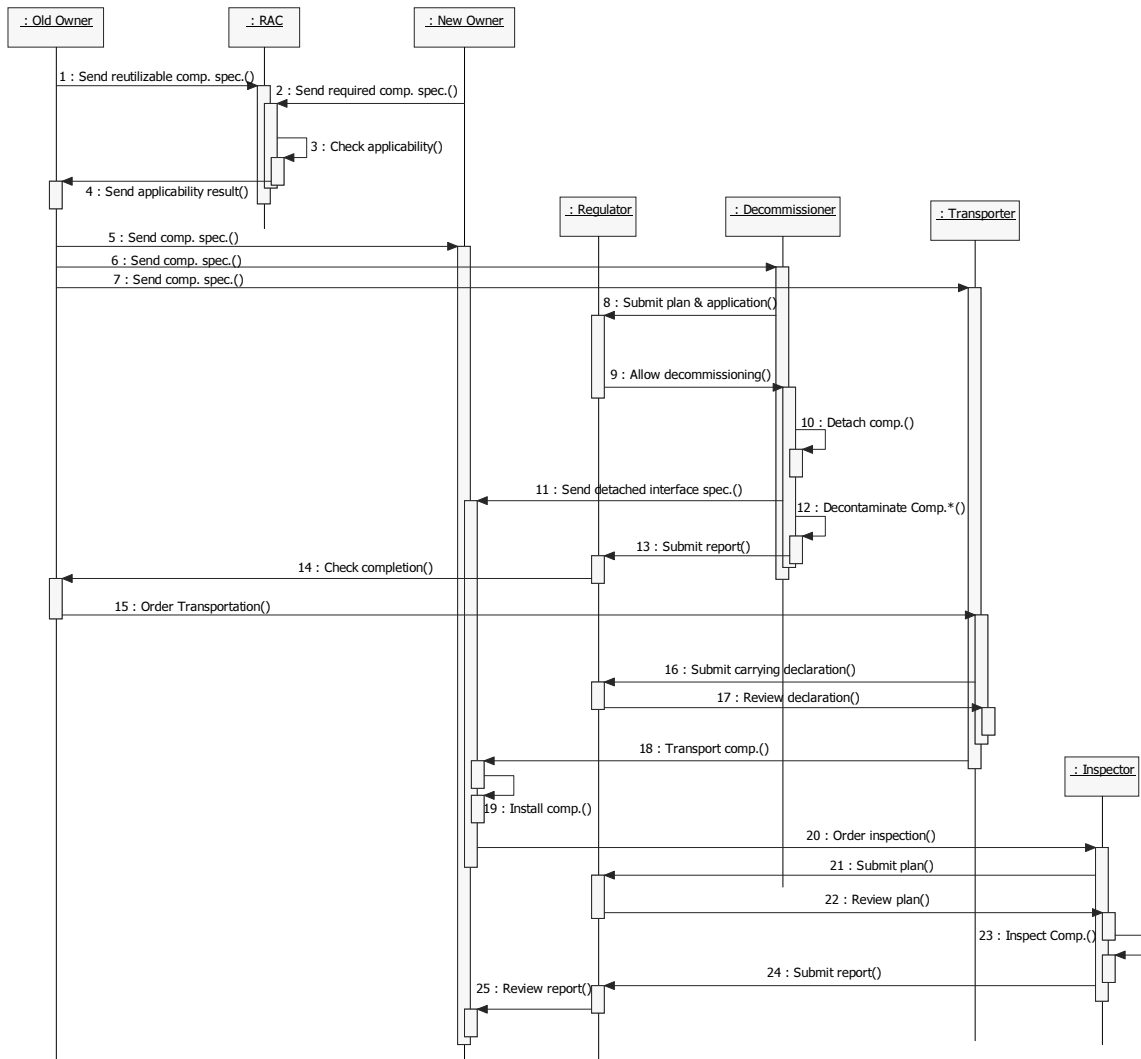
Figure 10 shows a State Machine Diagram

of Decommissioner. This shows the behavior of Decommissioner following the activities and arrival and sending of messages in a swim lane of the Activity Diagram.

