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Proposed Managements of ^{137}Cs Contaminated Soil: Case Study in South Tangerang City

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ABSTRACT

Recently, BAPETEN found contamination of ^{137}Cs while testing environmental radiation monitoring equipment in an area in South Tangerang City. The area, therefore, needs to be cleaned up by performing decontamination followed by the activity of treating the contaminated soil. The decontamination works were carried out by excavating the contaminated soil on the surface to a depth of more than 1.5 m, and then the soils were put into the 100L drum. Decontamination work resulted in a significant reduction dose exposure in the area to 0.3-0.75 μSv/h. The drums containing contaminated soil were then sent to the interim storage facility in BATAN Serpong facility for further treatment. To resolve the ^{137}Cs contaminant, some alternatives in the decontamination and management of the contaminated soils were studied. Some techniques and strategies for decontamination and managing ^{137}Cs are presented in this paper. Management that involves wet and dry methods will be proposed in this paper. By comparing and evaluating various alternative management methods, an appropriate method for treating the contaminated soil in South Tangerang City can be obtained. The objective of the study was to find a suitable management method for the contaminated soil based on the proposed alternative management methods. In the present case, the compaction method seems promising for use soon.

INTRODUCTION

In the middle of February 2020, Indonesia was shocked by the finding of ^{137}Cs radioactive contamination on an empty land in South Tangerang City by BAPETEN (Nuclear Energy Regulatory Body), and immediately the news media in Indonesia (newspaper and online news) were rumored with this sensational news [1,2]. Radioactive contamination has been found on an empty land close to residential buildings in South Tangerang. The location of the event is shown in Fig. 1. The higher activity compared to the surrounding environment causes great concern to the regulatory body, and in coordination with National Nuclear Energy Agency (BATAN), to carry out a mitigation plan of decontamination activity. The contamination needs to be handled well, carefully, and safely so as not to cause panic in the community, and more importantly that the activity can minimize the subsequent impacts such as the possibility of further spreading of radioactive contaminants into the surrounding of the location. The decontamination activities was conducted under the supervision of BATAN.

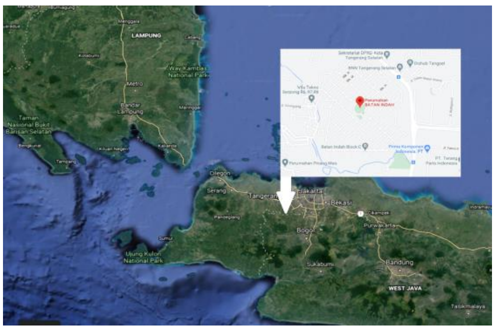

Fig. 1. A map of the location of radioactive contamination has been found

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Before conducting the studies of decontamination and management of the soil contaminated with ^{137}Cs, the nature of ^{137}Cs needs to be understood first. Radiocesium-137 has a high solubility property in solution and has a long half-life (about 30 y). When the ^{137}Cs reach the groundwater, it can become the primary causes of water contamination to the residents surrounding the location because it can be readily associated with plants and species existing in the terrestrial and water environment [3]. However the ^{137}Cs is not very mobile in the environment, but it tends to accumulate and bind strongly on the most surface of soil and hence leads to more localized absorption. Consequently, ^{137}Cs is difficult for uptake by vegetation through roots [4].

The close similarity of Cs^+ ion behavior to that of Na^+ and K^+ ions facilitates ^{137}Cs assimilation into living organisms through digestion processes [5]. If the human body is possessed with ^{137}Cs substance, cells in the body could become damaged due to the radiation that might penetrate the entire body deposited in the soft tissues such as muscle and nerve cell, and it might also cause cancer [6]. To protect the public health and workers, BAPETEN issues the regulations on Radiation Protection and Safety in the Utilization of Nuclear Energy, where the average effective dose limit for radiation workers is set at 20 mSv/y, while for the general public is set at 1 mSv/y [7].

The circumstances in which the problem of radioactive contamination (^{137}Cs) occurred in South Tangerang City have a different character from the event of nuclear accidents in Fukushima and Chernobyl. In the events of Fukushima and Chernobyl accidents, the contamination occurs in the surface soil due to the release of ^{137}Cs from the accident to the atmosphere, which makes it the most abundant radioactive atmospheric pollutant capable of becoming health hazards. The ^{137}Cs will then return down to earth as ^{137}Cs fallout and settle on the soil surface to a large extent as ^{137}Cs contaminants. Most of the contaminants had fallen onto the surface of the soil, so soil decontamination activities in Fukushima and Chernobyl were carried out by excavating the surface soil to a depth of about 5-15 cm [8-10]. This activity was intended to clean up the area from contaminants. Meanwhile, the ^{137}Cs contamination in South Tangerang City was different. Here the contamination came from ^{137}Cs source contaminating the surface and also the sub-surface of soil so that the decontamination method also has a slight difference in treatment. To perform the decontamination of the contaminated soil in South Tangerang City, a similar MARSSIM manual can help the decontamination activities [11]. The soil obtained from soil removal was put into 100L drums. The activity of decontamination in South Tangerang City has resulted in hundreds of drums containing ^{137}Cs contaminated soil. Fortunately, the location of the incident is located not far from the BATAN Serpong facility (± 4 km from the location), so the drums containing contaminated soil can be sent to the BATAN's interim storage facility for safe storage before further processing. This is the ex-situ method, where contaminated soil is excavated and then decontamination processes are done at another place.

