A SUGGESTED PROTOCOL FOR THE RADIOECOLOGICAL EVALUATION OF THE RUNIT ISLAND DISPOSAL SITE AT ENEWETAK ATOLL.

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1.INTRODUCTION

Between 1948 and 1958 a total of 43 nuclear weapons tests were conducted by the United States at Enewetak Atoll in the Marshall Islands. Together with tests conducted at Bikini Atoll, a total of 66 devices were detonated. While most of the large yield devices tested at Enewetak were exploded in the North West Quadrant of the Lagoon, the largest number of tests took place near Runit Island on the Eastern reef of the Atoll. [1,2,3]. All of these tests were essentially atmospheric tests, with the exception of two which were detonated underwater.

It was not until 1993 that the yield of all the exploded devices were finally declassified [1,4]. At Enewetak, five islands were partially or totally removed and large craters were formed on others. Surface topography was extensively modified due to the tests themselves and associated construction activities. Radioactive contamination of soils and lagoon sediments was widespread and contaminated debris was present on a number of islands [1,3]. In addition, there had been considerable dislocation of the indigenous peoples of the atoll who were evacuated from Enewetak and resettled at Ujelang Atoll, the most westerly of the Marshalls group [5].

The testing programme on Enewetak Atoll effectively ended with the "Fig" 0.02kt surface test on August 18 1958. Following this, US efforts in the region were directed at the rehabilitation of Bikini and Enewetak Atolls. The information available for the programme carried out is generally more extensive for Enewetak since an Environmental Impact Assessment was required and generated for the project [1]. The final adopted programme entailed the removal of radioactive debris and contaminated soil above a certain contamination threshold. This material was disposed of in the crater produced by the 18kt "Cactus" test conducted in May 1958.

The remediation operation was carried out between 1972 and 1980. Radiological surveys were conducted prior to and concurrent with the cleanup procedure. The stated purpose of the radiological cleanup was to minimise the annual radiation dose received by individuals to levels below those established in general from Federal Radiation Council guidelines. The cleanup was largely based upon transuranic element criteria [2]. In addition to removal of radioactive materials, dose minimisation also included as elements the control of the distribution of people resettling the atolls together with food source controls. Accordingly the adopted strategy concentrated on the removal of plutonium from the atoll and restrictions on the consumption of foods grown on the northern islands. At this time no survey effort was directed at well or rain waters and few samples of air were taken. Overall, the cleanup entailed the removal of some 100,000 cubic yards of surface soil from several sites and transportion to Runit Island where it was placed in a concrete lined waste disposal site [1,3].

The integrity of the construction on Runit Island has been called into question. Despite the extensive body of radiological research conducted at Enewetak, little appears to have been specifically carried out to resolve these concerns. Indeed, it has been referred to in the following terms: *A nuclear waste site presently exists on Enewetak which is unmonitored, and for which the U.S. Government has no future plans or financial resources appropriated to deal with."*[see: 6] This document therefore outlines the major concerns and suggests a programme of research designed to investigate the radiological integrity of the repository.

2. THE RUNIT DISPOSAL SITE

a) Site Location

The "Cactus" detonation took place on a surface prepared by bulldozing soil onto the reef at the northern tip of Runit Island. The resultant crater was approximately 37 feet (10m) deep and 346 feet (112m) in diameter. The geology is complex with the reef structure showing great variation in horizontal and vertical composition and structure. Shock effects from other nuclear tests have complicated the structure further [3]. The crater is located between the backreef and lagoon and much of the underlying rock has been severely fractured. While the beachrock surrounding much of the crater was deemed suitable for construction, it was limited on the lagoon side and highly fractured. Indeed, located on the lagoon edge of the reef plate, the crater has been stated to be located more on a sandbar than upon solid rock [3].

Around a quarter of the eastern circumference was open, permitting exchange of water with the ocean at high tide. Despite doubts about the long term integrity of a constructed containment structure and the likelihood of erosion of the contents in this location it was decided to proceed with construction [3]. This decision seems largely to have been predicated upon cost considerations and the relative ease of access.

b) Structure of the disposal site

Immediately after the device detonation, material pulverised in the event partially backfilled the crater formed. This material was contaminated with radioactivity from the explosion [2] and contained a variety of radionuclides. The total surface area of the crater was estimated at 6,900 square metres and about a third of this was covered with sedimentary deposits, the upper slopes being littered with rock rubble. The maximum volume at high tide was estimated at 44,000 cubic metres. Groundwater flows in the area south east of the crater are generally southwest into the lagoon. Prior to cleanup, it is estimated that around 17MBq of plutonium isotopes were released to the lagoon annually from the contaminated bottom material in the crater.