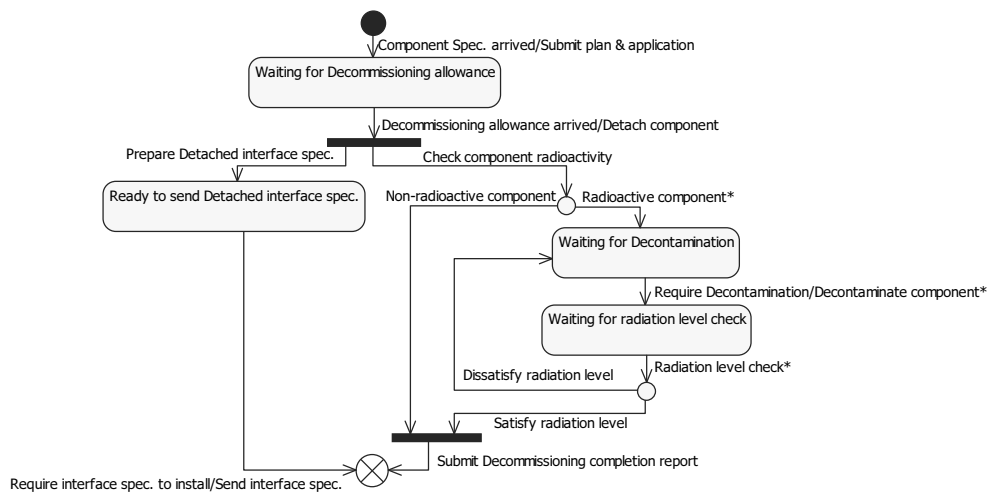
### 3.4 Step 4: Synthesize Candidate Physical Architectures

In Figure 11, physical components and their relationships are shown. Each component represents a class in the Class Diagram. An artifact is the specification of a physical piece of information that is sent and received between related components.