The technique of removal of the radioactive ^{137}Cs from the soil is necessary and important, therefore it is expected that the results of the study will find the appropriate technologies for further use. For this reason, in this study methods of decontamination of the ^{137}Cs contaminated soil and volume management of the waste generated from the decontamination work will be proposed and discussed in this paper. Information obtained from the activities of the decontamination and management of the wastes, such as procedures, methods, decontamination techniques, and management of the ^{137}Cs contaminated soil (also how to remove and treat the ^{137}Cs from the soil) will be explained briefly as well as some techniques and strategies for the treatment of the contaminated soils. The objective of the study was to find a suitable management method for the contaminated soil based on the proposed alternatives of management methods. The method obtained then can be used as consideration for stakeholders to manage the contaminated soil in South Tangerang City.

METHODOLOGY

To conduct this study, the existing primary and secondary data and the supporting information relevant to the decontamination of ^{137}Cs contaminated soil and its subsequent processing are to be used. An approach using the MARSSIM manual shown in Fig. 2 [11] can assist in the preparation of the initial survey activity procedures. A radiation walkover survey method by using survey meter was carried out to classify the area of the investigated location. Output of the survey activity was data about type and level of radiological from the contaminants, which were then used to classify contamination areas, work paths of workers in decontamination activities and to make recommendations on the activities and tools as well as the analytical methods to be used in the decontamination activities.

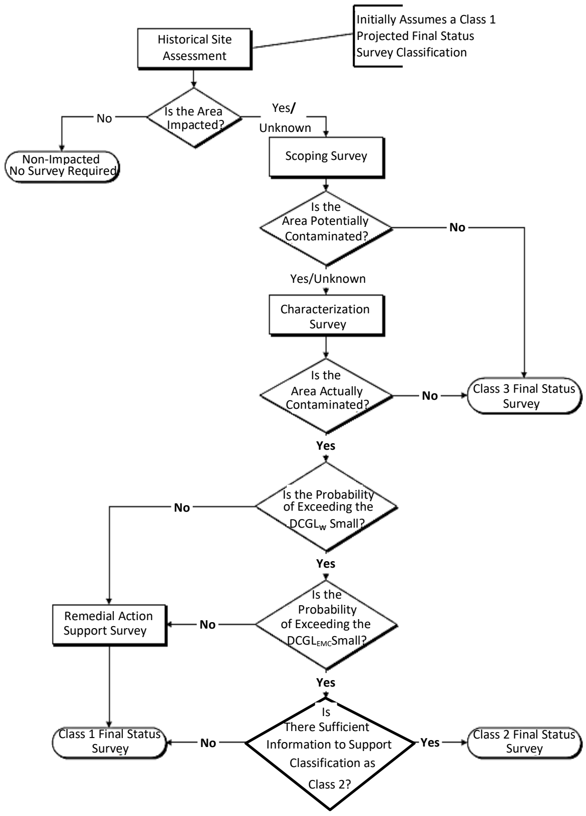

Fig. 2. Survey classification process of MARSSIM manual [11]

The walkover surveys showed that a radionuclide type of ^{137}Cs was obtained, which was allegedly originated from radioactive sources spread out over the area. Some hotspots were found at that location, and the dose exposure in this area was about 149 mSv/h [12,13]. The hotspot was then considered to be chosen as the center or target of the decontamination activity plan.

The surface of the contaminated areas was decontaminated by excavating these areas at a depth of more than 1.5 m with a backhoe, and the soil was collected and put into a 100L drum. Some hundreds of drums were obtained and brought to the IS facility at BATAN Serpong. Coring activities were carried out in areas that have higher radiation levels (near hotspots) as can be seen in Fig. 3. Soil coring results were sent to the radiometric lab to identify the distribution of ^{137}Cs intrusions into the subsoil layer. However, in this paper, we do not discuss the analysis of radiometric measurement results.

The excavated soils then became the object of assessment for the management of the contaminated soil. Knowledge about contaminated soil management was compiled from the assessment of several techniques for the accumulation of ^{137}Cs in the contaminated soil that has been published. The compilation of the several techniques was then reviewed to find a suitable method of treatment to be considered further as the method of treating the contaminated soil waste.

(a)

(b)

Fig. 3. Activities of decontamination and investigation in the land area: (a) excavate the surface and (b) coring of the soil layer

The strategy to reduce the number of drums containing contaminated soils can be shown in Fig. 4. Drums that have higher activity concentration levels are separated from those of low activity (less than 8000 Bq/kg [14]). Only drums that have high activity concentration will be further processed. The drums with low activity concentration then can be placed in a location that does not need to be controlled anymore, or the soils can be released into the environment with the approval from BAPETEN.

