

Figure 1. Mid-and-long-Term Roadmap Summary

圖三十三、日本 Fukushima-Daiichi NPP 中長程清理規劃

(三) 日本福島事故後環境污染清理現況

日本於 2011 年 11 月 11 日公布施行法案 "The Act on Environmental Cleanup of radioactive material released from Fukushima-Daiichi NPPs"。於此法案下日本環境部 (MOE)的執行策略爲成立示範計畫來執行包括土壤、建築物、道路、公園、水、森林等的清理。

清理示範計畫由設於 JAEA 的總部: "Headquarters of Fukushima Paternership Operations, JAEA" 規劃指揮。將福島事故中受污染區域分成 12 個不同污染等級的鄉鎮區域,進行清理技術示範,如圖三十四。



圖三十四、日本福島事故後環境污染清理示範規劃-12 個示範點

共12個示範點再區分成三組(如圖三十五),分別為

Group A: Taisei consortium(大成集團), 負責 Minamisoma-city, Kawamata-Machi, Namie-machi, Litate-mura,

Group B : Kajima consortium(鹿島集團), 負責 Tamura-city, Futaba-machi, Tomioka-machi, Katsurao-mura,

Group C: Obayashi consortium(大林集團), 負責 Hirono-machi, Oukuma-machi, Naraha-machi, Kawauchi-mura

各群的任務爲示範所負責的目標點內,包括林地、農地、居住地及建物、道路等清理所需技術,各種技術分成高、中、低三個等級,分別爲輻射劑量率 (1) > 100mSv/y, (2) 20-100Sv/y, (3) 5-10mSv/y。

Soliciting ideas for model-case decontamination demonstration (decontamination demonstration in 12 municipalities)

Group	Adopter	Municipalities
Group A	Taisei Consortium	Minamisoma-city, Kawamata-machi, Namie-machi, litate-mura
Group B	Kajima Consortium	Tamura-machi, Futaba-machi, Tomioka-machi, Katsurao-mura
Group C	Obayashi Consortium	Hirono-machi, Ookuma-machi, Naraha-machi, Kawauchi-mura

Soliciting ideas for demonstration of decontamination technologies (select 25 entities)

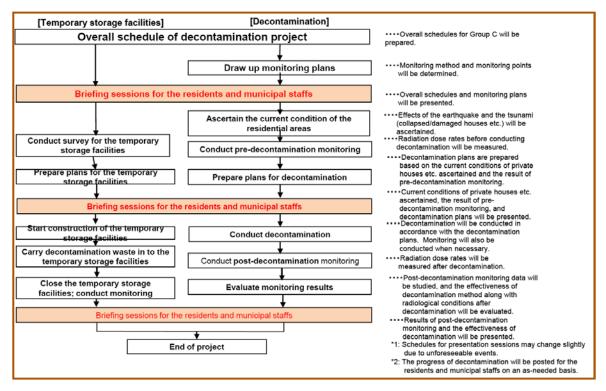
Entity	Themes for demonstration	Entity	Themes for demonstration	Entity	Themes for demonstration
JAXA	Volume reduction by thermophile aerobic bacteria	Takenaka Corporation	Multi-step washing of soil	Tokyo Institute of	Purification by adsorbing/coagulating/precipitatin g agents compounded with iron ferrocyanide
Natures, Inc	Decontamination by mole-cluster	Koriyama Chip Industry Co., Ltd.	Decontamination and volume reduction by washing and incinerating wood and tree bark	Technology	
	ozone water			Kictec Inc.	Decontamination by surface processing with ultra high-
Macoho, Co., Ltd.	Decontamination of road surface by wet-blasting	Toshiba Corporation	Technique to retrieve Cs from soil	Rictec Inc.	processing with uitra nigh- pressure water
Rohto Pharmaceutical, Co.,Ltd.	Volume reduction of radioactive material in soil	Kyoto University	Wash-off of Cs by nano-bubble water	Taisei Corporation	Surface decontamination for making woody waste into chips
Sato Kogyo Co., Ltd.	Decontamination of soil; volume	Obayashi Corporation	Increasing efficiency of decontamination of woodland, etc.	Konoike Construction	Volume reduction by wet classification of soil and surface grinding
Taiheiyo Cement	Removal of Cs from soil	Kantechs Co., Ltd.	Decontamination of wreckage and debris by dry ice	Co., Ltd.	
Corporation	Removal of CS from Soil	Mikuniya Corporation		Hitachi Plant	Volume reduction by classification
Nippon Steel	on Steel Volume reduction of removed dirt,		Organic volume reduction system	Technologies, Ltd.	of soil and heat treatment
Engineering Co., Ltd.	sludge, etc.	Kumagai Gumi Co., Volume reduction by special Ltd. washing equipment		Decontamination of street gutters	
Toda Corporation	Volume reduction by washing	Fukushima		Maeda Corporation	in the housing land by artificial zeolite blocks
Neonite Corporation	Decontamination technique of woody biomass	Prefectural Forestry Research Centre Development of dose reduction technique for woodland			Decontamination not by washing
				Shiga Toso	with high-pressure water; mitigation of contamination by hydrophilic coatings

