FEASIBILITY, COST AND SAFETY OF SOME REHABILITATION OPTIONS FOR THE MARALINGA TEST SITE

D. Vande Putte, E.P.S. Tufton and M. Myall
Costain Arup Electrowatt Consortium
Electrowatt, Grandford House, 16 Carfax, Horsham
West Sussex, RH12 1UP, England

ABSTRACT

The need to rehabilitate the former nuclear test site at Maralinga has required the development of safe and cost-effective clean-up measures. Options have been investigated, which include fencing-off parts of the site, removing surface soil, mixing surface soil and stabilising the contents of debris pits. The results of the study can be used in selecting the most suitable options or combination of options necessary to achieve a given radiological end-point.

INTRODUCTION

The United Kingdom carried out a series of nuclear warhead tests in Australia during the period 1952 - 1963. In addition to the main detonations, a series of minor trials was conducted at Maralinga range to test initiators, study the behaviour of fissile material under compression, assess the dispersion of radioactive materials during a fire and finally, to simulate the effects of accidental asymmetric or unsynchronised misfiring of a weapon. The latter type of trial caused the most extensive contamination, at a location known as Taranaki, on Maralinga range.

In the immediate aftermath, the larger debris was collected and buried in pits, and other remedial measures, such as limited ploughing were carried out. Further remedial action was deemed necessary and in 1967 Operation Brumby was implemented, among other things to mix several hectares of topsoil at Taranaki by ploughing, to provide fencing around the pits and most contaminated areas of Taranaki, and to cast concrete caps over the debris pits. Nevertheless, the whole of Maralinga range has remained a prohibited area. A Royal Commission to investigate the need for additional clean-up concluded that the test areas had to be made safe for unrestricted habitation by the Aborigines as soon as practicable. Among the steps necessary for rehabilitation of the range, is a feasibility, cost, and safety study of possible clean-up options. A number of such options were identified by a joint Australian-UK working group, and include fencing of restricted areas, soil collection and transport, soil mixing, and debris pit stabilization.

The Costain Arup Electrowatt Consortium was appointed to undertake the study of these options for Maralinga range. Another contractor was appointed to examine alternative options for soil burial, cleaning, and in-situ vitrification of the pits. The present paper shows the findings of the Costain Arup Electrowatt study.

SITE DESCRIPTION

The Maralinga range is located in the Great Victoria Desert of South Australia. The range includes a base camp served by a 38 km sealed road leading from the main transcontinental railway to the south. The area is essentially flat, with a mean elevation of about 240 m above sea level. The region is semi-arid, with little vegetation, consisting of occasional trees and poorly developed shrubs; the average rainfall is 210 mm/a. The geology consists of a superficial sand layer of between 10 cm and 10 m, under which is a horizontal layer of travertine limestone 10 - 20 m in depth, overlying sandy clay.

The radiological design basis for our studies was taken as the more heavily contaminated Taranaki site, located within Maralinga range. Contamination at Taranaki falls into two categories viz. buried in 21 pits, and dispersed on the surface (Fig. 1). The 21 pits are located within the inner fenced area. They may contain altogether up to 20 kg of plutonium mixed with 830 tonnes of debris (steel, baryte, bricks, lead, concrete, and cables) and occupy a nominal volume of 1118 m^3. Each pit is capped by a reinforced concrete slab 30 cm thick and of such dimensions as to extend 1 metre all round the edges of the pit. Typical pit dimensions are 3 m x 3 m x 2.5 m depth, although one pit is 15 m long. Surface contamination divides into two types, corresponding to previously treated, or untreated areas. The more heavily contaminated areas have previously been treated by mixing or covering with clean soil. The total treated area is 2.1 km^2. The average level of plutonium activity in previously treated soil lies in the range 40 - 400 Bq/g. The activity is highly inhomogeneous with the presence in soil of fragments of steel, light alloy and plastic contaminated with oxides of plutonium and americium. Three million fragments are estimated to be contaminated with about 0.8 TBq of Pu-239, the sizes of the fragments ranging from submillimetre minispheres of PuO_2 to a piece of steel plate with about 7 GBq of PuO_2 on its inner surface.