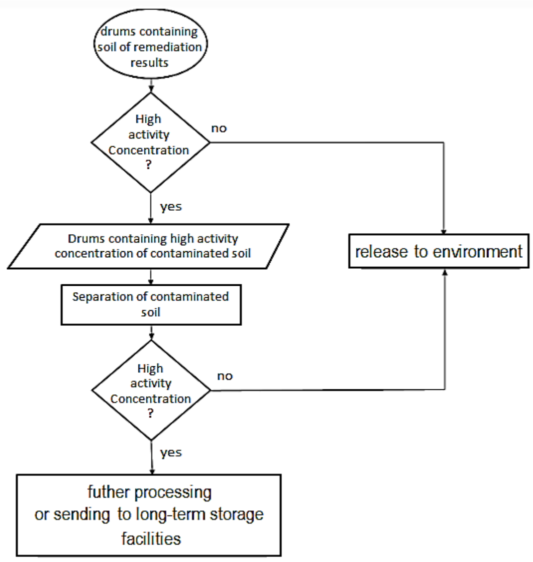

Fig. 4. Strategy to reduce the volume of contaminated soil from decontamination results

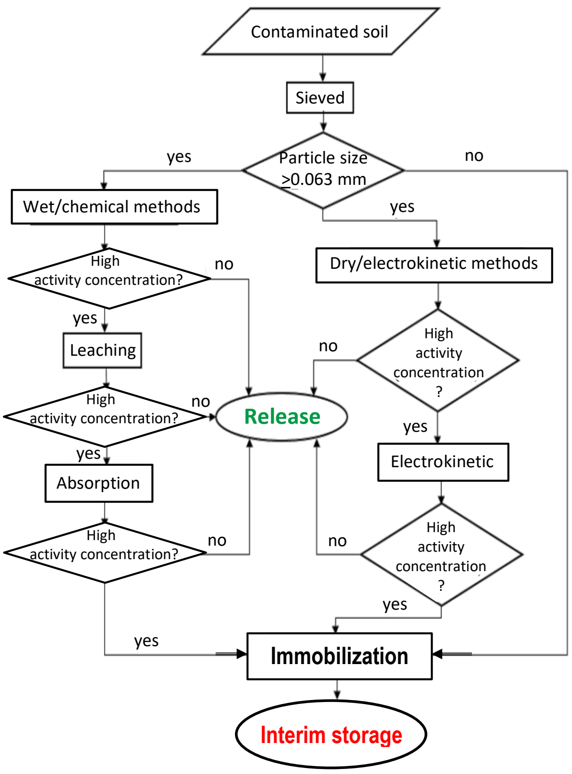

Fig. 5. The proposed methods of managing contaminated soil

To reduce the quantity of the contaminated soil, wet and dry treatment methods will be used as shown in Fig. 5. The volume reduction works (wet and dry methods) will be done in the interim storage at the BATAN facility (ex-situ processes). A suitable management method for treatment of the contaminated soil will reduce the amount of contaminated soil and also reduce the use of drums filled with contaminated soil, thereby increasing the capacity of the IS facilities.

RESULTS AND DISCUSSION

The discovery of ^{137}Cs source and the results of the coring activity analysis indicate a slightly strange result if these results were intended as radiological contamination of the soil surface. At the location, high activity was observed at the ground surface in one point, but at another point a high activity in certain depths in the soil was also obtained. This suggests that the ^{137}Cs radioactive contamination occurred at the location appears to be an intentional act, and the behavior could be suspected as an attempt to hide radioactive material in the area by irresponsible people.

The decontamination work resulted in a significant reduction in the activity of ^{137}Cs at the site. The concentration of ^{137}Cs in the contaminated area decreased from 149 to 0.3-0.75 mSv/h [12,13]. Soil with high concentration of ^{137}Cs will be processed further.

The next step is to study several treatment techniques to remove ^{137}Cs from the soil. An attempt can be made to remove ^{137}Cs from the contaminated soil by washing and filtering soil samples containing ^{137}Cs. Radiocesium is highly bound to the soil due to the presence of mineral debris in the contaminated soil structure [15,16]. The presence of minerals in the soil composition can bind ^{137}Cs strongly [17-20], so the desorption of ^{137}Cs from minerals is required. Removal of ^{137}Cs from contaminated soils can be done through wet and/or dry processes, where each of the processes has the advantages and disadvantages. But the main thing from this activity is that the principle of radioactive waste treatment must not be ignored, that is the reduction of volume of the treated waste.

In the initial stage, the contaminated soil was classified based on its particle size (<0.063, 0.063 <x <0.1,> 0.1 mm) [21]. Soils with a particle size of <0.063 mm were immediately immobilized because they contained high concentration of ^{137}Cs, as mentioned previously. Meanwhile, samples > 0.063 mm will be processed. The particle size distribution of soil is highly dependent on the characteristics of the soil at the contaminated location. The results of the particle size classification analysis of contaminated soil are shown in Table 1 [21].

Table 1. Analysis of particle size classification of contaminated soil [21]

No.	Surface effective dose rate of waste drum	Soil particle size (mm)	Volume (%)	^{137}Cs (Bq/kg)
		$\geq$ 1.0	28.3	1.5 – 886.0
1.	$\geq$ 0.05 mR/h (7 %)	0.063 $\leq$ x < 1.0	61.2	16.3 – 6700.2
		< 0.063	10.5	47.1 -19547.0
		$\geq$ 1.0	48.5	0.3 – 35.1
2.	0.02 – 0.05 mR/h (60 %)	0.063 $\leq$ x < 1.0	46.5	13.9 -436.7
		< 0.063	5.0	287.9 – 1663.7
		$\geq$ 1.0	52.4	2.5 – 7.0
3.	$\leq$ 0.02 mR/h (33 %)	0.063 $\leq$ x < 1.0	43.1	25.4 – 53.0
		< 0.063	4.5	85.6 - 377.2

The soil with particle size in a range between 0.063 and 1.0 mm provides the largest portion in soil particle size. Soils with the particle size of more than 1.0 mm are relatively easy to decontaminate from the ^{137}Cs, and soil with particle size 0.063 - 1.0 mm was selected to be processed to remove the ^{137}Cs contaminants by using the soil washing method. Soil with a particle size smaller than 0.063 mm containing high radioactive concentration is sent to a treatment facility for immobilization processes because ^{137}Cs bound strongly in the smallest particle size of soil. Very low efficiency of removing ^{137}Cs was obtained from fine particles (<0.063 mm) [21].