The "Cactus" crater was converted into a disposal site for contaminated radioactive soil and debris by construction of a keywall roughly contiguous with the crater rim. This wall was keyed to a depth of a foot into the reef where this was firm and to a depth of eight feet below the top of the adjacent surface where the reef was fractured or absent. The construction was designed to prevent scouring and undermining by wave action. It was not designed to prevent the migration of fine material from the crater bottom through groundwater action or in areas where beachrock was absent. The construction of the keywall was carried out at the same time as the first phase of filling the crater with contaminated soil.

Some concerns attach to the mechanical integrity of the concrete poured during construction of the keywall. The construction was hampered by tidal conditions which left excavations full of water even at low tide. Dumping of concrete into water filled formwork resulted in "laitance" or the partial separation of cement from the aggregate [3] . The phenomenon can seriously weaken concrete and change its porosity. This has obvious implications for the long term containment of the waste within the dome and also upon the migratory behaviour of contained radionuclides. This aspect, however, does not seem to have been been evaluated. During construction, a substantial number of the originally cast sections were replaced, but this seems to have been a result of misalignment rather than to rectify any identified mechanical or structural shortcomings.

Laitance and segregation was also found in the material placed in the bottom of the crater. Tremie operations were used to fill the crater. Contaminated soil was mixed with cement and a proprtion of clay mineral and pumped as a slurry through a pipeline into the water filled area. This uneveness in the tremie fill probably resulted from discontinuous operations, improper dumping of oversize material, difficulties in controlling the discharge end of the pipe and periodic pump failures during the operation [3]. Again, defects in the properties of the fill have significant implications for the long term integrity of the overall structure and the effectiveness of radioactive containment. The tremie zone is in relatively free communication with the groundwater.

After the phase of tremie placement the crater had been filled to approximately three feet above the reef. Subsequently, a soil cement process was used whereby soil delivered to the site was distributed using a grader and cement mixed into the soil layers using a disc harrow. After watering, the material was compacted using a vibratory roller. It has been recognised that this soil cement mixture above the water level did not attain the concrete like character originally anticipated [2]. The soil-cement operations were conducted leaving a central ("Donut") hole 100ft in diameter. This was filled with debris "choked" with clean concrete. Finally, the dome was capped using non-reinforced concrete. Operational difficulties meant that these sections of concrete laid differed markedly in thickness over the site. Following completion of the disposal site, two extensions were subsequently built onto the dome to accomodate radioactive debris which had been exposed due to tidal and current action. Prior to this, around 30-40 cubic yards of radioactive debris had been incorporated into the concrete cap sections. The potential impacts of this practice upon long term containment are not known, but in some places it is known that the concrete covering the debris is less than the 18 inches originally specified. The operation was concluded in 1980.

Subsequent core sampling [2] has shown that there exists poorly cemented soil in both regions under the dome. In addition there also appears to be substantial amounts of debris in the fill other than the soil designated for dumping under the structure.

3. RADIOACTIVE INVENTORY

The final radioactive inventory of transuranic elements is estimated at 131GBq in the crater, 147Gbq in the dome excluding the debris in the "Donut" hole. The debris in the central hole is estimated at 267Gbq giving an overall total of 545Gbq. In addition to the transuranic elements, an undetermined amount of long lived fission and activation products associated with the carbonate soil were also moved. Only the quantities of transuranics were measured during the field operations even though both caesium and strontium isotopes were also known to be present at radiologically significant levels.

Subsequent monitoring and investigation have largely addressed levels of transuranics in the fill [2] although ^{137}Cs and ^{90}Sr have also been intermittently determined [2]. These determinations have shown that total transuranics in the dome structure are in the region of 130 Bq/kg and 62Bq/kg in the crater fill. ^{137}Cs in both the dome and crater was found to be around 34Bq/kg and ^{90}Sr was determined at an average of 71 and 81Bq/kg respectively.

The radioactive inventory contained within the disposal site is, therefore, substantial. Moreover, current data are not adequate to assess whether or not escape of radionuclides is taking place. There is no regular monitoring programme in place and the collected data published to date have been neither intensive enough or frequent enough reliably to detect any changes caused by breach of the containment of the site.

4. SUMMARY

Overall, a number of concerns attach to the Runit Island Disposal Site and its ability to provide long term containment for the radioactive inventory emplaced there at the conclusion of weapons testing in the area. These concerns relate principally to the durability of the external structure and the potential for migration of radionuclides from the fill material to the external environment. Currently, no systematic monitoring programme appears to be underway.

Accordingly, a multidisciplinary research programme is required in order to establish existing baseline structural and radiological conditions relevant to the disposal site. A suggested programme is outlined below. Such a programme will necessarily involve scientists from diverse disciplinary areas including structural engineers, radioecologists, hydrologists, geologists and biologists.

The initial costs of such a programme will undoubtedly be high, principallly due to the expense of the proposed structural survey and establishing the sampling protocol. After the initial phase, costs should stabilise at a markedly lower level. Subsequently, routine periodic monitoring should be carried out in order to establish a robust time series of samples for monitoring purposes.

5. SURVEY AND RESEARCH PROGRAMME

a) Structural condition of the dome.