The contamination is spread over a depth of about 10 cm on average. The surface contamination, i.e. that corresponding to about 1 cm depth is thus about 50 - 500 Bq/cm^2. The untreated area extends beyond Fig. 1, with some 120 km^2 contaminated to $\geq$1Bq/g, with the contamination essentially in the first centimetre of soil. The relationship between contamination level and area is given in Table I for the untreated zones.

FENCING OF RESTRICTED AREAS

Specification

The fence is to act as an intrusion barrier with a minimum life of 30 years and should guard against burrowing by small animals, to a depth of 30 cm. It is not required to resist against deliberate human intrusion.

Technical Proposal

A standard 240 cm high chain wire security fence, topped with an additional 35 cm (3 strands) of barbed wire, is proposed. The fence would be supported on 40 mm diameter

TABLE I

Contamination Levels in Untreated Zones

Contamination Bq Pu/g soil	Contamination Bq/cm^2	Area km^2	Volume of soil m^3
1 - 5	1.3 - 7	110	6E6
5 - 10	7 - 14	5	5E5
10 - 20	14 - 27	4.9	2.5E5
>20	>27	0.1	4E3

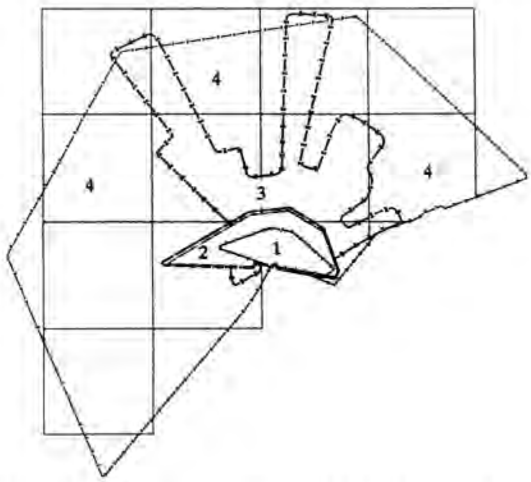

Fig. 1. Pit and plume areas at Taranaki. 1: pit area. 2: outer pit area. 3: treated plume area. 4: untreated area. Gridline separation = 3000 ft.

galvanized posts spaced at 4.5 m centres. The work would involve the initial excavation of a shallow furrow of about 30 cm by 15 cm using either a backhoe or a rubber-tyred chain trencher. In areas of other than rock, the fence's post hole footings of about 30 cm diameter by 75 cm depth, would be excavated by a tractor-mounted auger. In those areas with rock at or close to the surface, excavation would be by a hydraulic rockbreaker mounted on a rubber-tyred backhoe. The fence posts would then be concreted into position before hanging and stretching the chain wire. The final operation would be to pour a concrete cut-off wall, which would incorporate the base of the chain wire. In rock areas, a 15 cm x 15 cm nib would be formed and poured onto the rock surface.

The radiological end-point had not yet been defined at the time of study. However it is clear that soil would be uncontaminated or contaminated to a low level. For the purposes of this study a maximum of 1 Bq/g for α emitters in soil was assumed. Under normal circumstances, when no vehicle is moving and no excavation is being carried out, dust levels are about 0.033 mg/m^3 (1). At a normal breathing rate, and assuming that 10% of dust is respirable, this results in a dose of 3 μSv/a for a 24 hour per day residence. Higher dust levels can be expected while digging the furrow and fence post holes. The workman performing this task would be about 2 - 3 m away from the source of dust. Assuming the dust level at his position to be at the threshold of discomfort (4 mg/m^3), the dose to the workman would be 0.13 mSv/a for an 8-hour working day.

Therefore, no personal radiological protection equipment would normally be required for this work. The risk to workers from incorporation of plutonium in wounds is likely to be extremely small. Assuming an incorporation through wounds of 0.1 g of dust per week the resulting dose to the person would be about 0.05 mSv/a.

Cost and Timescale

The capital cost was determined to be AUS $1,050,000 per 10 km of fencing, of which AUS $100,000 is necessary for base camp infrastructure. The cost of additional fencing would be about AUS $950,000 per 10 km. The cost of patrolling such a fence would be AUS $200,000 per year. The direct cost of the fencing option is thus overwhelmingly sensitive to the need to be monitored continuously. The timescale required for erection of a 10 km fence would be 3 months, of which 1 month would be for support work and mobilisation.

