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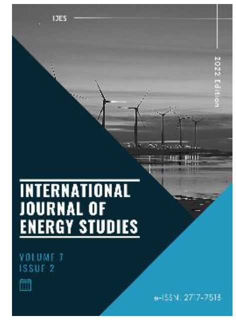

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Decontamination applications in primary circuit equipment of nuclear power plants

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Highlights

- Contamination is a radioactive pollution in the solid phase, which may exist in solution or be carried as a gas/vapor
- The main purpose of decontamination is reducing the activity level of contaminated equipment which may occur during operation or after decommissioning of nuclear power plants
- There are several decontamination methods exist in literature, when these are categorized, three different process emerge which are chemical, electrochemical and physical process.

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ABSTRACT

Due to the reactions taking place in the reactor, radioactive contamination occurs on and/or near the surfaces of the equipment used in nuclear power plants. Contamination is a radioactive pollution in the solid phase, which may exist in solution or be carried as a gas/vapor. It can be caused by a very small amount of radioactive material, and since every known element has at least one radioactive isotope, there are more than a hundred elements that can cause contamination. Removing of this contamination by physical and chemical methods is defined as decontamination. The main purpose of decontamination is reducing the activity level of contaminated equipment which may occur during operation or after decommissioning of nuclear power plants. By decontamination process, the radioactive contamination formed on the surfaces or in the depths close to the surface of the equipment is removed by chemical and physical methods. Within the scope of this study, decontamination applications in the literature were explained; regulatory perspective and legislative infrastructure issues for Turkey were discussed. Within the scope of this study, the decontamination applications in the literature were explained, the regulations of the Regulatory Bodies in other countries for decontamination were examined, and in this direction, the regulatory perspective for Turkey and the suggestions for the legislative infrastructure were discussed.

Keywords: Decontamination, nuclear power plants, radioactivity, contamination

1. INTRODUCTION

Contamination is a radioactive pollution which may take part in the solid phase, liquid phase or transport in a gas phase. It can be caused by a very small amount of radioactive material, and since every known element has at least one radioactive isotope, there are more than a hundred elements that can cause contamination.

It is possible to list contaminants under three categories; soluble (ionic), particulate and colloidal. Soluble (ionic) pollutants are associated with physical adsorption on material surfaces or ion exchange of reactive groups (usually acidic) found on the surface of most non-metallic materials. Non-ionic pollutants are pushed from the surface by the mutual repulsion of negatively charged species, and low amounts of adsorption can be achieved. However, ionic cations, especially in low concentrations, are attracted to the acidic surface and absorbed by the surface. Unfortunately, the most fission products and heavy radioelements are in this category. Colloidal and particulate contaminants can be easily adsorbed by the surface and precipitated on a substrate. To remove such contamination, specific reagents must be used to dissolve the contaminant [1].

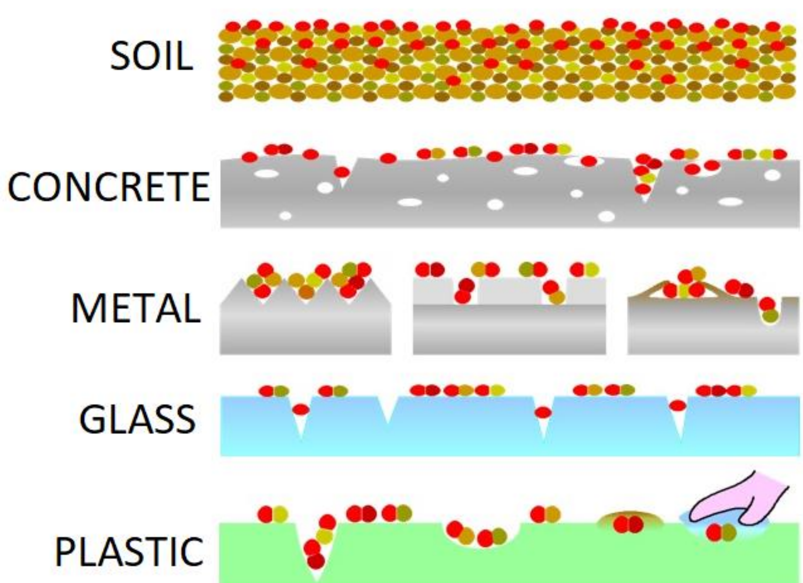

Figure 1: Location of contamination on surfaces of different materials [2]

In general definition of decontamination; it is defined as the process of removing radionuclides from contaminated surfaces of equipment or parts that have been exposed to radioactivity by various methods. These can be chemical, electrochemical or physical methods. There are also decontamination methods in which physical and chemical techniques are used together. There are different criteria for choosing the most suitable method [3].