圖三十五、日本福島事故後環境污染清理示範規劃-3個執行群組

示範計畫中所提出技術經過實際執行,將提供以下各點的驗證:

- 1. 驗證空間劑量率是可以被減少的。
- 2. 檢驗各種型態及體積的污染廢棄物清理的成本與效益。驗證各種污染廢棄物 減量技術。同時要記錄工作人員執行時間及所接受輻射劑量。
- 3. 驗證大範圍除污、高劑量率區域除污、及地震海嘯後所產生的殘礫殘骸的除 污方法。
- 4. 確認輻射管制和安全管理程序。
- 5. 驗證污染土壤分離、污染水處理、放射性廢棄物焚化各種方法的適用性。
- 6. 驗證放射性廢棄物安全暫貯及監控方法。
- 7. 提升民眾對除污作業的合作。

示範計畫執行流程如下圖三十六。



圖三十六、日本福島事故後環境污染清理示範規劃進行流程

目前示範計畫初步成果以清理目標分類,包括泥土除污、建築物屋頂及牆面除污、混凝土除污、水除污、樹幹除污等,彙整如表十二。

表十二、日本福島事故後環境污染清理示範規劃進行流程

Object	Technology	Demonstration Test Result	Remarks
Soil Decontamination	Rotally Sublimation System	60,000Bq/kg ⇒ <100Bq/kg Decontamination ratio > 99.9%	Taiheiyo Cement Corp.
	Blend Air Tornado Pump and Cyclone System	15,000Bq/kg ⇒ 330-390Bq/kg Scavenging ratio; >98%	Rohto Pharmaceutical, Co.,
	Multistep Soil Washing System	5,400-12,000Bq/kg ⇒ 1,100-1,300 Bq/kg Scavenging ratio; 79-94%	Takenaka Corp.
	Grain Size Separation System (Volume Reduction)	Soil Diameter Ratio; >5mm(20%), 0.075- 5mm(72%), <0.075(8%) Activity Ratio; >5mm(1%), 0.075- 5mm(12%), <0.075mm(87%)	Kumagai Gumi Co., Ltd.
	High Pressure Water Jet, Micro-Buble Voltex Breakdown and Turbid Water Treatment System	6,000-7,000Bq/kg ⇒ 800-1,000Bq/kg Decontamination Factor; 76-87%	Sato Kogyo Co., Ltd.
	Retreve System By using Oxalic Acid	5,000Bq/kg ⇒ 450Bq/kg Elution Factor; >91%	Toshiba Corp.
Roof Tile and Wall Decontamination	Dust Precipitator Type Sander(1), Strippable Paint(2)	Surface Decontamination Rate; (1)35-56%, (2) 50-68%	Shiga Toso
Concrrete and Asphalt Decontamination etc.	Decontamination by Mol-cluster Ozone water	Decontamination rate; (1)Hard Concrete, 60%, (2)Asphalt, 70%, (3)Building, 70%	Natures, Inc
	High Pressure Water Jet (J-Remover)	Concrete Surface; Decontamination rate; 94-99%	Kictec Inc
	Wet Blast Decontamination	Concrete, Interlocking Brick and Asphalt, Decontamination rate; 60-70%	Macoho Co,. Ltd.
Water	Artificial Zeolite Brick	Purification Factor; 47%	Maeda Corporation
Decontamination	Iron ferrocyanide	Purification Factor for swimming pool water; >90 %	Tokyo Institute of Technology
Tree bark Decontamination	Stirring device with water	Decontamination Factor; (1)Evergreen Tree; 39%, (2)Deciduous Tree; 45%	Koriyama Chip Industry Co,. Ltd.
	(1)High Pressure Water Jet and (2)Purification of collecting water by absorbing material(Neonite)	Decontamination Factor; (1)75- 94%(Depend on kind of tree), (2)>99%(under detection limit)	Neonite Corporation

各種除污對項實際進行情形,包括農地、道路、居屋、及大量污染泥土暫貯等, 如圖三十七至圖四十六。



Pulverization by tractor equipped with a vertical harrow



Scraping by tractor equipped with a rear blade instead



Disposal/ sandbagging by tractor equipped with a back hoe

- O Concentration of radioactive cesium within soil 10,370 Bq/kg → 2,600 Bq/kg (reduction :75%)
- O Air dose rate on the topsoil surface 7.1 μ Sv/h \rightarrow 3.4 μ Sv/h
- O Volume of disposed soil approximately 40t/10a
- O Time required for removal approximately 55~70min./10a

This method is applicable in agricultural land regardless of dose of radioactivity and land category.