SOIL COLLECTION AND TRANSPORT

Specification

Soil collection and transport is to be envisaged for the previously treated areas, and untreated areas. After top soil removal, the ground has to be covered by a 10 cm layer of clean soil which has to be revegetated. Haul distances to a repository of up to 30 km need to be considered.

Technical Proposal

The first task would be to remove large boulders and trees to prepare the area for cutting the undergrowth. The search for and collection of the boulders and trees would be accomplished using wheel loaders equipped with front bucket and rear chisel attachments. The vehicles would traverse the contaminated area in a series of parallel paths. If the boulders are partially buried in the soil the chiselling attachment would be used to dig them out. The chiselling attachment would also be used to dig out the tree roots down to a depth of at least 30 cm.

The second task would be to cut the undergrowth in preparation for surveying the areas. The undergrowth would be cut using tractor-hauled rotary cutters with an effective cutting width of 6 metres.

The third task would be to survey and mark out the area to delineate the zones of outcropping rock and soil zones too shallow for effective removal. The survey would be carried out by slowly traversing across the area in a series of parallel paths and probing the depth of the soil along the path to ascertain whether it is deep enough for removal. Zones unsuitable for soil collection would be marked by spray-painting.

The fourth task would be to remove the surface contamination from the rock outcrop faces and from the surface of the soil which is not deep enough for removal by wheel loader. Rock ripping and removal, and surface brushing are two methods of decontaminating the rock outcrops. Rock ripping and removal appears to be effective with the relatively high levels of contamination present in the previously treated area.

This would be done by using a Caterpillar D9N track type tractor with the rear mounted ripping attachment. For the low levels of contamination present in the untreated areas, wet brushing with low level vacuum removal of the surface debris should be sufficient to decontaminate the rock.

The fifth task would consist of removing the top layer of soil and smaller stones in order to remove the contaminated particles from the surface of the soil. The soil would be removed by traversing the area using a Caterpillar 980E wheel loader, with the bucket in the lowered position and its height set to give the removal depth of cut. When the bucket is full, the wheel loader off-loads its contents to a waiting dumper truck.

The sixth task would be to monitor the cleared area to ensure compliance with the required radiological end point, using a van with boom-mounted Ge-Li detectors.

The final task is to transport clean soil from the soil collection site and spread it over the site in a 100 millimetre thick layer. This would be done using a Caterpillar Motor Grader, Model 140G.

The work area would need to be cordoned off and become a controlled area with entry and exit of staff and equipment through a radiological control point. The cordon would need to be at a sufficient distance from the work area to allow any resuspended dust from the workings to deposit before reaching the support staff and exit control area.

In the previously treated areas high dust loadings can be expected. Values of $27 g/m^3$ of air are quoted for similar operations (1), and extensive contamination of exposed surfaces, e.g. equipment, can thus be expected, possibly levels in equilibrium with the activity in the first centimetre of soil, i.e. tens or hundreds of Bq/cm^2. Assuming the dust level to be as low as the threshold of discomfort ($4\ mg/m^3$), the dose to the workman could be near the limit of 50 mSv/a for an 8-hour working day. Clearly therefore, respiratory protection would be required. This would need to be provided by inlet air filtration of the cabs of vehicles, or by personal respiratory protectors, where manual operations are unavoidable. In addition, water would be sprayed on all cutting, ripping and mixing tools while working, to reduce the source of the dust.

In the untreated areas the same type of safety precaution would be as for soil removal from the treated area. However, the decontamination factors required for the inlet air of cabs in vehicles in some of the work areas could be lower. At the lower end of the contamination range there may be no need for inlet air filtration of the vehicle cabs.

Cost and Timescale

Costs were calculated for a selection of scenarios which varied both the area to be treated and the haul distances of the contaminated soil and the replacement top soil. For an area, previously untreated of $0.1\ km^2$ and a 5 km haul distance, the total cost was estimated at AUS $ 0.8M. For a corresponding area of $120\ km^2$ and a 30 km haul distance the cost would be AUS $ 420M. For the previously treated area ($2.1\ km^2$), the total costs would vary from AUS $ 8.0M for a 2 km haul, to AUS $ 10.7M for a 10 km haul. The costs do not include revegetation of the area. Significant cost savings could be achieved if no clean soil cover was introduced. The activities directly associated with soil removal and disposal operations would take up to 6 years, depending on the particular scenario and chosen manning levels.

