

PNE



CHAPTER 7. A SURVEY OF DECONTAMINATION METHODS



1. Introduction
2. Decontamination of Storage Cavities
3. Product Decontamination following Stimulation of Oil and Gas Fields
4. Surface Cratering
5. Retarcs
6. Plant Decontamination

Appendix 1 - Schedule of operations.

1. INTRODUCTION

The Peaceful Use of Nuclear Explosives (PNE) for engineering and scientific purposes is inextricably linked with problems of radioactive contamination both at the immediate site of the explosion and further afield. This chapter is an attempt to survey the published literature relevant to the contamination problems and decontamination solutions which have been proposed for dealing with them. Priority has been given to the problems associated with contained explosions for the stimulation of natural resources (eg gas and oil) and also the use of nuclearly formed cavities for the storage of such products. Some consideration has also been given to the decontamination problems arising from uncontained explosions, which are of an entirely different nature.



A voluminous literature exists on the subject of PNE covering engineering applications (including mineral acquisition), seismic effects, and radiological measurements. By contrast, the amount of literature devoted to the problems of decontamination is small, yet such considerations are vital if effective use is to be made of PNE projects.

At present the countries involved in active PNE programmes are the USA, the USSR and France, and by far the largest amount of information is available from the US Plowshare programme which has sponsored peaceful nuclear explosion experiments since 1961. Currently there are no firm plans for PNE experiments in the UK, although, as a member of IAEA it is conceivable that the UK could be asked to advise any member countries on the problems associated with PNE projects which they may consider undertaking.

Projects which have been undertaken or are currently being proposed fall into three main categories:

- (a) Contained underground cavities in which no radioactivity is released at the time of detonation. These may be created in order to assist the release of minerals (including metal ores, natural gas and oil) from the cavity and the surrounding media; the cavity itself may be used for the storage of commodities such as natural gas, and for the extraction of geothermal energy. US Plowshare experiments Handcar, Gasbuggy, Rulison, Ketch, Bronco and Sloop are in this category.
- (b) Partially vented "retarcs", where the disturbance of the surrounding media just reaches the surface with minimal release of radioactivity. These cavities have applications in quarrying and mineral extraction. US Neptune and Sulky events were of this type.
- (c) Surface cratering accompanied by widespread contamination. The main use of this type of explosion is for engineering purposes including the construction of dams, harbours, canals, reservoirs etc. and also for open cast mining. Numerous US and Russian events of this type have been conducted since 1961 eg US Sedan, Palanquin, Buggy, Cabriolet and Schooner events and the Russian "1003" event.

It is extremely unlikely that experiments of the types (b) and (c) would ever be feasible in densely populated areas of the world such as the UK and Western Europe. It is not, however, inconceivable that contained cavities of type (a) could be created either underground or, more probably, under the sea bed in these regions of the world. Consequently it is considered that the formation and use of contained cavities should be given first priority in any study of decontamination problems.

In the case of contained explosions, for storage or stimulation, after a suitable delay period only two isotopes, ██████████ ██████████ give cause for concern these unfortunately are the most difficult to remove from natural gas. They may have to be vented initially to the atmosphere, which is already significantly contaminated from these two gases mainly from (a) weapons tests and (b) nuclear

power production which is expected to increase. Thus decontamination, if a suitable method can be found, is infinitely preferable to releasing contamination and wasting the potential energy of the gas as would occur in venting to the atmosphere.

2 DECONTAMINATION OF STORAGE CAVITIES

Gas storage can possibly be provided in a stable, roughly spherical salt bed cavity or the highly porous and permeable collapsed rock chimney formed by a deeply buried nuclear explosion. The principal requirement is to detonate the explosive in a deep impermeable rock formation. The product contamination for storage applications may be less critical than for the stimulation application because to some extent the site can be chosen to minimize [redacted] problems by selecting rock formations with the least natural hydrogen and water content. Following the explosion and possibly chimney development, there would be a several months wait for appreciable decay of radioactivity; then the chimney/void would be penetrated by drilling and flushed to decontaminate the void spaces. A further well hole, whipstocked to the base of the void, would be provided for oil storage and recovery, but could initially become part of a circuit for flushing out the void. This would allow the use of water (and sea water) as well as gas for flushing. Otherwise venting and evacuation followed by pressurisation to dilute residual gases and repeating the sequence all through the vertical reentry hole are the likely non-aqueous purging methods available. Water flushing can remove most of the HTO and soluble fission products but [redacted] can only be displaced.

It is interesting to note that [redacted] () presumably not wishing to get involved with [redacted] decontamination, recommend a fusion explosive to produce a storage cavity for natural gas. The media for a nuclear cavity would be of low porosity and hence low water content so that the cavity gas tritium content would be mainly as HTO with some [redacted]. Decontamination methods based on dehydration and desiccation of the gas are proposed that can make use of commercially available gas processing equipment.

TID 23184
Jan 1966

2.1 Choice and Influence of Media

The gas and liquid content of the cavity/chimney will depend to a greater or lesser extent upon the media - steam from liquid water in sedimentary rocks and water of hydration - CO₂ and CO from carbonates will have associated C-14 and last, but not least, [redacted] and Ar-37 may arise from stray and delayed neutrons interacting with [redacted] in the rock.

[redacted] — [redacted] [redacted]
[redacted] [redacted]
[redacted] [redacted]

A large proportion of the [redacted], up to 75%, may become imprisoned as HTO in the glassy puddle at the bottom of the cavity. The composition of this puddle eg radio isotopes, which minerals are associated with them, their degree of fractionation and their relative solubilities will also depend upon the media.

In an effort to reduce significantly the radioactive burden of [redacted] found in the hydrocarbons produced by a Gasbuggy type explosion, two criteria for choosing the shot point have been stated (). These are that the rock should be free of solid carbon and relatively rich in carbonates. These criteria may also have an application to cavity storage.

PNE-G-68
Nov 1970

et al
US Pat
3703208
Nov. 1972

A recent patent () describes the use of oxidising agents, eg several tons of MnO_2 , disposed circumjacent to the explosive to provide a more oxidising environment tending to produce water products rather than . This water combines with inorganic materials and becomes immobilised thus minimising the content of evolved organic materials.

PNE 102F
Jan. 1965

DP 1106
July 1967

Four shots, not specifically for storage purposes, have been reported in salt beds and although a stable cavity has resulted, there has been accompanying fissuring extending to at least 60m (Table 1). The glasses formed in salt media are not resistant to leaching according to () and () describing the Gnome and Salmon puddle materials which showed marked fractionation. In contrast () reports that puddle material from shots in granite was not fractionated to anything like the same extent. It would appear that the glasses formed in media with appreciable alumina and silica content without excessive sodium or potassium content are extremely impervious to leaching. However, the material which would be formed in a limestone medium might not be so intractable to leaching, since calcium and magnesium oxides tend to react with water and would temporarily release trapped radionuclides. It can be seen that water flushing to remove HTO, etc could not be applied to salt bed cavities without the possibility of leaching contaminants from the glass puddle which even if not soluble could become mobile. On the other hand if the cavity was accessible to large quantities of water then it might be possible to remove all or the bulk of the leachable activity at the outset. Oil storage is likely to be near the coast and sea water will probably be used to flush initially and act as driving medium for recovering the oil, so that the puddle glass may remain wetted for long periods. However any contaminants leached from the puddle should remain in the sea water and not contaminate the product. During use it may be prudent to assay the sea water and renew as required.