Decontamination Factor (DF) is a kind of term that which express the efficiency of decontamination method and calculated by a formula which is given below [4]. The main purpose here is to determine how much the activity in the material has been reduced. This formula is given below:

DF = Initial Activity / Residual Activity (1)

Reduced Activity (%) = (1-1/DF) x 100 (2)

If the DF value of a piece is determined as 10 according to the above formula, a 90% decrease in activity is mentioned.

There are many decontamination applications in the literature. These were divided into categories within the scope of this study and each method was tried to be explained in summary. In addition, the practices carried out at different stages of nuclear power plants on decontamination and the latest regulatory situation and legislative infrastructure in Turkey have been tried to be explained.

2. DECONTAMINATION APPLICATIONS

The main purpose of decontamination is reducing the activity level of contaminated equipment which may occur during operation or after decommissioning of nuclear power plants. There are several methods exist in literature, when these are categorized, three different process emerge which are chemical, electrochemical and physical process.

2.1. Chemical Decontamination

Although chemical cleaning processes are generally sequential processes, it is a decontamination method based on the use of chemicals that will dissolve the surface oxides and penetrate the material to take up the radioactive isotopes in the remaining material.

The most difficult part in the removal of the oxide layers in the materials is the removal of oxides rich in chromium. This type of oxides is generally encountered in the cleaning of parts or equipment in PWR/VVER type reactors. For this, a special chemical, permanganate compound, is used [5]:

$$Cr_2O_3 + 2MnO_4 + H_2O \Rightarrow 2HCrO_4 + 2MnO_2(s) \quad (3)$$

$$MnO_2 + H_2C_2O_4 + 2H \Rightarrow Mn + 2CO_2 + H_2O \quad (4)$$

After the chromium oxide layer is removed, the oxide layer containing iron and nickel, called the actual decontamination, is taken. Due to the fact that most of the processes and chemical ingredients used here are commercial or patented, information on the subjects is not included in the literature in detail. The processes and chemicals used in chemical decontamination are listed in Table 1.

Table 1: Processes and chemicals used in chemical decontamination [5]

Chemical	Examples
Strong Mineral Acids	Nitric acid, sulfuric acid, phosphoric acid
Acid Salts	Sodium phosphate, sodium sulfate
Organic Acids	Formic acid, oxalic acid, citric acid
Bases and alkali salts	Potassium hydroxide, sodium hydroxide
Complexing agents	Picolinic acid, EDTA
Whitening	Calcium hypochlorite
Organic solvents	Kerosene, tetrachloroethane

Ozone Decontamination Process (ODP) was developed by the Swedish company "STUDSVIK" with the aim of recycling precious metals in the steam generators of PWRs. It has been successfully used in Ringhals-2 PWR type Nuclear Power Plant in Sweden. The process consists of a single step and is based on the use of ozone and cerium chemicals in a nitric acid solution. It is carried out at room temperature and low acidity (pH=2.0) [6].

Reduction-Oxidation Reactions (REDOX) and Sulfuric Acid-Cerium (SC) processes are chemical decontamination techniques developed by Japan Atomic Energy Agency (JAEA) on the same chemistry (use of cerium ions). Although the basic logic is the same as Strong Ozone Decontamination Process (SODP) and ODP processes, the difference can be shown that the processes are carried out at high temperatures. It has been revealed as a result of the tests that keeping the temperature high has accelerated the process. REDOX and SC is carried out in nitric acid solution and sulfuric acid solution, respectively.

Metal Decontamination by Oxidation with Cerium (MEDOC) process is a decontamination method that combines the advantages of accelerating the process with temperature and recycling ozone and cerium ion in SODP or REDOX. The oxidation of the metal by the cerium ion is given in the following equation [7]:

$$nCe^{4+} + M \Rightarrow nCe^{3+} + M^{n+} \quad (5)$$

One of the biggest advantages of the MEDOC process is that the Ce^{3+} ion formed due to the use of ozone is converted into Ce^{4+} ion, thus creating a continuous cycle in the process. The following equation gives the cerium ion re-oxidation of ozone in the acidic decontamination solution [7]:

$$O_3 + 2Ce^{3+} + 2H^+ \Rightarrow 2Ce^{4+} + O_2 + H_2O \quad (6)$$

Very low activity levels are also achieved in the MEDOC process (0.1 Bq/g). In addition, the amount of secondary waste generated is lower than other processes [7].