SOIL MIXING

Specification

An alternative to soil removal is mixing to reduce the average concentration. The aim is to mix the soil in the 120 km^2 untreated area down to a level of 1 Bq Pu/g, and cover it by a 10 cm layer of clean soil, thus providing additional protective cover.

Technical Proposal

The first three tasks would be identical to the first three in the soil removal option.

The fourth task would be to remove surface and near surface stones from the soil areas in preparation for soil mixing. This would be done by raking the area using tractor-hauled mechanised rakes.

The fifth task would be to remove the surface contamination from the rock outcrop faces and from the surface of the soil which is not deep enough for mixing. This is similar to the fourth task in soil removal.

The sixth task would be to mix the surface soil in the areas designated suitable for mixing. Ploughing and soil stabilisation without additives are two methods of surface soil mixing which were investigated. Ploughing is intended to turn the top layer of the soil over and provide air passages through it to improve the cultivation of the soil. In soils with any reasonable shear strength properties the mixing of the top layer of the soil is very restricted and the air passages through it are very pronounced and these are not the conditions required. The air passages can be reduced in size and the soil clods broken into smaller pieces by using a soil packer behind the plough. In soil stabilisation without additives, the top layer of the soil is cut into small fragments which are then thoroughly mixed in the mixing chamber of the machine before being layered down and tamped by the rear door. The vehicle would be a Caterpillar Soil Stabilizer, Model SS250. The tool is a multi-cutting pointed rotor which rotates to create a soil shear action that cuts the soil into small fragments. The consolidating action of the rear gate tamps the soil down.

The final tasks of monitoring and providing clean soil cover would be undertaken as for the soil removal option.

The same type of radiological protection would be required as in the soil removal option.

Costs and Timescales

Soil mixing of the 120 km^2 untreated area would cost an estimated AUS $175M. A saving of nearly 50% would be achieved if the final clean soil covering was not carried out.

The tasks would each last about 3 years and to a certain extent be running in parallel, with a 3 - 6 month offset. The whole operation would last seven years.

DEBRIS PIT STABILISATION

Specification

The objective of this task is to define methods for the in-situ immobilisation or containment of the pit contents to prevent release of plutonium to the biosphere. The methods should make use of a multiple barrier solution, based on overcapping, pressure grouting, sheet piling, concrete side walls, grouting beneath the pit in isolation or in combination.

Technical Proposal

The first task would be to carry out preparatory works. Indeed, the adjacent surface soil at Taranaki is contaminated. It is advisable to remove or blanket any contaminated soil in the pit working area before carrying out any stabilisation work on the pits. The methods for doing this have been described above. Much of the later work can then be done using traditional methods and practices.

The second task would be to stabilise the pit contents. Three possible schemes were considered to achieve this objective.

Direct In-pit Grouting (Fig. 2) would be a possible stabilisation scheme. If conditions allow, profiled steel sheet would be driven to a 4 meter depth on all 4 sides of each pit. Alternatively, an excavator would be used to break through any surface rock before driving the sheets to retain the sandy material below. This sheeting would minimize any grouting losses and would enhance the control of the operation along the longer sides. Boring-machine access trenches would be excavated to 1.5 m - 2 m below ground level on the longer sides of each pit. Subsequent operations involve the risk of contamination. After the trenches are excavated, the proposal is to erect a lightweight enclosure on portal framing using either fabric or light modular panels. It is important to provide a complete fabric lining which can be decontaminated. The enclosure will need lighting, power, filtered extract ventilation, and change facilities for pressure suits working. Indeed, all subsequent work would be carried out in pressure suits or by operatives in enclosed cabs fitted with filtered air supplies. Three grouting points are suggested for each side of each of the smaller pits, and at 2 meter intervals for each side of the larger pits. The basic procedure would be to bore to a depth of approximately 1.5 meters using water flush to return the spoil. This spoil should be clean, since the trench sheet would be nominally 2 meters or more from the pit itself. However the boring machine would require an enclosed cab and the returned flushing water would be monitored by a team of 2 men in pressure suits. After each bore had reached nominally 0.5 m short of the pit wall, the grouting lance would be driven 0.5 m in the small pits and by 2.5 m in the wider pits. The ends of the lances would be fitted with valved connections for the grout supply. The vent points would be formed by a small coring machine, cutting 50 mm diameter cores out of the cap slab. Four vents are suggested for each of the smaller pits and an equivalent distribution (one per 3 - 4 sq. m) for the larger pits. Each vent hole, once cored, should be plugged with a steel pipe with a float valve closure and termination to allow its connection to a manifold and a HEPA filter. The valve would be designed to close when grout reached it. The grout materials and equipment would be kept out of the enclosure. The intention is that grouting should be a wholly remote operation facilitated by simple valves on both the supply and the vent ends. Completion of the grouting should be signified by the closure of float valves on the vents and by rising pressure in the delivery system.