UCRL-Trans
-10517
Feb. 1971

Because of these uncertainties about puddle behaviour, dry rock may be preferred for gas storage making use of non-aqueous purging to decontaminate the cavity. Nevertheless the Russians have proposals () to construct cavity storage for natural gas using 2 explosions of 35kt @ 850m depth in a salt-bed. They also propose further storage in welded tuff using 3 explosions of 40kt @ 710m. Several authors incline to the view that 40kt is probably the maximum yield that could be tolerated on the grounds of seismic damage, yet

et al
PL-388-3/14
Nov. 1972

A recent analysis () of the general conditions making underground storage in France feasible, considers various media and other environmental factors, but plumps for a storage module with a useful volume of 20×10^3 m³ formed in plastic soil of the clayey type at a depth of using a device of nominal energy that has already been designed. Its predicted yield

VUF 3016
Mar 1966

TID23184
Jan 66

US Pat 3596/
Aug 71.714

CONF700101/1
p.753.1970

2.2 Venting, Purging and Flushing

Early access to the cavity can take advantage of the residual overpressure of the blast, but shortlived activity still present implies storage for decay rather than venting. Eventually release to the atmosphere will be required possibly/preferably through a plant such as that designed for Project Dribble. The process () consists of a remotely operated gas-scrubbing and filtering system, with provision for storage of liquid wastes for later disposal. To make purging easier, initial evacuation by pump has been suggested by () or the residual gases could be displaced by a denser fluid as suggested by Dunlap () or Siddons (). Several authors have discussed non aqueous purging of cavities although () concentrate on the removal of , mainly present as HTO vapour, by dehydration and desiccation. They investigated decontamination by cycling and evacuation.

Cycling of natural gas through the cavity and removing the [redacted] water vapour before reinjection would reduce the residual [redacted] each cycle. After a few tens of cavity volumes had been passed through the cavity, pressurisation of the cavity to its storage capacity would reduce the concentration of tritium in the gas to a permissible level. An interesting and possibly efficient scheme is an evacuation process using rotary pumps capable of handling gas volumes in excess of 10 ft³ per day at high vacuum. As the cavity pressure is lowered, water and HTO are vapourised and the discharge from the vacuum pump could be dehydrated to remove the [redacted] water. Residual free [redacted] and other non condensable [redacted] molecules present in the dehydrator effluent could be oxidised by catalytic methods to HTO and removed by another stage of dehydration.

With any dehydration method from 1000-10,000 "barrels" of [redacted] water could be recovered; this would need to be stored or disposed of at low cost, perhaps by controlled evaporation.

[redacted] () using aircraft oxygen tanks and tracers performed experiments indicating that continuous purging is superior to pressure cycling and that this can be accomplished with only a single access hole using concentric inlet and exhaust pipes.

Other theoretical studies and experimental results () mainly concerned with stimulation have indicated that the purging rate should be as high as possible and should proceed without interruption or else mechanical mixing, due to various factors affecting the gas flow, can recontaminate areas already cleaned by incoming gases. Although awaiting verification there are indications that cycling with 5 volumes of natural gas could achieve a decontamination factor of up to 20 for the cavity, the effluent gases being dehydrated to remove HTO and then burned to dissipate HT, [redacted] hydrocarbons and [redacted] through a stack to the atmosphere.

No positive method for removing [redacted] has been found so far - such methods that could be utilised are mentioned later, so one could sum up non-aqueous purging as follows:-

- (a) Use a fusion type explosive to minimise [redacted] production
 - (b) Vent, early to storage, late to atmosphere via plant
 - (c) Evacuate
 - (d) pressurise cavity with gas/air to dilute residual gas
 - (e) cycle natural gas or air through a whipstocked hole to base of cavity - and then out
- } through the post shot hole
- or

It can be seen that gaseous purging may require the passing of many void volumes of gas and for this reason [redacted] () has recommended the use of sea water to (a) displace residual gas and (b) remove HTO and soluble [redacted] [redacted]. This method is particularly convenient if the storage is off shore below the sea bed or inland near the shore, both for obtaining the water and its subsequent disposal.

* Using natural gas, together with burning off, provides a means of dissipating the radio nuclides throughout a large volume of air.

UCID 15259
 1967

UCRL 50519
 Dec 1968

CONF-700101
 (1970)753

2.3 Stored Product Treatment

ORNL TM-
3480
Jul 1971

██████████ () report laboratory tests simulating storage of natural gas in a cavity when ██████████ of methane by exchange with ██████████ water was essentially negligible for storage periods of about 30 days. Efficient removal of HTO vapour from the effluent gas however would probably be required. About 90% of the HTO was removed from Lewis Shale or salt samples prior to gas storage by purging the storage vessel with moist air.

PL429/20B
Jan 1971

██████████ () and ██████████ () have described the results of laboratory investigations made prior to an experiment under field conditions to determine how contamination of petroleum can occur indicating the following routes:-

- UCRL-Trans
10517
Feb. 1971
- by dissolution of radioactive noble gases
 - by desorption of radioactive isotopes from contaminated rocks and from the melt in the rubble chimney and zone of fissuring.
 - by the transfer of radioactive isotopes from the water in the seam or whipstock hole area.

Only the last 2 modes seem at all likely for storage applications, but no results are quoted. However after the statement that "no contamination was observed" we are told that "we have not (yet) ascertained the optimal conditions that will ensure minimum contamination of the stored substance by radioactive materials". We are led to conclude that the aqueous phase retains most activity and such activity that can be detected in the organic materials is not significant. Thus it would appear that product decontamination will for most purposes be confined to efficient dehydration techniques.

3 PRODUCT DECONTAMINATION FOLLOWING NUCLEAR STIMULATION OF GAS/OIL WELLS

Conf 700101
(1970) 567

Generally speaking specific papers on decontamination are conspicuous by their absence but a number of sweeping and sometimes slightly contradictory statements can be found. ██████████ () states that -

"The quantity of radionuclides in the hydrocarbon fluid may be reduced by waiting for radioactivity decay, removal and dilution. Any particulate matter by liquid may be easily separated from gases and the unwanted substances may be disposed of by safe and acceptable means".

Conf 700101
(1970) 577

██████████ give a little more detail () when dealing with Project Rulison and offer three solutions. The first, dilution with uncontaminated gas, is technically sound but because of the "emotional aspect" may not be feasible (ie acceptable to the unenlightened public). In any case before this could be attempted, the highly contaminated gas tapped on re-entry would need to be disposed of by safe means, probably controlling venting or flaring. ██████████ et al when referring to this state:-

"Uncontrolled venting of the gas, though it would be safe is probably not a good answer to the radiation problem and further it would be a terrific waste of energy which our economy can ill afford".