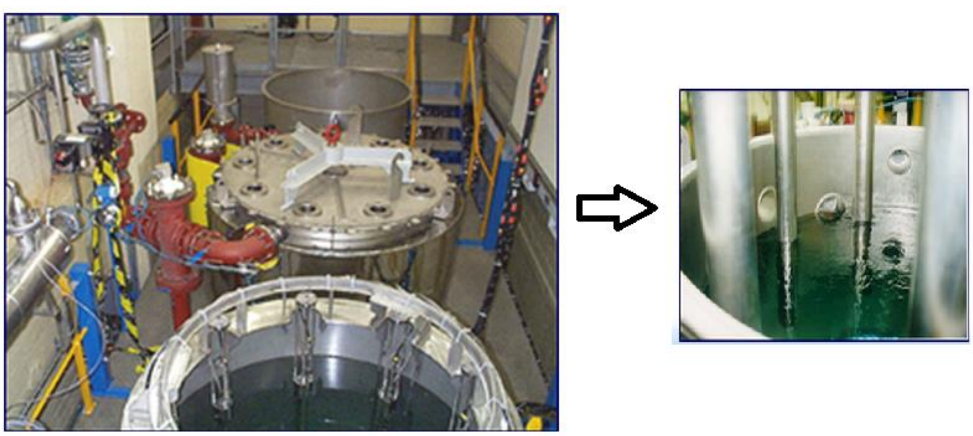

Figure 2: MEDOC process workspace [7]

There are many chemical decontamination applications in oxidation-reduction processes. The most common of them are:

- Chemical Oxidation Reduction Contamination (CORD),
- Hydrazine/Oxalic Acid/Potassium Permanganate (HOP),
- Nitric Acid/Potassium Permanganate/Oxalic Acid (NPOX),
- Canadian Decontamination and/or Remediation (CANDEREM, CANDECON),
- "EMMAC" decontamination developed by EDF,
- Low Oxidation Metal Ion (LOMI),
- "CONAP" decontamination developed by Westinghouse,
- "TURCO" decontamination developed by Turco Company,

CORD processes are the most widely used system in the world. It is used all over the world except the United States (USA). It basically consists of four basic steps. These are [8]:

- Conversion of Cr^{+2} ions in the chromium oxide layer to hydrogen chromate chemical by using permanganic acid,
- Reduction of permanganic acid with the use of oxalic acid (Mn^{+7} – Mn^{+2}),
- Decontamination with oxalic acid,
- Conversion of decontamination chemicals into water and carbon dioxide with the use of Ultra Violet (UV) and hydrogen peroxide.

HOP is a decontamination method developed for use at Fugen Nuclear Power Plant in Japan and very similar to the CORD process. In the HOP method, first the chromium-rich oxide layer is removed, followed by the iron-nickel oxide layer, which is rich in iron-nickel. Then, oxidation is carried out by using potassium permanganate at a concentration of 500 ppm and oxalic acid is used around 200 ppm for reduction. Depending on the material to be decontaminated, the DF ranges change from 3 to 20 [5].

Although NPOX is chemically similar to the CORD method, it can also be considered as a mixture of other decontamination applications. Nitric acid, potassium permanganate, oxalic acid and hydrogen peroxide are used as solutions. In addition, the system can be managed remotely, but it can be carried out in an ultrasonic bath. Archibald et al. [9], in their study with SIMCON-Simulated Contamination steel coupons containing zirconium oxide and cesium, noticed a decrease in the amounts of 95% cesium and 80% zirconium when ultrasonic bath is used.

The CANDECON and CAN-DEREM methods were developed by Atomic Energy Canada Limited (AECL). Although originally intended for the Canadian Deuterium-Uranium Reactor (CANDU), it later found application in the BWR and PWR. Chemically, a mixture of EDTA, citric acid and oxalic acid called LND-101A is used. It is applied at temperatures of 85-125°C and pH values of 2.7-2.8. As a result of the development studies, 50-500 ppm ferric ions are added to the solution, since the ferric ion has anti-corrosion properties [5].