Volume of disposed soil is larger.

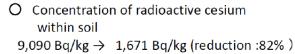
圖三十七、日本福島事故後環境污染清理示範規劃-農地整治(一)

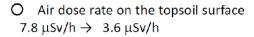


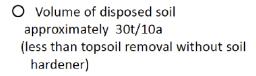
Spray of solution by dissolving magnesium hardener in water



Hardener solution permeates and topsoil hardens (7 to 10 fine weather days)





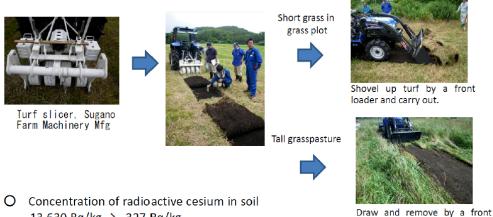




Removal of topsoil

- Hardening of soil prevents scattering of soil dusts, so it is effective for safety of operator.
- Topsoil was colored white, so it facilitates visual checking omission of removing.
- Cost of hardener is approximately 170,000 yen/10a.
- •No harmful effect to soil after decontamination.
- •The same result is expected when polyion or molecular polymer is used.

圖三十八、日本福島事故後環境污染清理示範規劃-農地整治(二)



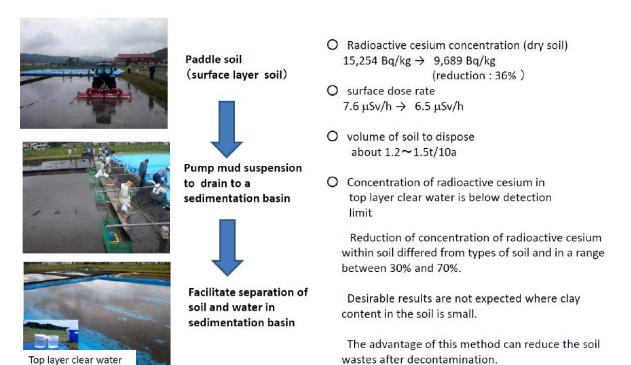
- O Concentration of radioactive cesium in soil 13,630 Bq/kg → 327 Bq/kg (reduction: 97%: scrape thickness 3cm)
- O volume of soil to dispose(including glass) approximately 40t/10a
- O Operation time 250 minute / 10a (approximately)

Decontamination efficiency is high, it is possible combining weeding and decontamination as one task.

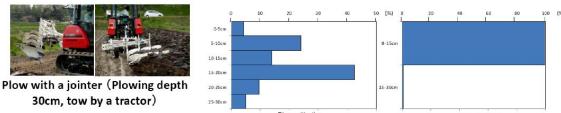
loader and carry out.

This method is applicable in a turf, grasspasture and weed where root matt is well grown.

圖三十九、日本福島事故後環境污染清理示範規劃-農地整治(三)



圖四十、日本福島事故後環境污染清理示範規劃-農地整治(四)



Plow cultivation Rotary cultivation Depth distribution of radioactive cesium after plowing in (30 cm)



the layer of 25 to 40 cm deep

topsoil was buried in

topsoil was buried in

the layer of 40 to 60

Plowing in (30 cm)

- O Surface dose rate $0.7 \,\mu\text{Sv/h} \rightarrow 0.3 \,\mu\text{Sv/h}$
- O Soil to dispose: no
- O Operation time 30 minutes / 10a

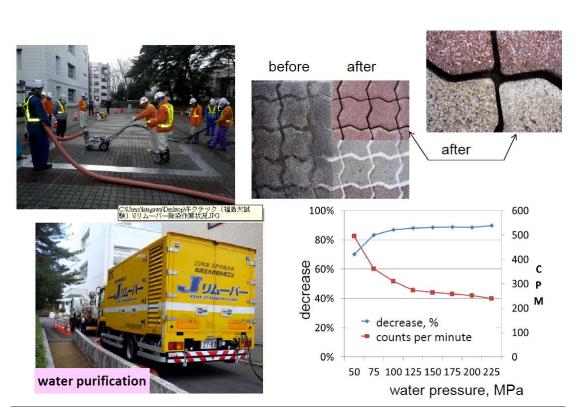
Before operation, risk assessment of ground water contamination and assessment of soil are essential.