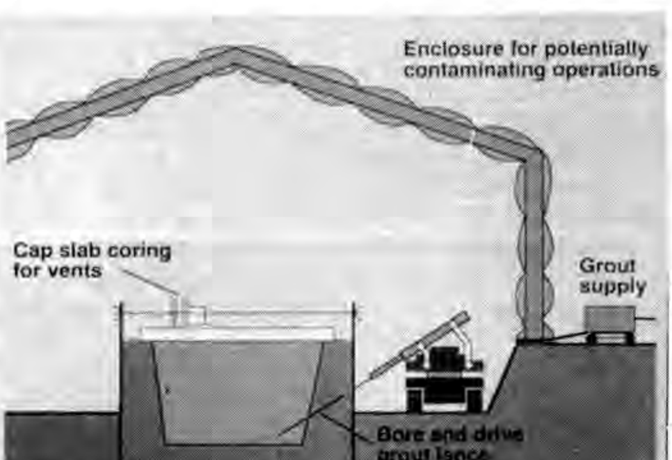

Fig. 2. Direct in-pit grouting.

After grouting, the grout supply lines could be released by men in pressure suits, and the lines cleared into the access trench. The open ends of the lances should be closed by valves and be uncontaminated. The vent piping and HEPA filters, which will be contaminated, could be removed and bagged for disposal or decontamination as appropriate. At the completion of the operation above, the pit top and its surroundings should be clean enough to work on conventionally. The boring-machine access trenches would be refilled with excavated material to cap level.

Another scheme for stabilisation would be rock and soil grouting. The objective of grouting the natural materials below and around the pits would be to prevent the inward movement of groundwater and to prevent any diffusion of the plutonium, and to provide a sorbing medium for any migrating plutonium. The zone which could be grouted - between the base of the pits and 10 to 20 m below ground - is above the present water table. Since the maximum pit cross-section is 6 metres wide by 3.7 meters deep, a borehole inclined at 45 degrees and 12 m long could reach the centre line of the pit from the ground level, with a margin between the end of the borehole and the base of the pit. It may also be desirable to grout the rock beside the pit bases where a vertical borehole can be used. Grouting a rock mass is highly site specific with respect to grout hole spacing, flow distances, pump pressures, mix design and so forth. Methods using packers such as; 'tubes à manchette' would enable up-stage grouting and better control of the grouting pressures. It was assumed that a 1 metre square grid of grout holes would adequately supply grout to fissures amounting to 1% of the rock mass. The grouted volume would be 2 metres thick, 3 metres larger than the pit on the plan, and brought up at the edges to meet the wall barrier.

A third stabilition scheme would be to provide cut-off walling (Fig. 3). The purpose of cut-off walls around the pits would be to prevent the flow of water horizontally into and out of the pits and to prevent intrusion by horizontally burrowing animals. This can be achieved with steel sheeting or with concrete. The installation of sheet piling is a comparatively simple process in soil of friable rock. The piling would be set

Fig. 3. Cut-Off walls.