The EMMAC method consists of oxidation and reduction steps. Refurbishment of steam generators or decontamination of hydraulic parts of primary circuit pumps can be shown as areas of use. While the DF is around 50-70 in reducing the activity of the hot leg, this number is around 60 in reducing the activity of the cold leg. The system is customized for decontamination applications of stainless steel parts used in primary circuit piping. It is also widely used in France. The most important reason for this is that the process is specific to material and contamination, and that the wastes generated are compatible with the waste system in nuclear power plants [10].

The LOMI method was developed by the Electric Power Research Institute (EPRI) in the 1980s. Other methods used before this process are oxalic-citric acid or low concentrations of complex organic acids. The biggest disadvantage of these is that they create large volumes of secondary radioactive waste. Therefore, the LOMI method has been developed and the amount of secondary waste has been reduced to lower levels. The most important advantages of using LOMI can be considered as being more effective, generating less secondary waste and reducing corrosion problems [10].

The CONAP method is a four-step decontamination method developed by the company "Westinghouse". In the first step, the contamination surface is treated with alkali and then oxidized with potassium permanganate. Then, the process of dissolving the oxides with suitable complexants and forming complex structures is applied. Finally, the purification of the process solutions on the surface of the decontaminated part is carried out. In the trials made on the primary circuit cooling parts, the DF is over 10,000 [11].

The TURCO method is used as a commercial method under the company "Turco" located in Cincinnati, Ohio. Chemically, it contains alkaline potassium permanganate, which is widely used in the nuclear industry. This chemical is one of the strong basic and oxidizing chemicals; it consists of sodium hydroxide or potassium hydroxide (5-20%) and potassium permanganate (1-5%) [12].

Electrochemical decontamination is the general name for the chemical decontamination of equipment or parts with the aid of electricity. Electrochemical decontamination is also an anodic dissolving technique. The material to be decontaminated is made anode, and stainless steel or copper is used as the cathode. In some applications, the decontamination tank itself acts as a cathode. During the decontamination process, the metal dissolves from the surface in a controlled manner. This method is also used in surface smoothing and polishing processes on materials such as stainless steel today. In addition, the electrochemical process increases the resistance to corrosion and facilitates subsequent decontamination. In cases where the materials to be decontaminated need to be reused, the surface properties become important and improvements in roughness are required. However, if the part is to be scrapped, secondary waste amounts become more important than surface roughness.

Due to the use of electricity, the part to be decontaminated must be conductive. These can be stainless steel, copper aluminum, lead or molybdenum. There are many different parameters in electrochemical decontamination applications. These are parameters such as electrolyte solution, temperature, electrode potentials, current density and solution mixing. Before applying the electrochemical process, insulators such as oil, dirt and rust from the obstacles in the conduction of electric current on the material surface should be cleaned and then the process should be applied [13].

Figure 3: Electrochemical decontamination process in a phosphoric acid bath [4]

2.2. Physical Decontamination

In cases where chemical or electrochemical methods cannot be used, physical decontamination methods have been developed as an alternative. The most important purpose is to clean the contaminants from the surface, as in other methods, however this process is carried out mechanically. The most important advantage compared to other methods is that it can be used for almost any type of material. For example, for parts with high porosity surfaces, physical decontamination may be the only solution [14].

Ultrasonic cleaning is the most widely used type of physical decontamination. This technique, developed by EPRI, is especially used for fuel bundles and simple shaped parts. Ultrasonic cleaning is the process of removing contamination from the material in the tank by applying high-frequency sound waves into a liquid-filled tank. Ultrasonic energy reveals the effect called “cavitation” and ensures the realization of cleaning. Cleaning is usually done in water. Depending on the nature of the material to be cleaned and the degree of contamination, various chemicals are added to the water to increase the effectiveness of cleaning [14].

For decontamination with carbon dioxide ice, carbon dioxide balls varying in diameters of 1-3 mm and a temperature of -38°C are used. It is a decontamination method based on the principle of removing the contamination on the surface by accelerating these balls with compressed air and hitting the surface [15].

In decontamination with pressurized water, it is basically aimed to clean the contaminated material from the surface by using water at high temperature and high pressure. The temperature difference here accelerates the chemical reactions between the contaminated surface and the decontamination solution, and the contamination is removed from the surface with the energy of high pressure water. In the abrasive-containing decontamination method, dry or wet abrasives are sprayed onto the surface at high speed and the process continues with the reuse of the abrasive material after the contamination is removed from the surface. Systems use wet or dry abrasive material and compressed air under pressure. Such systems provide effective results for large contaminated parts, painted metals and locally contaminated equipment during disassembly operations. Compressed air is used as a carrier in dry decontamination [4].