The second solution is to pipe the chimney gas to a suitable area where it can be utilised industrially, with only occupational exposure to workers, probably to generate electrical power or just as a fuel or for chemical production.

The third solution is to work out a method of separating the contaminated from non-contaminated gas. This would be quite a technical undertaking since krypton has a boiling range close to methane. Further any [redacted] which has formed [redacted] methane is extremely difficult to separate from [redacted] methane.

Conf 700101
(1970) 753

The first step of any procedure will be to remove the bulk of the activity from the cavity/chimney. [redacted] has considered a contained explosion similar to Gasbuggy in which [redacted] are produced. After initial venting purging is necessary but gaseous purging may be unsatisfactory because the passage of many void volumes will be needed to flush out the contaminants to the degree required. If it were certain that tritium was present only in the form of water vapour, produced gas could be dried when drawn off and 97% of the water vapour (and HTO) removed. It was originally thought that significant exchange of [redacted] between water vapour and gas would take place during prolonged contact perhaps promoted by the radiation field in the chimney. However up to now a constant [redacted] ratio indicates that this is not true for Gasbuggy (where [redacted] total tritium was in the gas phase). Thus flushing the chimney with water has been considered and this is particularly attractive if the cavity is offshore below the sea bed or near the shore inland.

Filling the cavity with water will drive out most of the original gases which will need to be vented at a controlled rate. The water filling the chimney will acquire [redacted] and on the basis of experience at Windscale () could be discharged to the sea within the limits of [redacted]. The cycle could be repeated as necessary [redacted] because of their gaseous precursors will have been dispersed throughout the rock rubble () but are still retained preferentially by the rock. The refractory nuclides held in the solidified puddle of glasslike rock at the bottom of the cavity are unlikely to be leached out by the water over a short period of contact.

3.1 Contaminants

The principal sources of information on the nature and levels of contamination come from Projects Gasbuggy (10 12 67) and Rulison (10 9 69). Other sources are laboratory experiments and Soviet experience. However, most of these results have been obtained from nuclear explosives related to weapons testing not obviously designed for minimum [redacted] production. The many interesting reviews of Gasbuggy results notably by [redacted] () and [redacted] () are summarised below but can only be a guide for future applications. Smith has also reported Rulison calibration flaring results ().

UCRL-50635
Apr 1971
[redacted]
et al
ORNL-TM-
2862
Feb 1970
ORNL 4646
Sep 1971

The rare gas fission and activation products are expected to mix with the cavity gases but there was no evidence for their precursor entrapment implying that the total amount of these isotopes is present in the gas. [redacted] was not detected and neither were any other fission products that could have been present in the gas or on particulate matter carried by the gas. [redacted] was detected, primarily as [redacted] in the cavity gas but also as [redacted] and [redacted].

After decay as expected [redacted] (distributed between hydrogen and the various hydrocarbons) are responsible for essentially all of the activity in the gas phase. Samples of liquid hydrocarbons taken from the Gasbuggy Well (25 2 69) have been analysed () and the results indicate that [redacted] distributed over all the hydrocarbons in relation to their hydrogen content.

Conf. 700101
(1970) 1547

() have for some time been conducting laboratory experiments which indicate that appreciable contamination of shale oil will occur from [redacted] water or [redacted] hydrogen while contamination from [redacted] hydrocarbons should be much less severe.

OL
PL-429/208
Jan. 1971

UCRL-Trans
-10517
Feb. 1971

An actual stimulation test in a Russian oil field is described by (). Very small amounts of [redacted] were observed in nearby bore holes afterwards. After 2 years the practice zone was re-entered and the somewhat different isotopes detected appeared to be associated with the water content of the petroleum. Another version of this work () states that "over an entire period of operation the (adjacent) well's output showed no traces of contamination by solid explosion products and petroleum extracted directly from the crushed zone was free from radioactive contamination.

3.2 Venting and wellhead uses

The chimney created following nuclear stimulation fills with gas containing gaseous radioactive products and it has been proposed that, after the decay of short lived radioisotopes, the longer lived radioactive gases are removed by producing the gas reservoir. The effect of this would be to mix the contaminated chimney gas with new natural gas from the formation. The produced contaminated gas could be flared or diluted further at the surface with other natural gases. Glass () suggests that instead of venting, the contaminated gases are withdrawn as quickly as possible for storage in another geologic horizon eg. a sub surface aquifer, so that the pressure in the chimney will not have built up to values near the equilibrium pressure of the reservoir. Thus the amount of reservoir gas contaminated and the consequent disposal problem are minimised. () criticises the use of natural gas for flushing the chimney mainly because of the number of chimney volumes of gas that would need to be produced. The stratified gas bearing formations are likely to be at many points within the height of the chimney and vary in productivity. An efficient flushing mechanism cannot be achieved because intimate mixing will be patchy and even with the most intimate mixing, flaring the first chimney volume would be expected to reduce the radioactive concentration by only a factor of two and the second chimney volume by a factor of four and third chimney volume by a factor of eight - and so on. () invention does not depend upon intimate mixing of contaminated and uncontaminated gases, instead he proposes the injection of a denser, oxygen deficient gas (such as CO₂ or propane) at the base of the chimney simultaneous with production of the contaminated gas from the upper portion of the chimney so that contaminated chimney gas will not be forced into the formation. A gas richer in the heavier gaseous material may be produced from the lower portion of the chimney to back flow the heavy gas out of the chimney and at the same time, uncontaminated light natural gas may be injected into the top portion of the chimney to assist and avoid over-mixing of the chimney gas with new natural gas from the formation.

US Patt.
3566966
Mar 1971

US Pat. 3596/
714
Aug. 1971

Similar considerations will presumably apply to () recommendations () for chimney flushing by seawater, instead of gas, to remove HTO and soluble FP's as well.

Conf. 700101
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CONF 700101
(1970) 1589

ORO-4201-2
Nov. 1972

The only author (so far detected) to use "Decontamination" in his title or to mention () decontamination in any detail is (). He also considers the removal of T (present as HT, CH₃T, C₂H₅T, etc) in a production gas stream. Flaring procedures have allowed dilution of the cavity gas with gas around the cavity but are undesirable on a production scale because of the release of radioactivity to the biosphere, the waste of "marketable" gas and the interruptions to production. The quantities of gas involved and the economic situation point to a process having a large throughput involving inexpensive or reusable process materials.

In theory, exchange reactions provide a method for [redacted] decontamination, but in practice a number of problems have yet to be solved:-

Can a catalyst be found to speed up the reactions ?

Can secondary reactions between steam and methane spoil the exchange ?

Can natural rocks be found that will act as a catalyst or as a T-retaining medium ?

Can rocks be impregnated with a catalytic material which will induce isotope exchange ?