In the first proposal of treatment of the contaminated soil using wet method, several methods were carried out using leaching solutions to extract/remove ^{137}Cs from the contaminated soil. The use of chemicals as leaching solution such as citric acid, citric acid + HNO_3, NH_4NO_3, $FeCl_3$, $(COOK)_2{\cdot}H_2O$, $(NH_4)_2SO_4$, $H_2C_2O_4{\cdot}H_2O$, NaOH, Na_3PO_4, and KI solutions has been reported by several researchers [20, 22-25]. In this sudy, oxalic acid and KI chemical agents have resulted in high removal efficiency value to decontaminate ^{137}Cs from the soil. Around 50 % of ^{137}Cs can be removed from the contaminated soil by both chemical agents. The price of both chemical agents is also reasonable.

Shibata *et al*. [26] conducted a study on ^{137}Cs decontamination by flushing with water to the simulation of ^{137}Cs contaminated soil. The results show that only about 7 % of ^{137}Cs is extracted by water and the remaining 90 % of ^{137}Cs is still strongly bound in soil samples. Most of the ^{137}Cs accumulates in soil samples with particle size of about 425 μm, which is the particle size of minerals in soil (vermiculite). It is predicted that ^{137}Cs is absorbed in the frayed edge of vermiculite. The extraction ratio will increase with longer processing period.

Yanaga and Parajuli [19,23] conducted an extracting ^{137}Cs from solution by contacting artificially contaminated soil with KI solution, and as a comparison they also carried out soil washing with demineralized water. The results show that the process of removing of ^{137}Cs from contaminated soil increases with the increase of KI concentration in the solution. Increasing the processing time does not increase the extracted ^{137}Cs. This is due to the strong bonds between ^{137}Cs and minerals in the soil samples. Extraction with water only, on the other hand, gives small amount of ^{137}Cs released into the solution as shown in Fig. 6.

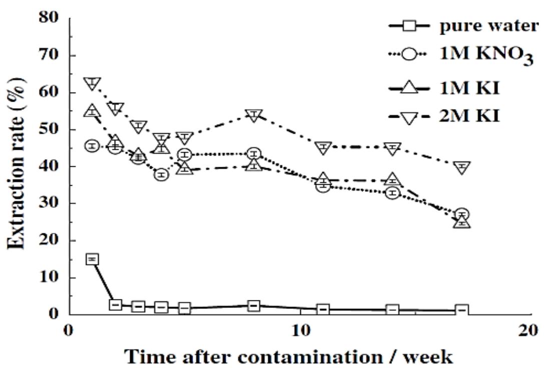

Fig. 6. Variation of extraction time versus ^{137}Cs removal from solution [19]

Hirose [22] extracted ^{137}Cs from contaminated soil using Milli-Q water, Ammonium Acetate, and Acetic Acid solutions. The results of the overall extracted fractions of ^{137}Cs using the three-step sequential extraction process could only produce less than 30 % of ^{137}Cs that were removed from the solution.

Kim *et.al*. [21] developed a soil washing system to remove ^{137}Cs using several extraction solutions such as H_2O, citric acid, citric acid + HNO_3, NH_4NO_3, $FeCl_3$, $(COOK)_2{\cdot}H_2O$, $(NH_4)_2SO_4$, $H_2C_2O_4{\cdot}H_2O$, NaOH, and Na_3PO_4 solutions. The results shows that the $H_2C_2O_4{\cdot}H_2O$ chemical agent provides the highest efficiency value for the removal of ^{137}Cs from the solution, almost up to 50 %. Oxalic acid will form a stable metal-complex with ^{137}Cs, and dissolves hydroxides. Besides, the $H_2C_2O_4{\cdot}H_2O$ is also reasonable in price, so $H_2C_2O_4{\cdot}H_2O$ is an optimal chemical agent for washing the soil. They did not use HNO_3 or H_2SO_4 solutions to extract ^{137}Cs from soil to avoid strong acid in the next processes.

The solids part obtained is expected to be low in ^{137}Cs concentration, so it can be released into the environment. The obtained liquid containing ^{137}Cs was then reprocessed by the absorption method with a variety of absorbent materials, both derived from natural materials, organic, or modified materials.

To reduce the concentration of ^{137}Cs in the extracted solution, some methods such as adsorption/ion exchange, electrochemical, and biomaterials processes are proposed. Among them some processes are the most attractive for decontaminating ^{137}Cs from solution, i.e., adsorption/ion exchange and electrochemical processes with considerable removal capabilities. Adsorption materials generally can be divided into three categories: carbonaceous, clay, and biomass materials/biosorbents.