Large quantities of slightly contaminated metallic scrap are produced following the decommissioning of nuclear power plants. These scraps occur not only after disassembly, but also as a result of maintenance or replacement of equipment. Most of these wastes are large in volume and consist of equipment such as heat exchangers, steam separators or steam generators. This type of equipment, by design, consists of valuable materials that can be recycled, including stainless steel and Inconel alloys. It is possible to recover such metals by melting such equipment or materials that are not very contaminated.

The melting process, as a decontamination technique, completely destroys the components in the contaminated material. Decontamination efficiency varies widely depending on the radioisotope present. Radionuclides remaining in the molten material are homogeneously dispersed and effectively immobilized [16].

Surface cleaning techniques are generally preferred for the decontamination of concrete structures and buildings. While applying decontamination in buildings, first of all, necessary preparation and safety precautions are taken. In order to ensure that the surfaces are unobstructed, all kinds of pipes and support parts must be disassembled and removed from the structure. As in physical applications, the decontamination process produces a lot of dust, so the working area is placed under vacuum in order not to spread the contamination. In addition, in case of flammable and explosive materials in the environment, necessary precautions are taken and these are removed from the site. The applied methods are divided into 2 as superficial and highly destructive. Chipping, grinding and etching applications are to superficial methods; applications where cutting, drilling and explosives are used can be given as examples of high-destructive methods [17].

2.3. Decontamination Stages

Decontamination practices in nuclear power plants can be applied during the operation stage of NPP as well as after the dismantling process. In general, the methods and objectives applied in both stages are similar. The main purpose of the decontamination process applied before dismantling is to reduce the dose rates to which nuclear power plant workers are exposed. Decontamination processes take a long time; for this purpose, as long as the limits determined for the employees are not exceeded, decontamination is not preferred much during the operation stage [18].

The maximum dose rates for the personnel working in all nuclear power plants in the world are specified. For example, United Arab Emirates Federal Authority for Nuclear Regulation (FANR) determined the dose rate for the personnel working at the power plant during the normal operation of a nuclear facility for a five-year period and the dose rate to be taken in a year within these five years should not exceed 50 mSv [19]. Likewise, in the radiation protection regulation published by the Canadian Nuclear Safety Commission (CNSC), for the personnel working at the nuclear power plant, for a five-year period and on the condition that the dose rate to be taken in a year within these five years does not exceed 50 mSv [20]. It is the responsibility of the operator to ensure these rates. If there is an increase in the dose amounts taken by the working personnel as a result of increased activity due to a leak in a power plant or for any other reason, decontamination is applied for the necessary equipment or parts.

The large volumes of contaminated materials produced after the dismantling activities of NPP can be significantly reduced by the use of appropriate decontamination methods. The main criteria to consider when choosing a decontamination process include:

- Existing cleaning criteria,
- Decontamination efficiency,
- Volume of secondary waste produced,
- Operational security and personnel experience,
- Licensing,
- Cost,
- Dose commitment.

The most important purpose of the decontamination process applied during and/or after the dismantling process is to restore the site, reduce contamination of equipment or parts, and bring it to the release limits so that it can be reused or harmless to the environment.

Since the main purpose of decontamination methods is to remove contamination from the material surface, there are no significant differences between different types of reactors. The most important difference in LWRs is that the oxide films found in BWRs are different from PWRs. For this purpose, although some decontamination methods are quite effective for PWRs, they are not very effective for BWRs and can give low decontamination factors. The main difference in heavy water reactors is that during decontamination, the deuterium moderator and the coolant (if it is a deuterium-cooled reactor) are emptied from the system and stored in a special tank. The remaining system can be decontaminated with any of the decontamination methods used in PWR and BWRs [21].

3. DECONTAMINATION FROM A REGULATORY POINT OF VIEW AND CURRENT SITUATION IN TURKEY

In the IAEA's safety standards series "Decommissioning of nuclear power plants and research reactors" WS-G-2.1 [22], as the definition of decontamination, it is the process of reducing or destroying the contamination on surface or inside the materials, structures or equipment in a NPP. It has been mentioned that the dismantling of a reactor should target the application of partial or complete decontamination. In addition, it was stated that decontamination application can be used before, during or after the disassembly process, as well as for cleaning the internal or external surfaces of the system or equipment, the structural surfaces and the tools used during disassembly. Also, as the targets of decontamination in article 6.13 of the document it is stated that [22]:

- Reducing the spread of radioactivity during dismantling,
- Reducing the volumetric amount of solid radioactive waste,
- Increasing the reusability of materials or equipment.