ORO-4201-2
Nov 1972

ORNL-701-3337
Mar 1971

[redacted] () following up [redacted] () has found that certain sandstones, clays and shales can reduce the T-content of [redacted] water (HTO) at room and elevated temperatures. He also found no exchange between HTO and methane (CH_4) up to 300°C unless a catalyst was present. Certain rocks were found to have an intrinsic catalytic activity. Various synthetic catalysts, based on Rh or Pt, were all excellent exchange catalysts. Because of the current interest in Rio Blanco, a sandstone and a shale from the site were tested but found to be inert with respect to T-exchange, but further work is indicated.

It may be possible (eventually) to remove [redacted] from a gas stream by passing it through a bed of rocks - silicate type or containing metal hydrides - or perhaps with water or steam flowing countercurrent in the presence of a suitable catalyst.

[redacted]

Scrubbing of the gas with NH_3 or H_2S is another possibility but experimental verification of reaction rates and equilibrium constants is required.

[redacted] suggestions for [redacted] decontamination are based on:

- (a) solubility of [redacted] in water which is however too small to be effective in any exchange process
- (b) synthesis of a clathrate or fluorine compound in the post shot environment but nothing is known about their stability.

The foregoing methods are still only possibilities and it would appear that the gas, at least in the early stages, will have to be used industrially with occupationally exposed workers.

In this connection [redacted] also suggests using the contaminated gas for ammonia synthesis during which both T and [redacted] are removed at different stages of the normal process. The gas hydrocarbons are partially oxidised to CO and H_2 . An iron catalyst then converts steam and CO to H_2 and CO_2 ; the gas is subsequently washed with water to remove CO_2 (and T can be removed from H_2 in this step by reaction (1)). The gas is then passed through a tower counter-current to liquid N_2 which condenses Ar, CO and residual CH_4 (and [redacted] although it may be necessary to add inert [redacted] as a carrier) and adds the required amount of N_2 to the process stream.

Nucleonics
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Oct 15 '70

The ammonia process seems to be the only suggestion in the PNE literature that holds any promise for [redacted] decontamination. However other methods exist (see also Section 3.4) for the separation of gases that might have some application for PNE work. For instance adsorption methods could use Zeolites or activated carbon, the latter is often used at reduced temperatures. One fairly recent application of the latter, is the GEC Mini-Release Radwaste System designed to hold up [redacted] allowing short lived [redacted] to decay before discharge of gaseous effluent from nuclear power stations. It is claimed that [redacted] takes 20h to pass through whereas Xe takes up to 15 days.

3.3 Decontamination techniques for oil

The oil being considered here for most PNE applications is a solid hydrocarbon, Kerogen, contained in a finegrained sedimentary rock known as oil shale. Oil is extracted from the shale by retorting when Kerogen decomposes above 350°C to gas, water and a liquid hydrocarbon mixture (crude oil leaving a carbonaceous residue. Nuclear explosives could break up shale for subsequent above ground retorting, but it would be more attractive if the broken shale could be retorted in situ thus avoiding the problems of mining the shale and disposal of the spent shale after retorting. The likely method for in situ retorting is being studied now for Project Bronco in which the shale would be ignited at the top of the nuclear broken chimney and combustion would be maintained by introducing air. The hot combustion gases, preceding the burning front, would decompose the Kerogen into vaporised shale oil which would condense in the lower part of the chimney and be pumped to the surface. The carbon residue remaining would provide fuel for the advancing flame front. The oil as it condenses in the chimney can be contaminated by picking up various fission products notably [redacted] [redacted] which have gaseous precursors and [redacted] [redacted] [redacted] which form volatile compounds. Depending on whether the explosive is fission or water or hydrogen together with [redacted] hydrocarbons.

CONF 700101/2
(1970) 1343

CONF 700101/2
(1970) 1347

ORNL-TM-2399

ORNL-TM-1775

[redacted] () have presented the aims of Project Bronco but until some actual results are available all knowledge of contamination levels and behaviour comes from small scale exposure and retorting tests as described by [redacted] () and [redacted] (). Although the mechanism by which [redacted] is held by contaminated shale is not known, it appears likely that it is present as [redacted] water and the [redacted] of the shale hydrocarbons occurs during retorting. [redacted] were able to remove most of the [redacted] (over 90%) from contaminated shale by contacting it with a gas phase containing water vapour for prolonged periods. Thus a significant fraction of the [redacted] could probably be removed by passing moist air through the chimney prior to retorting. Appreciable removal could also occur during the retorting operation by the flow of hot moist gases while working up to the retorting temperatures. If the effluent gases are dehydrated this could remove the [redacted] water vapour and allow the gases to be recycled to the chimney. [redacted] work () may lead to a catalytic material that can remove HI from the gas stream.

ORO-4201-2
Nov 1972

Only small amounts of [redacted] could be removed from the crude oil by contacting it with water, or with solid drying agents. When [redacted] crude oil was distilled, the [redacted] content of each of the recovered fractions were equivalent indicating that [redacted] is probably present as part of the hydrocarbon structure.

Fission product activity in the oil was mainly due to finely dispersed solids which could be removed by filtration. Distillation of the crude oil caused more than 99% of the radionuclides to remain in the pot residue.

██████████ contamination of the oil shale could be drastically reduced by employing an all-fission explosive to break the shale, which would in effect increase the relative importance of the fission product yield. The best results available however do not suggest that fission products will significantly contaminate the more valuable shale oil products produced by distillation but the recovery of byproducts from the residues could be hindered.

██████████
PL-429/20B
Jan. 1971

Russian accounts () of the performances of their stimulated oil well, claim that no contamination by solid explosion products resulted. This could refer to the presence of gaseous fission products and their precursors. After sludge clearance of the post-shot hole with HCl (15%) the water content of the recovered petroleum increased and its radioactivity increased by several orders of magnitude (up to 10^6 Ci/litre).

3.4 Cryogenic, Distillation and Diffusion methods for separating gases

██████████
CONF 700101
(1970) 1589

██████████
Applied Cryogenic
Engineering

We have seen mention () of cryogenic applications for the removal of ██████████ and this may in the long run be the only way of preserving the "fuel" role of the gas following decontamination. A well established scheme exists for processing natural gas to recover helium () during which 95% of the gas stream is liquified by liquid N_2 before being throttled into a separator. Here the crude He product containing an average 75% He, 25% N_2 , 0.1% H_2 and <0.1% CH_4 leaves for purification. The liquid natural gas remaining could with suitable rectification be broken down into C_2H_6 (Bpt 184.5 K) ██████████ (Bpt 119.9 K) and CH_4 (Bpt 111.7 K) etc. The C_2H_6 and CH_4 could be recombined, still with CH_3T and C_2H_5T but minus the majority of HT and ██████████

Further decontamination depends upon the separation of isotopes and one method, fractional distillation, requires the distillation to be performed at as low a temperature as possible since the relative volatility usually increases with decreasing temperature.

The economic penalties attached to the foregoing cryogenic methods may not be so formidable if the helium could be recovered too, in the interest of conservation and tritium has become the most important source of He-3. Most other ^{inert} gases can be obtained from liquid air and would be uneconomic to produce ^{them in} this way except perhaps for the radioactive ██████████ isotopes.