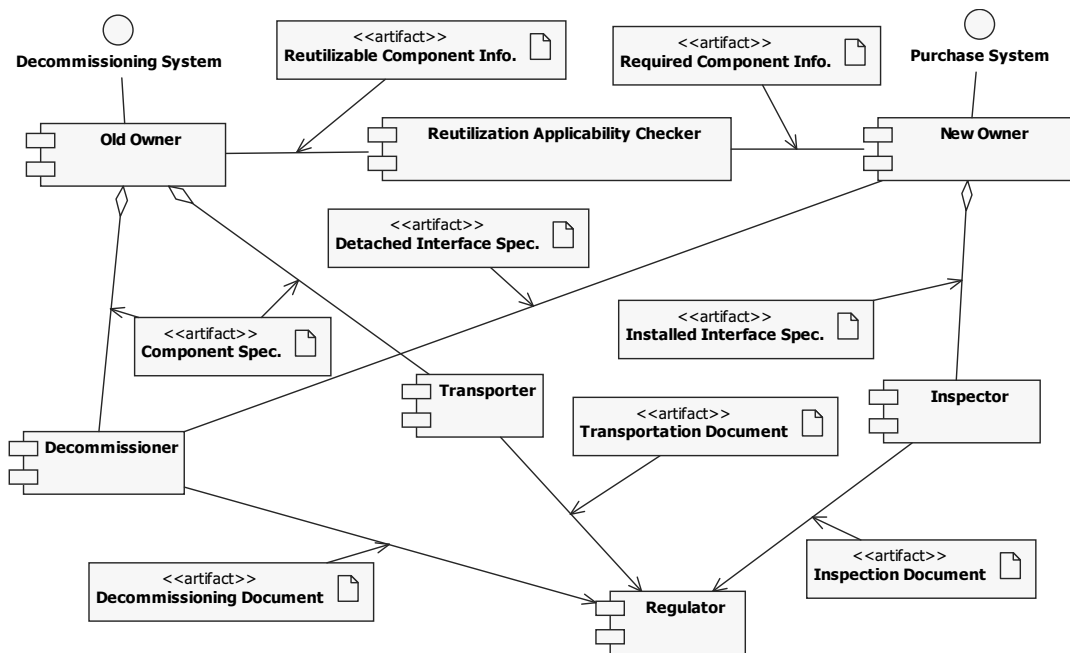




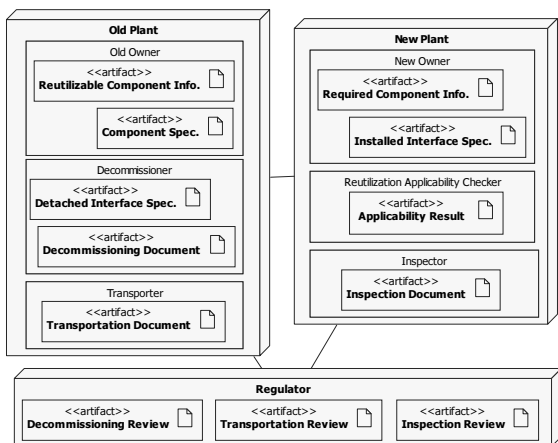
[Figure 9] Sequence Diagram



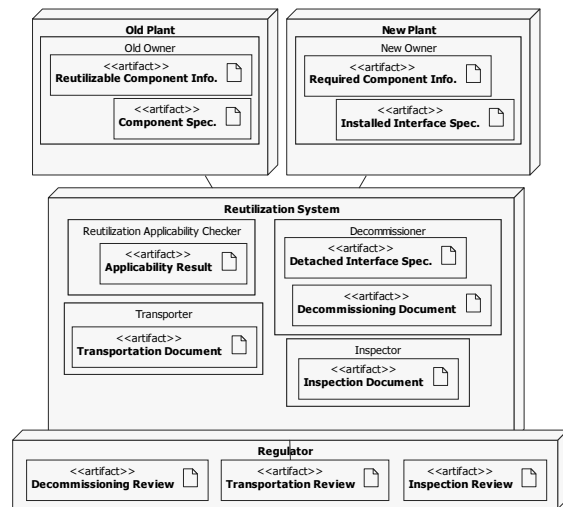
[Figure 10] State Machine Diagram of Decommissioner



[Figure 11] Component Diagram



[Figure 12] Deployment Diagram



[Figure 13] Alternative Deployment Diagram

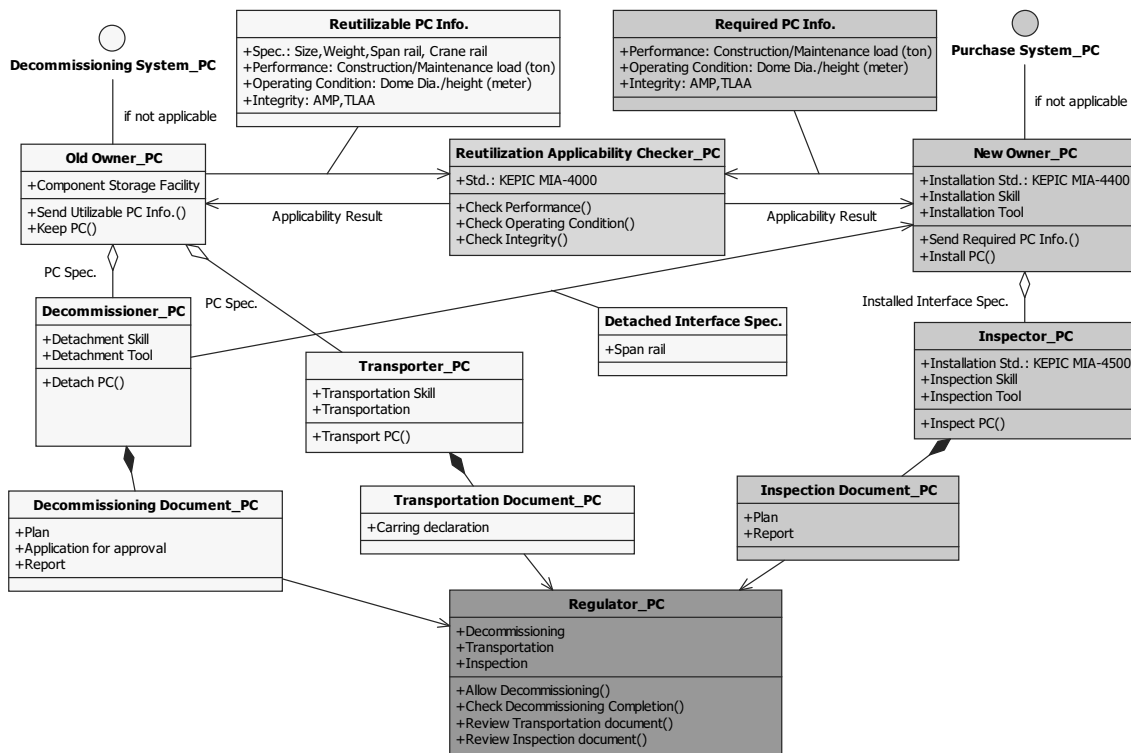
Figure 12 shows a Deployment Diagram. This Diagram indicates the New Plant checks the reutilization applicability. Old Plant and New Plant control a component reutilization process directly. This reutilization system is easily adopted when the component reutilization is not familiar.