There are many methods that can be applied in decontamination application, especially with the dismantling program. In addition, these methods have developed with the research and development activities carried out in the countries. In the aforementioned IAEA document, this issue is discussed in detail and it is mentioned that it is possible to achieve much more efficient results by exchanging information at the international level.

It is of great importance to evaluate the efficiency of the method to be applied while determining the decontamination strategy. It is recommended by the IAEA to consider the ALARA principle alongside the efficiency assessment. The following criteria are included in the evaluation of the method [22]:

- Targeted decontamination level,
- Estimated dose amount to be received by the employees,
- Aerosol formation amount,
- Availability of a system that can measure whether the targeted dose can be reached,
- Volume, category and activity estimation of primary and secondary wastes,
- Non-radiological hazards (toxicity level of the chemical used).

According to the IAEA [22], decontamination is divided into two as before and after disassembly. The main goals of decontamination before disassembly are to reduce dose rates (radiological protection goal) and to prevent further dissemination during disassembly (safety goal). On the other hand, the decontamination targets carried out after disassembly are changing the waste category of the part to be disposed (thus gaining an advantage in terms of price and labor), reusing or recycling the material and reducing the dose rates for waste management.

Regulatory procedures for the decontamination applications applied in NPP’s in the USA are carried out by many institutions and organizations. Nuclear Regulatory Commission (NRC), the regulatory authority in nuclear reactors, has primary responsibility. The regulatory document “Changes, tests and experiments” (10 CFR 50.59) contains the requirements for decontamination. According to the NRC, if the decontamination process is adequately addressed in the safety analysis report, in case there is no change in the technical specification and there are no unresolved safety problems, only filling out the “Safety Assessment Form” and regular reporting for decontamination are considered sufficient [23].

Similar to the USA example, the regulatory approaches of Japan, Finland and South Korea to the decontamination applications were also examined. The most important factor in choosing these countries is that they request a separate plan or program for the decontamination process from the operator. For example, during the Operational phase, the licensee has to submit an "Operational Safety Program" regarding decontamination for NRA (Japan Nuclear Regulatory Authority) approval. In this program, there are articles related to monitoring of radiation doses, dose equivalents, radioactive material density and decontamination on the surfaces of objects contaminated with radioactive substances [24]. Similarly, in STUK's (Finland Nuclear and Radiation Safety Authority) YVL B.5 “Nuclear Power Plant Reactor Cooling Circuit” guideline, it is mentioned that a “Decontamination Plan” for systems included in or associated with the primary circuit must be submitted for approval to STUK [25]. In South Korea, with the decontamination process, the operator has to submit the "Decontamination Safety Report" to the regulatory body [26].

Although decontamination practices are not formally regulated alone in Turkey, references have been made to this issue in some regulations. Sections of the relevant regulations are explained below:

In the Radioactive Waste Management Regulation [27] published in the Official Gazette dated 09 March 2013 and numbered 28582, wastes are classified as very short-half life, very low-level, low-medium-level and high-level. Very short-half life ones are wastes that contain radioactivity above the exemption limit and that, after being stored for a maximum of a few years, will fall below the release limits and become eligible for release. Very low level ones; these are radioactive wastes that contain radioactivity above the exemption limit, are not classified as very short-half life radioactive waste, and contain activity concentrations below the release limits about 100 times. Low and medium level ones; these are wastes whose radioactivity levels are higher than the activity concentration of very low-level radioactive wastes, but which are not classified as high-level radioactive waste. The high-level ones are classified as spent nuclear fuels, which are considered as radioactive waste and radioactive wastes that arise as a result of reprocessing.