Other potential large scale methods for separating gases have been developed mainly for the purification of crude helium but are probably capable of adaption for other groups of gases. One diffusion process utilises bundles of silica glass capillary tubes possibly as small as 0.003" diameter. The glass has much greater permeability to helium than to hydrogen, the next most diffusible material. All other gases diffuse through the glass with even greater difficulty. Another diffusion process uses organic membranes such as polystyrene or ethylcellulose to separate Helium from natural gas. A palladium membrane may be used to separate He-3 from T. This separation may also be carried out by adsorbing the ██████████ on active carbon at low temperatures.

Any pair of inert gases can theoretically be separated by thermal diffusion but the method is of practical interest only in connection with the separation of isotopes.

Separation of the components of a gas mixture by "mass" or "sweep" diffusion is effected by taking advantage of the different rates of diffusion of the components into steam or some other gas which is easily separated from the desired component(s). This could be of interest since large amounts of low pressure steam could be available at very low cost from combustion of the spare natural gas that was unfit for domestic consumption.

3.5 Precautions in use for domestic consumption

ORNL 4646
Sep 1971

Several authors, notably [redacted] et al (21) have considered the radiological implications of commercial utilisation of contaminated natural gas and conclude that the most significant radiation exposures are likely to occur after combustion of gas to form carbon dioxide and water vapour (HTO). They state that CO₂ originally present would be removed from the gas (before it could be marketed) taking with it the chief source of C-14 activity, achieving a decontamination factor of 2-3 with respect to C-14.

The removal of drip liquids and dehydration techniques at the well head and/or primary processing plant would leave [redacted] present only as HT and CH₃T etc. [redacted] is not retained to any significant extent by the body and the primary mode of exposure is from immersion in [redacted] contaminated air. Similarly human exposure to methane would be quite limited and it is presumed that [redacted] methane would behave much like [redacted] hydrogen gas and not to be retained to any significant extent by body water.

Several authors () estimate that flushing with 2 to 5 chimney volumes of gas should remove about 95% of the contaminants from the well. The average level of contamination in the gas removed for this initial flushing period would be about 3 picocuries per cubic centimeter. Combustion of the gas removed during the initial flush is expected to lead to air contamination below maximum permissible levels because of air dilution.

The concentration of [redacted] in undiluted cavity gas could be as high as 0.04 microcuries per cubic centimeter, or 20,000 times the maximum permissible concentration for breathing, which is 0.2 picocuries per cubic centimeter. Removal of the first few chimney volumes of gas may lower the concentration in the gas subsequently produced by a factor of 10. The gas then produced when burned with an air dilution of 15 to 1 would yield combustion products still about a hundred times greater than permissible levels. Continued pumping and dilution with uncontaminated gas will probably be required to obtain permissible levels for home consumption, unless some method, such as the cryogenic removal of [redacted] and HT (Section 3.4) can be incorporate

4. SURFACE CRATERING

4.1 Excavation

The surface cratering technique has been extensively investigated both on paper and as a result of Plowshare events and Russian experiments. The principal application of surface cratering would be in civil engineering projects involving major earthmoving tasks, such as the construction of reservoirs, harbours, dams and for mining purposes.

Much has been written about the spread of contamination from FNE surface craters and it is possible to form a fairly good picture of the contamination problem.

[REDACTED] (48) have studied the contamination pattern from the Sedan event (1962) and state that the radioactive products present in the fireball became mixed with the mass of earth moved by the detonation. As the fireball cooled, condensation occurred and radioactivity in various forms was scavenged by earth materials entering the cloud. The quantity of soil moved in the Sedan event was estimated at 7.5×10^6 tons of which almost 5×10^6 tons was distributed around the edge of the crater and to a distance of some 7,000 ft and at depths up to 80 ft. This was the immediate (or bulk) ejecta and on to this was superimposed fall-out (or missile) ejecta extending in significant depth to 16,000 ft from the crater.

The areas of ground involved are thus seen to be very large indeed (~ 30 sq miles).

[REDACTED] is regarded by most authors as the principal contamination problem, mainly because of its ease of migration into water sources. [REDACTED] which have gaseous precursors also have a wide distribution and these appear high on the list of isotopes hazardous to man (49)

Induced activity arising from neutron irradiation of the soil will also contribute to the radiation field although the isotopes present will depend largely on the original chemical composition of the soil. Russian work (50) indicates that [REDACTED] are likely to be the most hazardous long lived induced isotopes.

Fall out contamination from the drifting cloud contributes 5-10% of the total radiation field. The same Russian paper shows fallout dose rates of 0.1 mr/h out to distances of 50Km and 0.01 mr/h out as far as 240Km from ground zero in the downwind direction. The isotopes [REDACTED] predominate in the soluble fraction of fall out activity.

So far the only method of reduction of activity in surface craters which has been practised is the use of isotope decay. [REDACTED] (51) has summarised all the nuclear experiments of importance to the cratering programme but he makes no mention of post-shot approaches to the craters nor any decontamination measures.

[REDACTED] (52) in a comprehensive review of FNE reports that over 90% of the prompt fall-out (or missile ejection) falls within 10Km of the detonation. He considers [REDACTED] as the hazardous isotopes and recommends the use of fusion rather than fission devices to minimise the fission product contamination. However, he recognises the increased [REDACTED] hazard from fusion devices but makes no proposals for dealing with it.

When considering the exploitation of nucleary produced craters there are three hazards which must be recognised. First there will be a $\beta\gamma$ radiation

field arising from the presence of fall-out particles and also from neutron induced activation. Secondly there is an ingestion and inhalation hazard by resuspension from the contaminated soil. Thirdly there is the special case of [REDACTED] which will appear as [REDACTED] water and will quickly find its way into the water system of the area.

No techniques have been proposed for dealing with the first two categories other than appropriate device design (to minimise fission products) and the use of delayed approaches to allow for decay to occur. Clearly, earthmoving operations aimed at ground decontamination would have to be on a massive scale because of the areas involved coupled with shielding or even remote control of equipment and economic factors will probably rule out such operations. [REDACTED] (53) has reported on decontamination associated with the Palanquin event, but this only involved the normal procedures for protection of personnel and washdown of vehicles and equipment.

Consideration of the uses which might be made of surface craters will determine the need for decontamination. [REDACTED] (47) has suggested the creation of harbours, canals, reservoirs and dams, all of which involve subsequent filling of the crater(s) with water. Soluble contamination would then be removed by leaching and arrangements would have to be made for dealing with the contaminated water, either by dilution or by chemical treatment. The only non-water application for surface craters appears to be in the removal of overburden from mineral deposits, about which little has been written and no experiments performed (41,47).

Some proposals have been made for dealing with contaminated water (and tritiated water) and these are discussed in the next section.