Modified 2 layered plow (Plowing depth 45cm, tow by a tractor)



Two layered plow(Plowing depth 60 cm, tow by a D6 bulldozer)

圖四十一、日本福島事故後環境污染清理示範規劃-農地整治(五)



圖四十二、日本福島事故後環境污染清理示範規劃-道路除污(一)

DEMONSTRATION of DECONTAMINATION

- Decontamination Pilot Project: Concrete, Asphalt -

♦ high pressure water







surface stripping



blasting





圖四十三、日本福島事故後環境污染清理示範規劃-道路除污(二)

DEMONSTRATION of DECONTAMINATION

- Decontamination Pilot Projects: Building -



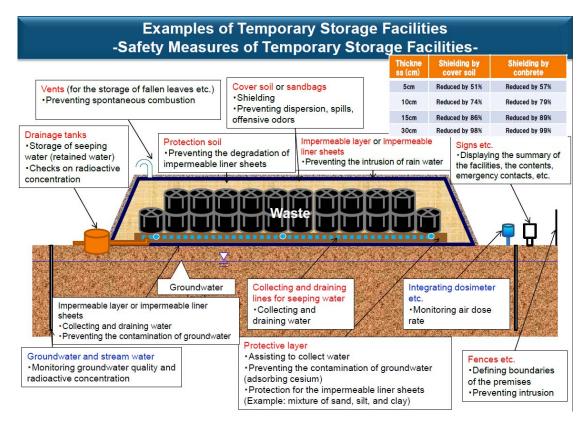








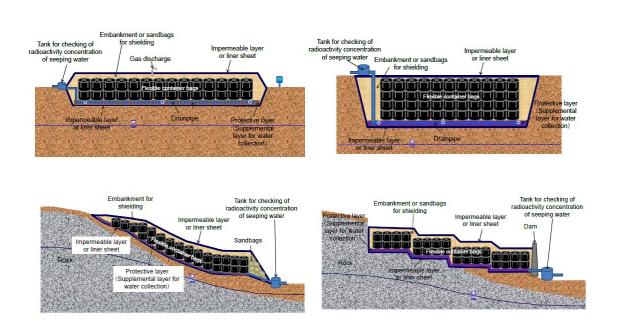
圖四十四、日本福島事故後環境污染清理示範規劃-屋頂除污



圖四十五、日本福島事故後環境污染清理示範規劃-污染泥土暫貯(一)

DEMONSTRATION of DECONTAMINATION

- Temporary storage for radioactive waste -



圖四十六、日本福島事故後環境污染清理示範規劃-污染泥土暫貯(二)

示範計畫的執行,爲後續大規模清理提供技術數據及執行經驗。目前發現:

- 1. 對於農地稻田及屋頂瓦片除污,尚未找到有效方法,
- 2. 對於樹林,需要長期以及更謹慎的除污方法,以保護生態,
- 3. 對於大量泥土除污以及減量技術,需要投入研究。

未來由政府主導的示範計畫需持續進行,同時可以提供人員訓練的效果。示範計 書的總目標為:

- 1. 降低輻射劑量,
- 2. 讓居民盡早回家成爲可能。

(四) 膠體除污技術

核研所 TRR 燃料池清理工作,在池水清理完畢之後,池壁清理爲整個 TRR 燃料池清理的重要步驟,影響後續再利用的可能性。池壁清理時,主要的安全顧慮爲污染空浮,因此如何固定混凝土結構表面污染物爲關鍵技術。TRR 燃料池壁總面積爲 980 平方公尺,目前開始評估大面積混凝土壁面膠體固定污染及除污技術。

日本 JAEA 的燃料精煉廠(Uranium Refining/Conversion Facility)的流化床系統清理工作中,大量桶槽系統需要以人工除污。桶槽內粉末狀殘餘物質(如圖四十七)清理必須抑制空浮污染。