Within the scope of the Regulation on the Releasing and Removal of the Site from Regulatory Control [28] published in the Official Gazette dated 09 March 2013 and numbered 28582, releasing limits as a result of the decontamination of solid radioactive waste or materials is explained in detail. In the relevant Regulation, there are provisions that methods such as decontamination or holding can be applied to reduce the activities of radioactive waste and substances to the releasing limits. In addition to the information mentioned above,

- The Regulation on Safe Transport of Radioactive Material [29] published in the Official Gazette dated 08 July 2005 and numbered 25869, since the wastes will arrive at the decontamination facility by land, air or sea transport,
- The Radiation Safety Regulation [30] published in the Official Gazette dated March 24, 2000 and numbered 23999, since the entire decontamination process is related to radiation,
- The Regulation on the Protection of External Personnel Against the Risks That May Originate from Ionizing Radiation [31] published in the Official Gazette dated 18 June 2011 and numbered 27968, since decontamination facility has controlled area and personnel to work with radiation,

should also be considered.

4. CONCLUSION

Contamination is a radioactive pollution in the solid phase, which may exist in solution or be carried as a gas/vapor. Removing of this contamination by physical and chemical methods is defined as decontamination. The main purpose of decontamination is reducing the activity level of contaminated equipment which may occur during operation or after decommissioning of nuclear power plants. Although chemical cleaning processes are generally sequential processes, it is a decontamination method based on the use of chemicals that will dissolve the surface oxides and penetrate the material in such a way that they can take up the radioisotopes in the remaining material. Although electrochemical methods show similarities with chemical methods in terms of process, they are seen as advantageous in terms of less secondary waste generation. In addition, it is preferred for equipment to be used again since the process is more controlled and gives more effective results in terms of surface roughness. In cases where chemical or electrochemical methods cannot be used, physical decontamination methods have been developed as an alternative. The most important purpose is to clean the contaminants from the surface, as in other methods, however this process is carried out mechanically in physical methods.

The main purpose of the decontamination process applied before dismantling is to reduce the doses exposed to the NPP workers. The dose limits for NPP workers are specified for each country. It is the operator's responsibility not to exceed this dose. In the "Radiation Safety Regulation" [30]: “The effective dose for radiation workers cannot exceed 20 mSv on average for five consecutive years, and 50 mSv in any one year” provision is included. These values are accepted values in almost all countries. In accordance with this purpose, the operator is required to carry out decontamination of the whole system or decontamination for a particular equipment or part in cases where these conditions cannot be met. But decontamination processes take a long time; for this purpose, as long as the limit set for the workers is not exceeded, decontamination is not preferred much during the operation stage.

The most important purpose of the decontamination process applied during and/or after the dismantling process is to restore the site and reduce contamination of equipment or parts, and bring it to the release limits so that it can be reused or harmless to the environment.

Another issue mentioned in this study is explaining decontamination from a regulatory point of view. Decontamination studies have not been presented as a single regulatory document in any country. It is usually given in the form of provisions contained in different regulations. Considering for Turkey, it is thought that it would be appropriate to determine the decontamination requirements in a regulation regarding the dismantling phase. The most important issue here is the submission of a detailed plan, program or a report regarding the decontamination that the regulatory body will request from the operator of the nuclear power plant. Preparing a detailed plan or program by the operator and submitting it to the regulatory authorities for approval is considered as a method that will facilitate the regulatory agency's information and follow-up regarding decontamination safety. In line with this purpose, "Decontamination Safety Assessment Form" in the US regulation, "Operational Decontamination Safety Program" in the Japanese regulation, "Decontamination Plan for Systems Associated with the Primary Circuit" in the Finnish regulation, and "Decontamination-Related to Decontamination" in the South Korean regulation has been examined and the information contained in each document has been evaluated. The information required to be included in the decontamination plan, program or report is summarized in the figure below.