Gaseous [REDACTED] and HT are formed as primary products from fusion and, to a lesser extent fission devices, but do not persist in this form. The [REDACTED] readily exchanges with hydrogen in hydrogenous materials such as hydrocarbons and water.

[REDACTED] hydrocarbons have been discussed in Section 3 and the present section is devoted to [REDACTED] water (HTO). In surface cratering or accidentally vented shots the HTO occurs as steam in the cloud(48) from which it is entrained by fall-out particles(54) or condenses and precipitates as rainfall. Once on the surface the HTO associated with fall-out becomes leached by rain and the eventual fate of the [REDACTED] is as liquid HTO associated with soluble isotopes. Several authors agree(47,48,49,52) that [REDACTED] is the most significant radioactive species for safety considerations and for this reason its distribution has been studied in some detail.

[REDACTED] et al(48,55) made a detailed study of the in-depth distribution of activity from [REDACTED] at the Sedan crater 3 years after the event and found maximum activity levels located some 4 ft below the newly formed ground surface. The same workers found that [REDACTED] was the most abundant radio nuclide in ejecta and biological samples 5 years after the Sedan event(55).

[REDACTED](52) comments that the ultimate fate of [REDACTED] is very dependent on the environment in which the detonation takes place. Thus in high rainfall areas or in the ocean dilution very quickly reduces [REDACTED] water to below tolerance level, but in arid areas a careful assessment of the hazard must be made. Water-soluble contaminants other than [REDACTED] (of which the most important from the radiological viewpoint are [REDACTED]) are readily removed from ground water by ion exchange on soil particles, and thus do not travel any appreciable distance with the ground water. [REDACTED] water, however, travels with the ground water and in some circumstances may even travel faster(56).

Three techniques have been mentioned to minimize the hazard from [REDACTED] in water, but their applicability will very much depend on particular circumstances. Dilution with [REDACTED] water from rivers, rainfall or the sea has already been mentioned. It is the obvious method where plentiful supplies of water for dilution are available and probably occurs naturally to a large extent. [REDACTED](55) found that despite a 12 year RA half-life the actual half-residence time of [REDACTED] was 29 days in a tropical rain forest or 18 months in a dry desert.

The use of delay time for [REDACTED] decay has been mentioned by [REDACTED](57), eg if water supplies are obtained some tens of miles distant from the site of an explosion the rate of travel of ground water is such that a residence time of c.100 years (8 half lives) will have occurred.

The possibility of collecting the highly [REDACTED] portion of a water supply and allowing it to evaporate away has been mentioned by [REDACTED](58).

It has been concluded by [REDACTED](56) that "although there are important environmental limitations, no major technical obstacles exist to the creation of properly located nuclear craters or chimneys for water resources management".

5. RETARCS

5.1. AGGREGATE PRODUCTION

If the explosive is buried deeper than would be normal for crater formation the spall velocity of the surface material is too low and the volume of material being pushed by the cavity gases during the recompaction phase is too large. Under these conditions the material overlying the crater is fractured and lifted into the air but not enough to have any of the material fall outside the crater. Since most rock occupies more volume when broken than when unbroken, a mound is produced rather than a crater. This structure, called a 'retarc' can be used for several applications, one located on the side of a hill enables ready access to all the broken rock by surface equipment. Experience has shown that fragmentation size will depend upon the nature of the rock but is generally determined by the preshot pattern of cracks and planes of weakness.

The Sully event did not crater as expected and there was no large radioactive dust cloud for the γ -radiation detectors to observe⁽⁴⁶⁾. Instead a small dust cloud of relatively low activity was produced, followed immediately by a continuous stream of much more radioactive gas which flowed from the resulting pile of rubble for a considerable length of time. This outflow was presumably different in composition from that which had been anticipated, but from the point of view of the chimney rubble, the residual activity was much less than would have resulted from a contained explosion. It is likely that much of the soluble activity resulting from gaseous precursors or volatile compounds depositing extremely fine particles, will be absent because of the venting, and most of the residual activity would be mixed or diluted into the rubble or aggregate at low levels.

We have not encountered any references to the decontamination of rubble intended for aggregate purposes other than ██████████⁽⁴⁷⁾ who suggests washing prior to emplacement to remove ██████████ as HTO. The likely scheme would presumably entail an initial wait for short lived nuclides to decay. This would be followed by remote collection possibly on a conveyor belt system and then the material would be immersed, batchwise or continuously, in successive baths of water, acid leach liquor and water rinse. Induced activity will be relatively unaffected by this process but will only decay with time.

Residual levels of activity following washing are difficult to predict but as the purpose of aggregates is to form a mass of material, self shielding of residual γ -emission may be expected from its own bulk and that of other less active diluents.

For applications like rockfill for dams and road beds the material will probably be sealed producing additional shielding.

Wash waters would need to be controlled and disposed of in a manner fitting to the site. If the contaminant of most concern is HTO, this could probably be eliminated by controlled evaporation, dilution would require large sources of water like the sea to be freely available.

Two principal routes exist for the recovery of metals by means of PNE, the leaching route and the "open cast" route. In the first a sealed underground cavity is created and the surrounding rock is fissured by explosion of a nuclear device. The metal ore is then extracted in situ by leaching the ground with a suitable liquid, usually an acid, and the ore solution is recovered at the surface. The other method involves the use of nuclear explosives to remove the overburden of rock from buried ore deposits. [redacted] (38) presented a summary paper on nuclear mining to the Las Vegas conference.

The leaching method has been studied principally in the case of copper because of its favourable ore formation. Although vat-leaching and dump-leaching of mined ores is practiced as a means of extracting copper in the USA, the in-situ leaching of underground ores is little used. However, the potential cheapness of PNE as an underground rock fracturing technique, and the attraction of metal extraction without having to physically mine and transport ore have brought about re-evaluation of the method. A number of papers on copper extraction by leaching were presented at the Las Vegas conference but only two of these consider the problem of decontamination of the copper product in any detail. [redacted] (39) state that [redacted] (as [redacted] water) will be by far the dominant nuclide in the recirculating leach liquor, assuming a fusion device is used. Among other dangerous elements which are likely to be present, the long half life isotopes [redacted] (40) appear to be the most important. These authors and [redacted] (40) presented papers in which experimental leaching of rubble from contained PNE craters had been studied in the laboratory. Both found that the bulk (80-95%) [redacted] water was present in the leach liquor during the early stages of extraction when less than 5% of the copper was involved. Thus the bulk of the [redacted] contamination could be separated in this way and disposed of by dilution or evaporation. The other elements except Ru¹⁰⁶ were separated during the normal copper extraction process and it was demonstrated that Ru¹⁰⁶ could be separated by electrolytic purification of the copper.

A paper on overburden removal related to ore recovery was presented at Las Vegas by [redacted] (41) the contamination problems with this method are more severe than those found in surface cratering because the principle of the operation requires that the most highly radioactive soil and rock near the crater should be removed. [redacted] base their approach upon first allowing a decay period (unspecified) followed by remote control working, shielding operators by placing them inside air conditioned insulated vehicle cabs with radio contact. Normal rules of working in a radioactive area would have to be followed and all vehicles decontaminated when leaving the active area. There is also a requirement to segregate the hopefully "clean" ore from the contaminated overburden. In view of the probable extent of the radioactive area which would be created by a surface crater it is difficult to see this type of mining operation being carried out in the foreseeable future.