Alternative Deployment Diagram is shown in Figure 13. As an independent node, reutilization

system directs whole component reutilization process. This alternative reutilization system may be developed when the component reutilization business is brisk.

### 3.5 Step 5: Validate and Verify System

Figure 14 shows a Class Diagram of a polar crane (PC) which is developed to verify the



[Figure 14] Class Diagram of a polar crane reutilization

component reutilization system as a test case. This diagram satisfies all the system requirements in Figure 5. All actors and UseCases in Figure 5 are described as classes and class operations respectively in Figure 14. For example, Transporter (actor) and <Transport> (UseCase) in Figure 5 are illustrated in Figure 14 as Transporter\_PC (class) and Transport PC (class operation) respectively.

To validate the reutilization system, Figure 5, System Use Case, is compared to OpsCon which is introduced in 3.1. Each OpsCon item is reflected in Figure 5 as follows;

- Old Owner reduces decommissioning works such as <Dismantle> and <Dispose in LLW Disposal Facility> exporting reutilizable components.
- New Owner reduces a purchase work, <Supply> importing the required component.

- The regulator associates with the reutilization system.
- The reutilization system includes <Detach> and <Transport>, extends <Decontaminate> from the old owner. Also, it includes <Install> and <Inspect> in the new owner.

#### 4. Conclusion

Prior works have documented about decommissioning wastes and radioactive waste recycling. However, still reusable component also has been considered as the waste and no reutilization system has been developed for the reusable components from the unexpected shutdown NPPs.

Component reutilization system development was conducted in this study by OOSEM. According to the OOSEM, stakeholder needs and

system requirements were analyzed by OpsCon, Use Cases, and Capability. After then, logical architecture and physical architecture were defined using Class, Activity, Sequence, State Machine, Component, and Deployment diagrams. Finally, V&V System was conducted through a test case, polar crane. All Behavior diagrams were correlated analyzing the component reutilization system.

Polar crane which is a representative Non-radioactive component was applied to the reutilization system and its Class diagram was developed for V&V. Polar crane Class diagram verifies corresponding to the Capability in Figure 6 and validates reflecting OpsCon in chapter 3.1.

As of now, the regulation allows only non-radioactive component reutilization. Therefore, the reutilization is limited as non-radioactive components in the secondary side.

On Systems Engineering aspect, OOSEM enables demanders and owners to modify this component reutilization system if necessary. Because the reutilization system was built based on the classes and their interactions, system users could consider which classes and interactions are effected by the modification. For example, if a component demander wants to use a component as an independent unit for research, installation class and its interactions are not necessary and this class based OOSEM serves easy way to modify the component reutilization system.

This research requires further study on cost evaluation of the reutilization system. Future

work should focus on the cost benefit evaluation of a component reutilization to determine whether a component reutilization is valuable or not.

## Acknowledgement

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