Carbonaceous materials, or *activated carbon*, has been pioneered for the investigation of adsorptive materials for the removal of various contaminations (heavy metals or radionuclides) from aqueous solutions. This material has a good active adsorption site and has a special porous structure (large specific area), which can adsorb organic and inorganic contaminants. To increase the absorption ability to be more selective towards certain metal ions or radionuclides, several chemical additives are often added to carbonaceous materials [27]. Carbonaceous materials have low stability and selectivity properties towards the target metal ions, so they require modification with a selective inorganic ion exchanger to enhance the adsorption capacity and improve their stability and selectivity properties. On the surface of such natural materials as rice husk and areca nut are given with nickel hexacyanoferrate (NiHCF) [28] or potassium nickel hexacyanoferrate (KNiHCF-GAC) to absorb Cs ions in solution [29]. The results show that these materials have better performance in absorbing Cs ions in solution and gave the maximum adsorption capacity for KNiHCF-GAC reaching 163.9 mg/g. The disadvantage of this material is the stability of the properties of the final product that is still rough. The process of making these materials to achieve a standardized product still needs to be considered. And many more absorbent materials are made from activated carbon such as those made as carbon nanotubes, but are not discussed in this paper.

Other natural materials that can be used for radionuclide decontamination of ^{137}Cs include *clay material* as an electrochemical process. The material is very attractive with its good ion exchange capability, where ions such as Na, K, Ca, Mg existing at their exchange site will replace their position with ^{137}Cs in the clay material and then the sorption of radionuclides can occur into the material. Many clay materials have been intensively studied such as zeolite, bentonite, kaolinite minerals as absorbent materials to absorb ^{137}Cs, both for treatment processing purposes and as buffer material in the near-surface disposal facilities [30,31]. However, for decontamination activities, these materials need to be modified to increase or improve their absorption capacity (cation exchange capacity / CEC). Modification of clay material by using nickel [32] or by pillarization of clay (montmorillonite and goethite materials) before they are used as absorbent [33]. Since clay materials have an alumina octahedral sheet in their structure (especially for bentonite and zeolite), the lattice has an unbalanced charge because the Al-octahedral sheet gives the excess of negative charge. If any cation is present in the solution (such as ^{137}Cs), it can be counterbalanced to this negative charge to neutralize the compound [34]. Figure 7 is the illustration of the bentonite structure.

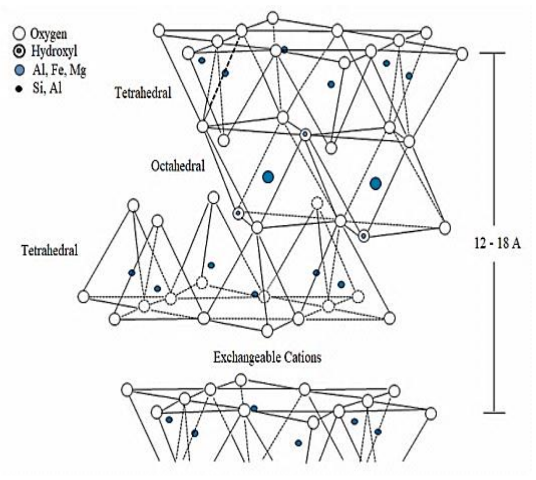

Fig. 7. The structure of bentonite mineral [34]

Clay material is widely used as an alternative material for the decontamination of ^{137}Cs in soil. The advantage of using natural materials is that they are easy to obtain, they have an attractive price, and they can be easily attached to the immobilized material of the radioactive waste packages.

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Biomass material (as *biosorbents*) used to absorb metal ions has also attracted the attention of researchers. Cross-linking between persimmon waste and sulfuric acid was used by Pangeni *et al*. [35] to eliminate ^{137}Cs from the solution. The adsorption capacity towards ^{137}Cs becomes greatly increased after this process. There is also biomass material made of walnut shell and pine cone for absorbing ^{137}Cs by functionalizing with NiCHF and Fe (III) HCF which are useful for increasing the absorption capacity of materials to metal ions. Both of these chemicals are used to increase the absorption capacity of the absorbents against metal ions. The advantage of this material is that it is easy to manage after use. The incinerator unit combustionprocess can complete the volume reduction process by almost 91.9 % by volume (at 500 ^{o}C for 2 hours).

The use of other materials with more sophisticated technology (advanced materials) can also be considered to eliminate ^{137}Cs from the environment such as the use of graphene-like layers that are chemically durable and resistant to radiation emission. The use of Prussian blue nanoparticles (PBNP)-incorporated with polyvinyl alcohol (PVA) to form a composite of nanoparticles [36] or to create unique structural properties of the titanate nanotubes is also promising to absorb ^{137}Cs from solution [37]. There are many more materials in the form of composite nanoparticles prepared by researchers to remove ^{137}Cs from solution. The modification and combination of these materials are of considerable concern and necessity to improve their adsorption capacity. Removal of ^{137}Cs from the solution by using an adsorption and ion exchange methods is summarized in Table 2 [26].

Table 2. Summary of the decontamination of ^{137}Cs from solution by using the adsorption and ion-exchange methods [26]

No.	Materials	Properties
1.	Activated carbon	Large in specific area, low in cost, low stability and selectivity
2.	Functionalized active carbon	High selectivity and capability, hard to separation
3.	Clay minerals	Large quantity, stable, low in cost, low stability and selectivity
4.	Biosorbents	Renewable, potential in volume reduction, low in cost, low capability and selectivity
5.	Advance materials	High capability and selectivity, fast kinetics, facile separation, complex synthesis procedure, high cost

The liquid which is "clean" from ^{137}Cs or at a low concentration of ^{137}Cs can then be released into the environment or used as a mixing fluid in the immobilization process. The contaminated soils that the ^{137}Cs have been extracted from then can be classified as soil having low radioactive content. Upon approval by BAPETEN, the soils and solutions can be released into the environment. Meanwhile, the absorbent materials which are rich in ^{137}Cs radioactivity concentrations are immobilized as waste packages before delivery to the IS facility.