A thorough structural survey of the dome and extensions is required in order to assess the condition of the external concrete elements. This should include:

i) an exhaustive external inspection to check for deterioration such as spalling, cracking and deterioration of expansion joints. Particular attention should be directed at areas of the keywall where laitance could have occurred during construction. Porosity and compression strength of the concrete should be determined.

ii) imaging techniques should be used to establish the degree to which the concrete is contaminated by objects disposed of into the capping sections.

iii) the current stability of the key wall should be established, particularly in areas where the wall was constructed over fractured reef or where reef was absent.

iv) current stability of the structure in relation to wave action, particularly extreme events should be remodelled. This should focus particularly on areas liable to undermining and scouring by the action of the sea.

v) current stability of the cap in relation to progressive soil compaction and consolidation under the structure should be determined.

vi) time series of aerial satellite images should be used to establish changes in the geomorphology of the island likely to affect the integrity of the overall structure.

b) Condition of the fill

A survey of the fill material is required in order to assess the current condition of material and held under the dome above and below the water table. This can be coupled with a radiological assessment of the fill material in order to derive an inventory of the dumped contaminants and should be conducted in order to provide a representative coverage of samples. This should include:

i) drilling of a series of cores through the concrete capping sections into the contents of the waste disposal site to the bottom of the crater. The obtained cores should be used to establish the current disposition and condition of the fill with respect to mechanical and physical properties.

ii) characterisation of the radioactive contamination present in the fill including activation and fission products as well as transuranic elements at various depths.

iii) characterisation of the radioactive contamination present in the water permeating the fill material.

iv) characterisation of any gaseous emissions and associated radioactive content.

c) Characterisation of the island structure

A thorough survey of Runit island is indicated in order to identify changes resulting from the tests and from natural processes. This will help to establish the likely long term stability of the structure. Elements of this could include:

i) construction of the two and three dimensional geology of the island in order to identify the major features and their significance to long term integrity of the disposal structure.

ii) analysis of satellite and air photographic imagery to help define the degree to which the island has been structurally impaired by the testing programme and the longer term significance of this to the island.

iii) analysis of the same data in order to identify the progress of natural changes due to erosion.

d) Characterisation of the hydrological regime

The hydrology of the area in which the disposal site is situated should be characterised as well as for the island as a whole. This will involve the drilling of a number of boreholes external to the dome. In addition the information determined from the internal assessment of the dome contents should be considered in order to determine:

i) patterns of groundwater movement towards and away from the structure, taking into account water movements through the reef structure from both terrestrial and marine sources.

ii) radionuclides in waters sampled from the boreholes both internal and external to the structure to identify the pattern and extent of any mobilisation of radionuclides.

iii) the extent of percolation of water through the fill material under the influence of the tidal regime.

iv) the impact of the keywall structure on the movement of water from the terrestrial and marine environments.

v) the extent and influence of fissures and cracks in the substrate upon the water movement through the site.

d) Radiological and Biological studies

Studies are required to establish current levels of radioactive contamination generally present in the area. A sampling programme should be developed to maximise the likelihood of detecting any changes in the cycling of radioactivity indicative of releases of radioactivity from the disposal structure.

i) soil surveys should be conducted to determine levels of radioactive materials present over the whole island, concentrating sampling effort in the vicinity of the dome. This will establish current baseline levels. In addition, a suitably directed and intense programme will serve to establish whether any contamination gradients exist which may be indicative of leakage from the dome structure.

ii) groundwater studies to establish concentrations of radionuclides in groundwater resources in order to establish current baseline levels (also Section c) above).

iii) lagoon water surveys over an appropriate area to establish current baseline levels of radionuclides.

iv) lagoon sediment survey over an appropriate area, including those adjacent to the dump facility.

v) plankton from lagoon and ocean waters to establish a time series against which trends may be evaluated.

vi) aquatic macrophytes, molluscs, crustaceans, lagoon and ocean fish should be surveyed to establish baseline conditions of potential foodstuff items and as indices of potential leakage from the site.

vii) corals should be monitored since they are known to incorporate radionuclides into their hard structures. *Porites* or a similar genus should be chosen as a standard and work carried out to determine the time sequence of radioactivity laid down in calcareous parts and to monitor changes which may take place in the future.

viii) include sampling and analysis of soil, water and biota at a remote site to control for contamination resulting from atmospheric testing in the Marshalls and at other sites.

6. CONCLUSION

The proposed programme outlined above would, if emplaced, constitute an holistic approach to the monitoring of the Runit Island radioactive disposal site. No monitoring programme is currently in place. It is now some sixteen years since the structure was completed and to date no comprehensive programme to monitor either the structural aspects of the site or the radioecological impacts has been established. By selection of appropriate sampling and analysis protocols, it is possible that use can be made of the considerable historical body of data collected, but the programme needs to be expanded considerably beyond the limited scope employed in earlier studies.

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