Other minerals which have been mentioned as amenable to recovery by PNE include sulphur, (42) molybdenum, (43) uranium (44) and iron (45) but no detailed considerations of decontamination have been published.

6. Vehicle and Plant Decontamination

It may not be inappropriate to consider here the implications of providing vehicle access to the contaminated areas resulting from vented explosions. It is likely that initial entry for reconnaissance by landrover type vehicles or helicopter will produce dusty conditions. Alternatively it may be necessary to treat an area affected by fallout, by

- (a) physical removal of soil
- (b) dilution by intermingling (using grader, scraper or dozer, etc ()
- (c) inhibition by covering with clean top soil.

before appreciable decay has occurred. There is also the slight possibility that fission-fusion explosives may produce significant amounts of alpha emitters in the residual contamination, that will not decay like fission products and are notoriously difficult to detect on other than smooth plane surfaces. Thus reconnaissance and recovery vehicles, remote-controlled or other wise; because of their air breathing engines and ground contacting surfaces will acquire internal and external contamination by particulates on body, chassis and engines and will need to stay in or near the controlled area.

The operations suggested in this section will involve setting up a vehicle decontamination and maintenance site and, whilst the main purpose of such a site will be the decontamination of vehicles destined for disposal, it is strongly recommended that all vehicles of the "active" fleet are given, at least, a partial decontamination treatment whilst the site and facilities are in operation. The active area may well be sub-divided into regions of different activity with appropriate designations eg there could be a downward progression from Yellow - Red - White area (as at Maralinga where all vehicles kept for working in the active areas were painted and designated - yellow). Vehicles for use in active areas should be painted in a distinguishing colour but there is normally no advantage to be gained from applying barrier paint since the nature of the contaminant is such that is more easily removed than the barrier paint. However it is important that existing paintwork is complete and in good condition and floors of cabs, etc, could be given a false floor (of roofing felt perhaps) cut to fit. Seats, controls, VHF radios etc should be protected by the use of PVC or other plastic covers.

DECONTAMINATION OF "YELLOW" VEHICLE FLEET

When vehicles are withdrawn from the "yellow area" some form of decontamination will be necessary. On principle, complete decontamination should be the ultimate aim although, in cases where the vehicle is considered unfit for further service, and will be disposed of by burial, some relaxation in the case of very resistant or inaccessible contamination might be permitted.

In view of the difficulty of monitoring for a contamination on compound items such as box section chassis members, it will not be possible to declare such items entirely free from contamination, and they will have to remain within the controlled area. On the other hand, there is no reason why items of simple construction, or items which can be dismantled into parts suitable for decontamination and monitoring, should not be completely freed from activity and taken out of the "yellow area" if so desired. It is quite probable that some vehicles, considered as being unserviceable, can be cannibalised to provide replacement parts for other vehicles of the "yellow fleet". In such cases it is recommended that, where possible, the parts in question should be decontaminated as completely as possible before installation or storage.

The schedule of operations set out below should result in a high degree of decontamination. Whether or not the full scheme is implemented will depend upon such factors as the mechanical condition of the vehicle and its various components, and its ultimate fate. These are factors which can only be assessed on the job.

It must be emphasised that the operations described in the schedule are designed to achieve as full a measure of decontamination as possible whilst, at the same time preventing the unnecessary spread of contamination and reducing to a minimum the possible hazards to decontamination personnel. To this end the operations should be carried out at a suitable site in the "yellow area" using the proper equipment such as ramps and "cattle grid" etc., and strict control maintained over liquid effluent from the wash-down techniques and rags and brushes, etc. used for cleaning. All such materials must be regarded as active waste and treated accordingly.

A. LANDROVERS

I. GENERAL PRELIMINARY TREATMENT

(a) ENGINE

Remove cartridge oil filter and, whilst engine is still hot, drain of sump, gear box, transfer-box, front and rear axles. Refill with flushing oil, run up engine and transmission and drain off again. The flushing oil should be tested for β and γ activity by counting a smear paper which has been dipped in the waste oil. Drain petrol tank, disconnect feed pipe and purge tank.

(b) Cooling System

Drain, treat with 5% Calgon and finally flush through with water.

(c) General Dust Removal

Using a suitable vacuum cleaner with the appropriate attachments, remove all loose dust, working in the following sequence:-

(i) Outside and inside hood. In the case of soft-topped vehicles it is probable that further decontamination of the hood would be uneconomical and having reduced the major dust hazard, this item should be removed and sent for disposal as active waste.

(ii) Outside and inside truck and driving cab, including the back of the instrument panel, tool-box and top of fuel tank, etc.

(iii) Inside engine compartment with particular attention being paid to the radiator which should be vacuum cleaned from the front.

(iv) Inside brake drums. This will necessitate jacking up the vehicle and removing the wheels.

The effectiveness of the dust removal operations should be checked by monitoring.

II. CHASSIS TREATMENT

Before complete cleaning of the chassis can be attempted the engine and gear box should be removed. However, since this will involve some work beneath the vehicle, the potential hazard from falling dirt should first be reduced.

Caked mud, oil and dirt should be removed from the underside of the chassis using high-pressure steam, delivered from trigger controlled lances. Parts thus treated must include the underside of the wings, road springs, wheel back-plates, front and rear axles and differential housings, propeller shafts, steering arm and track rods.

Removal of Power Unit.

The battery, distributor, coil, dynamo, starter motor, radiator and air filter should be removed and the outside of the engine block, gear box and mountings cleaned off with steam. The engine and gear box should then be removed from the chassis.

After removal of the power unit, final cleaning of the chassis, including the engine compartment, can be completed using steam treatment. A final hose down of the whole body and chassis should serve to remove all loose activity. If smear tests show any residual areas of high activity, further treatment with steam E.S.C. () or Southend Paste () is recommended.

III. TREATMENT OF POWER UNIT

After removal from the chassis, the engine and gear box should be treated with E.S.C. or steam to remove residual grease. The gear box assembly should then be detached from the engine. It is unlikely that any contamination will be present inside either gear box or transfer box and these items can be left intact. The outside of the unit should be smear tested to ensure that any residual activity is below maximum permissible level as laid down in The Radiological Safety Regulations. It will be advisable to dismantle the transmission brake and clean with the aid of a vacuum cleaner.

The engine can now be dismantled and the components thoroughly degreased. It is possible that some active particles may have entered the combustion chambers via the induction system. Thus, if any attempt is made to remove carbon deposits from the pistons and cylinder head, a vacuum cleaner should be used to remove the loosened carbon. All engine parts thus cleaned should be checked by smear tests.