Yu has carried out his research on the decontamination of ^{137}Cs using electrokinetic methods [25] to remove ^{137}Cs from the soil. The soil which has a high radioactive activity is put into a column. The column is then given a DC electric voltage and flush water to maintain the soil pH. Electrokinetic decontamination works by electro-osmotic effect, removing contaminants by flushing the soil, where the flow is driven by very low pressure such as that in soils with low permeability of a clay material. The location of the electrodes will determine the electric field lines, and the electrodes causes the ions to move along the electric field lines to reach a high level of flow direction control. Electromigration of charged species is independent of soil pore size and thus it applies equally to coarse and fine-grained soils. This method has been widely used to remove heavy metals from soil. To decontaminate contaminants from the soil, electrokinetic technology applies a low-level direct current to the contaminated soil, where the electrodes are placed in the soil samples. The contaminants are then deposited at the electrodes. Based on the difference in electrical voltage, the metal ion as a positive charge (such as ^{137}Cs) will move and be deposited at the cathode part, and *vice versa* for the anode. Large forces may restore the charge balance on a time scale in the system. By assuming that there is no net charge accumulation in each compartment (electrically neutral), the electric current will be constant along with the one-dimensional medium. To make the cathode saturated with ^{137}Cs, long treatment time is required. Figure 8 is a schematic diagram of the electrokinetic process used to extract metal ions/radionuclides from soil.

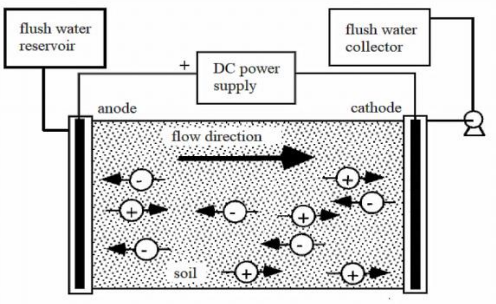

Fig. 8. Schematic diagram of the electrokinetics soil decontamination process [25]

The soil is flushed constantly with water at a low velocity to collect the radionuclide that accumulates at the cathode. The effect of electrokinetic processes on the soil also depends on the sorption and diffusion parameters of radionuclides in the soil. High sorption and slow diffusion properties of the soil make radionuclides cleaning up process take a long time, up to a few months. Increasing DC current on the soil sample can reduce the treatment time. In materials that have good absorption ability such as bentonite, the treatment time will be longer. Fig. 9 shows the type of remaining fraction of ^{137}Cs after treatment using electrokinetic method. A high Kd value will cause a much longer treatment time of ^{137}Cs [25].

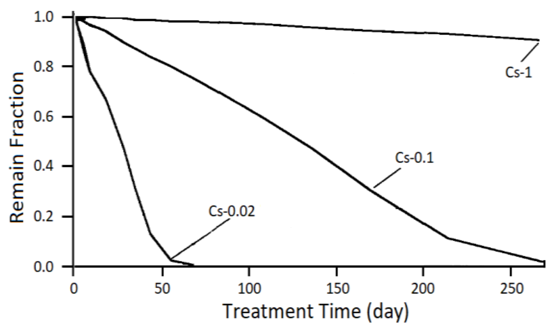

Fig. 9. The remaining fraction of activity during the treatment, with the variation of Kd values (m^3kg^{-1}), modification from ref. [25]

Unfortunately, the use of electrokinetic decontamination methods has limitations when non-target contaminants are present in large quantities in the environment. Removal of non-target contaminants from the soil may be preferable to the target contaminants. There is a change in the soil pH near the electrode due to the electrolysis reaction after decontamination. The pH of soil near the cathode is very high about 10.8 and near the anode is very low about 3.5 [38].

The presence of organic matter in the soil can reduce the decontamination ability of electrokinetic devices. Radionuclides will be associated with organic matter in the soil so that the effect of soil pH is also important. Increasing pH in the soil causes the functional groups in organic matter to do protonation processes, causing radionuclides to be absorbed strongly in organic matter.

Electrokinetic decontamination process at least will be affected by several parameters such as the activity of metal ion concentration in the soil, electric current density, electrode distance, flow of washing solution (chemical agent), type of soil sample, treatment time, soil pH, etc. Manipulation of all parameter values will result in the optimal conditions of the electrokinetic process to be able to decontaminate metal ions or radionuclides such as ^{137}Cs from the contaminated soils. With time, this method has been studied by Cameselle [39], Shahrani [40] and Mao [41]. Then to improve the decontamination results of ^{137}Cs, the electrokinetic method is combined with other methods such as water flushing [42], acid-enhanced [43] and electodialytic [44].

The electrodes which are rich with ^{137}Cs are then immobilized by compaction and cementation methods as waste packages. The waste packages are then sent to the IS facility for safe storage.