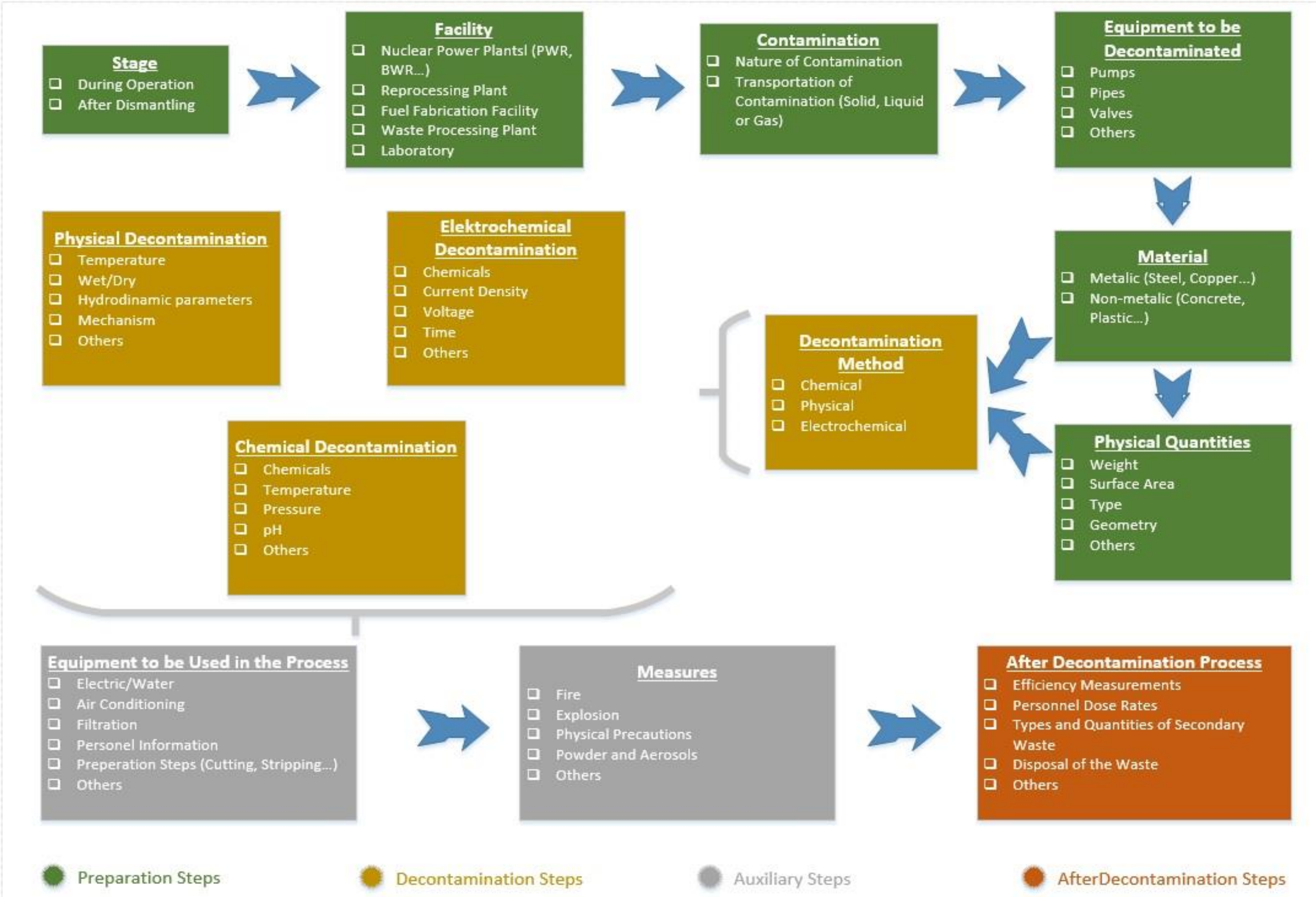

Figure 4: Schematic representation of information required to be included in the decontamination plan, program or report

NOMENCLATURE

AECL	Atomic Energy Canada Limited
BWR	Boiling Water Reactor
CANDECON	Canadian Decontamination
CANDEREM	Canadian Decontamination and Remediation
CANDU	Canadian Deuterium-Uranium Reactor
CITROX	Citric and Oxalic Acid
CNSC	Canadian Nuclear Safety Commission
CORD	Chemical Oxidizing Reduction Decontamination
DF	Decontamination Factor
EDTA	Etilendiamin tetraasetik acid
EPRI	Electric Power Research Institute
HOP	Hidrazin/Oksalik Acid/Potasium Permanganat
JAEA	Japan Atomic Energy Agency
LOMI	Low Oxidation-State Metal Ion
LWR	Light Water Reactor
ODP	Ozone Decontamination Process
PWHR	Pressurized Heavy Water Reactor
REDOX	Reduction Oxidation Reaction
SODP	Strong Ozone Decontamination Process
TAEK	Türkiye Atom Enerjisi Kurumu
IAEA	International Atomic Energy Agency
VVER	Vodo-Vodyanoi Energetichesky Reaktör

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

CONTRIBUTION OF THE AUTHORS

Yasin ÇETİN: Writing, reviewing, performed the experiments and analyse the results.
Adem ACIR: Reviewing, analyse the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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