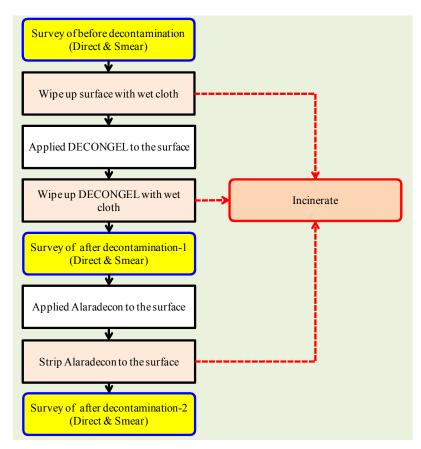
圖四十七、桶槽內表面粉末狀殘餘物質清理需求

初步除污採用真空吸取方式,因爲粉末粒徑只有 0.1 至 0.2 micrometers,清理工作不順利,進行八個月清理工作,盡力吸取約 12 噸粉末,表面污染濃度已經降至 15Bq/Cm²。後續採用膠體除污技術,固定粉末污染物並除污,採用膠體除污的好處之一是執行方法簡便,不需要特殊裝備。小區域教體除污實驗彙整如表十三。

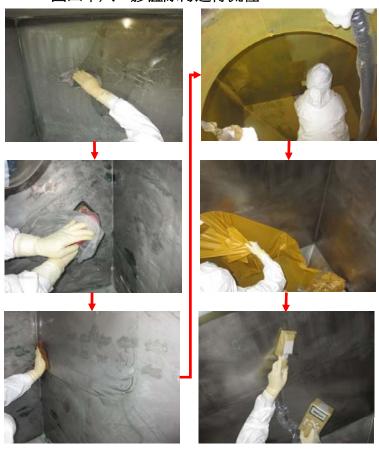
表十三、膠體除污實驗

			Fitness	Main characteristics
Wat process	Asid cleaning		×	Satisfy a decontamination target.
Wet process				Must treat a waste fluid.
	Blast			Satisfy a decontamination target.
				Must set up a Blast system.
				Must treat a spent bit.
	Grind		×	Satisfy a decontamination target.
				Must set up a dust catcher system.
	Aspigel Neorever Gel Alaradecon DECONGEL	Agnigal	Δ	Satisfy a decontamination target.
Davina		Aspigei		Must neutralization a spent gel.
Dry process		Neorever	×	Not satisfy a decontamination target.
		Alaradecon	×	Not satisfy a decontamination target.
				Quick-drying and good strippable
				Spent gelcan be incinerated.
		DECONGEL	0	Satisfy a decontamination target.
				Slow-drying
			Spent gelcan be incinerated.	

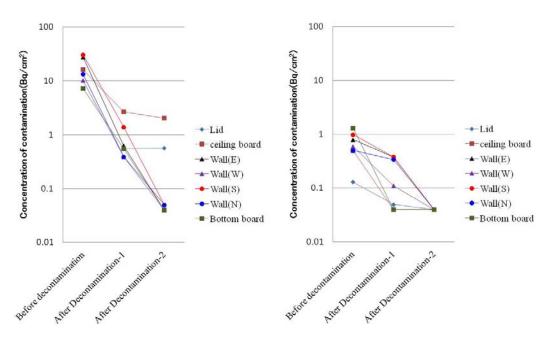
經由實驗結果選擇 DECONGEL 為主要教體除污劑,並選擇 Alaradecon 搭配,以補足乾燥速度的需求。膠體除污進行流程步驟如圖四十八及圖四十九。經驗顯示,除污劑乾燥速度影響效果甚鉅。膠體除污執行結果如圖五十所示,效果相當顯著,表面污染濃度約能降至低於 0.1Bq/cm²。



圖四十八、膠體除污進行流程



圖四十九、膠體除污進行步驟



圖五十、膠體除污執行成果

除污工作所產生的二次廢棄物如表十四。產生除污效益的膠體除污劑廢棄物僅 42 公斤,約占 16%。

表十四、膠體除污產生之二次廢棄物量

protective clothing	54 kg
Rubber glove	27 kg
Wet cloth	148 kg
Spent DECONGEL	10 kg
Spent Alaradecon	32 kg

四、建議事項

- (一) 日本濱岡(Hamaoka) NPP 一、二號機, 爲 BWR-4 反應器及 MARK-1 廠房,與國內核一廠同型,應爲核一廠除役規劃最適當的 reference plant,應持續收集參考其除役進展資訊。
- (二) 池壁清理爲整個核研所 TRR 燃料池清理的重要步驟,日本 JAEA 膠體除污劑使用經驗顯示除污效益卓著,值得參考。
- (三)日本因福島事故影響,核能電廠停止運轉進行安全評估及針對海嘯的防護補強,造成 2012 年夏季中西部地區(60Hz 供電區)電力供應缺口達 7300MW。儘管日本在國際上大量蒐購天然氣,亦無法補足用電需求。國內亦應該從能源安全層次務實的考量能源配比議題。