The last proposal–perhaps this is the easiest method to do–is the compaction method applied to the drums containing contaminated soil which has a high concentration of activity (>8000 Bq/kg) [14]. The drums with high activity concentrations are obtained by separating them from drums with low activity concentrations. The soil is put into 100L drums, and then the 100L drums are inserted into the 200L drum and then the compaction process is done in the inside of the 200L drum. The 200L drum can contain 3-4 compacted 100L drums. The 200L drums then are sent to the IS facility. The advantage of the compaction method over the previous methods is fast volume reduction processes and no secondary waste.

The advantages and disadvantages of each of the proposed management processes are summarized in Table 3.

Table 3. Summary of the 3 proposal of management of contaminated soil.

No.	Methods	Advantage	Disadvantage
1.	Wet	• Large in the specific area	• Low stability and selectivity of final product
		• Large in quantity	• Secondary wastes
		• Renewable	• Ex-situ processes
		• Attractive in prices	• Needs to be made in pilot scale
		• Easy in the volume reduction processes	
		• Easy attached to the matrix of immobilization material	
		• High selectivity and capability	• Expensive
		• Fast kinetics	• High cost
2.	Dry	• In-situ and ex-situ processes	• Long process time
		• Wide range of contaminant	• Low selectivity
		• No secondary waste	• Depend on soil condition (pH, absorption, diffusion, organic matter)
		• Less expensive	• Acid-basic fronts in soil
			• Needs to be made in pilot scale
3.	Compaction	• Process fast	• Ex-situ processes
		• Facilities are available	
		• No secondary waste	

When comparing among the three managing methods of ^{137}Cs contaminated soil, the first method (the wet method) is quite promising for future use. This is due to the many conveniences it has (materials, technology, costs). Raw materials are widely available in nature so the prices are relatively cheap, and the technology is more proven. The engineering costs are also attractive with relatively affordable operational costs. Unfortunately, this method still needs to be further developed into a pilot scale before commercialization. On the other hand, natural materials for absorbent products are still difficult to standardize because of their low stability and selectivity.

The wet method becomes an economical way to manage contaminated soil on a medium scale, as Korea did when they managed their contaminated soil by ^{137}Cs and ^{60}Co [21]. Radionuclide contamination occurred around the TRIGA Marks I and II reactors, which were operated by KAERI. The contamination was due to its long-term operation. The contaminated soil was cleaned-up by excavation works, and about 4000 drums of 200L filled with contaminated soil were collected. These drums were then brought to the IS facility for processing in 1988. This incident made KAERI develop technology for decontaminating the soil contaminated with ^{137}Cs and ^{60}Co: washing system for soil contaminated with radionuclides. The soil washing system consists of several unit operations which are joined in an integrated process to separate soil components from contaminating materials.

To design a contaminated soil washing system, by considering the surface effective dose rate of each drum, Kim took 50 drums out of 4,000 drums containing contaminated soil. Ten kilograms of soil samples were taken from each selected drum. Soil samples were dried and sieved to obtain 3 types of soil particle sizes. Then the 3 types of soil particle sizes sample were measured for its radionuclide level with a multichannel analysis (MCA) unit. The soil washing system is designed to decontaminate the contaminated soil with particle size > 0.063 mm. During the leaching process, soil contaminated with leaching solutions (oxalic acid) will produce a large volume of liquid waste. To reduce the volume of liquid waste, chemical sedimentation and ion exchange methods have been applied in the design of soil washing systems. The result shows that 75 % of the ^{137}Cs and ^{60}Co can be removed from the leaching solution. The addition of a hydro-cyclone unit between the scrubber and the sedimentation has increased the removal efficiency of ^{137}Cs and ^{60}Co from the soil washing system by 30 % compared to that without the hydro-cyclone unit [21].

Absorbents that are made from advanced materials may be more suitable for processing contamination of valuable and expensive materials with a scale that is not too large, balanced with their operating costs.

The dry method (electrokinetics) promises to solve the problem of decontamination of contaminated soil in-situ [43,45,46]. The electrokinetic technique can be used for the decontamination of soils, sediments, and any porous material. This technique is preferred to be applied to saturated soils. It can also be used to treat a wide range of contaminants such as decontamination of heavy metal or radionuclide contaminants [47,48].

Electrokinetic techniques have been applied to the Naval Air Weapon Station (NAWS) to decontaminate the presence of heavy metals Cd and Cr from electroplating and metal finishing operations. Many soil sample tests were carried out in the laboratory to obtain the soil characteristics of the site. Sodium chloride and metal sulphide were present in the site. This led to the production of chlorine gas along with oxygen at the anode wells and hydrogen sulphide gas at the cathode wells. This required additional off-gas treatment in the design system. After 22 weeks of work, low contaminant concentrations were found in several areas, but a review of progress shows that several factors have retarded the remediation progress. The poor performance of the decontamination treatment is due to the high concentration of chloride in the soil as a characteristic of the location. Chloride ion causes changes in soil pH and in turn can slow down the process of transporting contaminants to the electrodes. Scale tests did not accurately reflect the effects that would occur due to the remediation process (competing ions affecting the pH soil and contaminant transport [47]) and also could not predict the efficiency or the duration accurately. Therefore, the target level was not met [48].