B. TRAILERS

The decontamination of trailers should be a relatively simple and straightforward operation. Loose dust should be removed by vacuum cleaning and the more resistant mud and grease treated with high pressure steam. The wheels and brake drums should be removed and the brake assembly cleaned out with the vacuum cleaner followed by steam treatment if necessary. A final scrub down using Detergent N.10^() should remove all activity. Thus, provided all the tyres are changed, there is no reason why trailers decontaminated in this manner and finally checked by smear tests should not be used outside the "yellow" area.

C. TRUCKS AND LORRIES

The decontamination of these vehicles should follow along the lines suggested for landrovers viz:-

I Preliminary treatment of engine, cooling system, and general dust removal.

II Steam cleaning of chassis, removal of power unit and the final decontamination of the chassis.

III Dismantling and cleaning of power unit.

D. CRANES AND PLANT

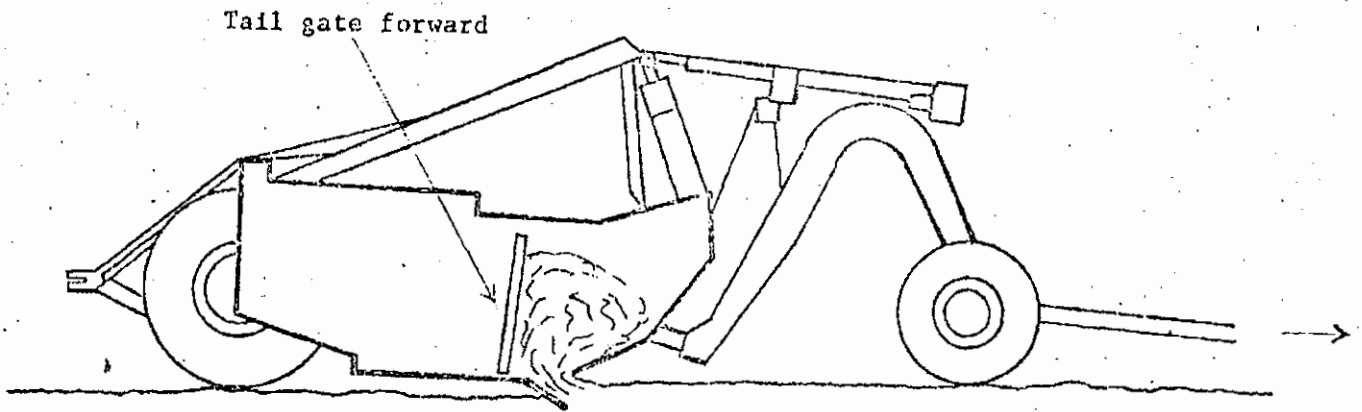
In the absence of precise details of construction of this vehicle only a broad outline of a decontamination procedure can be given. The general principles established under Section A should be followed in so far as they are applicable. Loose dust should be removed by means of the vacuum cleaner and caked mud and grease treated with high pressure steam. The jib should be fairly easily cleaned but the cable and hoisting gear may require more serious attention. The amount of dismantling that will be necessary will depend upon the fate of the vehicle. If it is to remain within the "yellow area", a general clean up with the minimum of dismantling should suffice. If, on the other hand the vehicle is to be moved out of the "yellow area" or is scheduled for disposal, it will have to be more completely dismantled and the components parts decontaminated as already described.

E. DISPOSAL

It is anticipated that the techniques outlined above, if carried out thoroughly, will remove most of the loose activity. The subsequent fate of the vehicle will obviously depend upon its mechanical condition as a whole and upon the condition of the various components. Some of these, which are of simple construction, or which can be dismantled into parts suitable for thorough cleaning, can be completely decontaminated without much trouble and possibly used as replacement parts for other vehicles, including those used in the 'clean areas'. Such items would include fuel pumps, carburettors, differential assemblies, etc. Other items, such as starter motors, dynamos, exhaust systems and instruments etc., because of their more complex structure, cannot be thoroughly cleaned and thus cannot be guaranteed completely free from contamination. Such items should only be used as replacements for 'yellow' vehicles or else disposed of by burial. Tyres must be included in this latter category, since it is not possible to remove all particles that may be embedded in the rubber.

Items scheduled for disposal by burial should first be broken up by hammer or oxy-acetylene cutter under supervision, to ensure that they are completely useless. Tyres should also be rendered valueless by cutting. Components such as hoods, seat covers, tyres, wood used in the construction of the vehicle or as chocks, as well as rags and brushes, etc. used in decontamination operations should not be burnt because of the possible spread of contamination as fly-ash. Such items should be disposed of by *other approved methods.*

- () Emulsifying solvent cleaner eg 'GUNK'
- () Abrasive paste incorporating complexing agent to solubilise contamination - Southend Paste Spec HR 379
- () Built detergent powder incorporating complexing agent Spec. HR 378

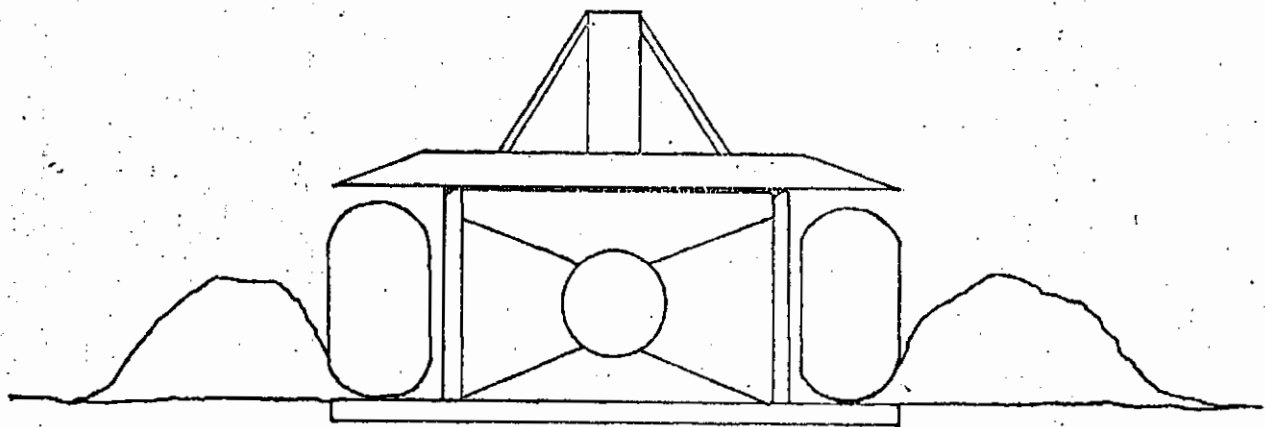


SIDE VIEW

Showing soil being picked up and mixed

The normal functions of a scraper are digging, hauling and spreading. The mode shown here combined the digging-blade position and the spreading-tailgate position so that soil could not reach the bowl but was instead mixed and ejected to either side.

A motorised grader following behind the scraper levelled the windrows achieving at the same time further mixing and distribution.



REAR END VIEW

Showing soil being deposited in windrows

SCRAPER IN USE FOR SOIL MIXING