Fig. 4. Cap and tumulus.

out 1 meter clear of the edge of the cap slab. Each pile would then be lifted into place by a mobile crane and driven by a hammer handled by the same crane. After the perimeter was completed, the protruding tops would be cut down prior to the placement of the overcapping slab. A number of options are available in terms of shuttered or trench-fill formation, mix design, and reinforcement for the construction of concrete walls. An unreinforced mass concrete wall, without bentonite, is suggested for this scheme. After preparatory work a trench 1 meter wide would be marked around each pit, the inner face 1 metre from the edge of the cap slab. During excavation of the trench, the sides would be retained by trench sheeting (light sheet piles to prevent the soil between the trench and the pit falling in and revealing the pit contents). The trench sheets would need to be strutted across the open trench. Stop-end formwork would be used to limit the volume of concrete poured at any one time. The props would be recovered during the concrete pour and when the wall was cast up to the required level, the sheeting would be withdrawn for re-use. At the end of this sequence, the wall would be ready to receive the edge of the overcap slab.

Capping provides isolation from above. After reviewing the international experience on such multi-barrier concepts and a consideration of the objectives, we recommended a combination of concrete slabs and of tumuli made from natural materials over the pits. Upward migration of radionuclides would be resisted by a bitumen membrane and a fine-grained natural layer. The bulk of the tumulus, and the presence of concrete, would discourage accidental human intrusion (Fig. 4). The proposal is to lay mass concrete with a top surface fall of 1:50 and a minimum thickness at the existing slab edge of 150 mm. Outside the existing slab edge, the ground should be excavated, if previous operations have not already done this, to 150 mm below the original cap slab level and out by 1 meter from the edge or as far as is needed to cover any wall. The slab may be cast with the edges retained only by the excavation, but an improved edge for the membrane would be achieved by shuttering to form a clean vertical surface to which the bitumen could be applied. The finish of the concrete should provide a clean and even surface, with a drainage fall, to which the bitumen can be applied. The first soil layer would be a silty sand, excavated from nearby, tipped and bulldozed over the membrane. Alternatively, a stabilized material could be formed by mixing lime and/or bitumen with natural materials. The layers above the silty sand are suggested as 500 mm of sandy gravel and 500 mm of cobbles. The progression from fine to coarse material should prevent an excessive loss of one layer into the one below during consolidation by the bulldozer. These two coarser layers are intended to provide the draining medium through which the rainwater will run down to the general ground level. The final layer of natural material is suggested as a nominal 750 mm of "boulders", that is stones of more than 150 mm in size. This layer is intended to be the primary defence against wind erosion, gully erosion by rainwater, and larger burrowing animals.

Costs and Timescale

The costs and timescales for debris pit stabilization are shown in Table II below.

CONCLUSION

Feasible, cost-effective rehabilitation options for the Maralinga range have been developed, in parallel with other option studies (2). These can be used in the next step, which is to select options or combinations of options required to achieve desired radiological end-points. An important milestone in the rehabilitation program has thus been achieved.

TABLE II

Costs and Timescales for Debris Pit Stabilization

	Cost in AUS $ x 1000					
	Const. Time Mths	Direct Field Cost	Field Support Cost	Overhead Salaries	Base Overhead Cost	Total Cost
In-Pit Grouting	10	4,365	100	756	1,123	6,244,000
Rock/Soil Grouting	20	7,257	171	1,350	1,961	10,739,000
Sheet Pile Walls	3	1,545	10	225	438	2,218,000
Concrete Cut-off	12	2,334	35	960	1,048	4,257,000
Caps & Tumuli	9	3,020	57	675	890	4,642,000
Combination in-pit and adjacent rock & soil grouting with concrete cut-off & tumuli		15,076	200	1,750	2,500	19,526,000

ACKNOWLEDGEMENTS

The authors wish to thank the Australian Department of Primary Industries and Energy, and the Australian Nuclear Science and Technology Organisation (ANSTO) for permission to publish this work. Dr J. M. Costello of ANSTO kindly reviewed this paper; the authors wish to express their gratitude to him for this.

REFERENCES

1. AUSTRALIAN IONISING RADIATION ADVISORY COUNCIL, Radiological safety and future land use at a Maralinga atomic weapons test range. Report AIRAC-4, 1979.
2. "Rehabilitation of Former Nuclear Test Sites in Australia", Report by the Technical Assessment Group, Department of Primary Industries and Energy, Australian Government Publishing Service, Canberra, 1990.