Clean-up of uranium contaminants in the vicinity of the Paducah Gaseous Diffusion Plant owned by the US Department of Energy (DOE) has been undertaken. Very low permeability is the characteristic of the soil at this location. The contaminant that was targeted was TCE (Trichloroethylene). In a 150 square feet area with a depth of 15 feet, the site consists of 4 feet of graves and clay layers over 40 feet of sandy clay loam with interbedded sand layers. Steel panels are used as electrodes and contaminants are captured by activated carbon granular as they move towards the electrodes. To collect the vapor containing TCE, the collector system is designed and placed above the ground. The concentration of TCE in the carbon treatment zones become high due to the TCA captured, and the removal efficiency was around 98 % [48]

Compaction is a method to reduce the volume of solid waste. The drum is crashed by applying higher forces and the waste compaction processes occurs directly in the drums. This method avoids the possible extension of waste volume and diminishes aerosol emission. This method applies to drums containing contaminated soil only of a high radioactive concentration. The drum sorting process needs to be done before doing the compaction. The volume reduction factor of the compaction method depends on the waste composition. In the incident of land contaminated in Tangerang Selatan City, it is likely to resolve the managing of the contaminated soil by this method because BATAN already has solid waste compaction facilities so that this process can be carried out immediately. Other management processes still need to be further developed in the pilot-scale before they can be used in real terms.

The management of contaminated soil when the location of the incident is far from a waste treatment facility with a large area impact will have a different approach than if the location of the incident is near to a waste treatment facility, as happened in Chernobyl and Fukushima.

The incidents at Chernobyl and Fukushima Daiichi NPP have contaminated the large areas with radioactive fallout. Large-scale clean-up activities have been carried out by excavating the soil surface layer with a thickness of 5-15 cm depth over a large area. A large amount of contaminated material has been generated, which is then collected in a temporary storage facility (TSF) to isolate the contaminated material [49]. The contaminated material is then sorted according to the IAEA classification to allow ex-situ washing activities, especially for the removal of ^{137}Cs from the contaminated soil. To provide safe and secure storage while waiting for waste retrieval for disposal in suitable disposal, these facilities are sometimes equipped with engineered covers to reduce radioactive exposure such as a thick layer of sand or compacted clay [50]. TSFs have been constructed in many places. Generally, there are three principal management options for the management of the contaminated soil: maximalist (all wastes are retrieved, treated, conditioned, and disposed of), minimalist (do nothing, all wastes are left in the present conditions), and intermediate (some of the wastes are retrieved and treated) options [51].

Among the three options, the intermediate option can be the basis for the optimization of contaminated soil management. Especially for long-lived wastes that need to be considered, re-disposal is the only the acceptable option. Processing of contaminated soil can be performed by incineration, soil washing, and electrokinetic methods. In the short term, improvement of conditions in some TSFs can be carried out by eliminating of growing vegetation and by providing adequate cover on the TSF surfaces. Temporary storage is only possible as long as conditions are considered safe, and waste retrieval is required as soon as possible. The TSFs are ideally located at a reasonable distance from the processing facilities, washing facilities for contaminated soil, or not too far from the existing disposal facilities or from locations that are intentionally designed for new disposal facilities [51]. If we compare the incident in South Tangerang City with those in Chernobyl and Fukushima, the Chernobyl and Fukushima incidents have a much larger scale. The distance of the TSF location and the processing facility are varied, so it requires a very high cost for collection of decontamination results, sorting, on-site processing, transportation, and final processing (off-site). In the case of the incident at South Tangerang City, no TSF was required because the contaminated soil was brought to the BATAN facility after cleaned-up.

As mentioned in the previous discussion, the first proposal is more promising to be implemented soon. However, it needs to be made in pilot-scale while the compaction method that is already available at the BATAN facility can be operated immediately. In South Tangerang City, ex-situ processes are more suitable because the location of the processing facilities is relatively close and the amount of the contaminated soil is relatively small. For this reason, we suggest that the compaction method is the most suitable to be applied to manage the contaminated soil originated from South Tangerang City.

It is expected that at the end of the processing activities, the number of drums containing contaminated soil can be reduced from the IS facility by releasing it to the environment as clearance waste upon approval by BAPETEN. Only drums containing contaminated soil which are very difficult to process will be stored at the IS facility, or they can be put in a disposal facility, so the existing IS facilities can then be increased in capacity.

CONCLUSION

The accident of land contaminated by ^{137}Cs in the South Tangerang City area is a momentum to conduct decontamination technology study in our institute. Options of decontamination technology for the contaminated site needs to be considered and to be prepared. An efficient decontamination strategy suitable to the site conditions becomes an urgent need. Traditional extraction methods and technologies that have been available at BATAN shall be reconsidered and need to be improved. Adsorption/ion exchange or wet methods seems more promising to be applied soon. However, the compaction method may be used because this method is easier to operate and compaction facilities are available at BATAN facility.

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AUTHOR CONTRIBUTION

Budi Setiawan analyzed all the decontamination techniques, arranged the methods of managing contaminated soil, wrote and improved the manuscript. Dadong Iskandar and Sumarbagiono provided suggestions for manuscript writing. Gustri Nurliati, Heru Sriwahyuni, Mirawaty, and Nurul E. Ekaningrum provided the documents on wet decontamination methods. Pungky A. Artiani, Kuat Heriyanto, and Yuli Purwanto provided the documents on dry decontamination methods. Meanwhile, Budi Setiawan conducted a study on the management of contaminated land in Korea, Fukushima-Japan, and Chernobyl-Ukraine, so that Budi Setiawan contributed as the main contributor to this paper.

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