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Toxic and Hazardous
Materials Agency
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**Treatment Alternatives
for Explosive-Laden
Spent Carbons**

(Task Order Number 10)

Final Report

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> Explosive-laden spent carbons from four Army Ammunition Plants (AAPs) have already been processed by a commercial reactivator. Thermal reactivation for reuse was accomplished with about 90% yield (weight basis), but the product was sometimes structurally weak and thus liable to crumble, forming undesirable fines. The only experience with reactivating explosive-laden carbons to date is in rotary kilns; other processing techniques are discussed in this report. (JES)

There is no experience in the incineration of these carbons to an ash, as the APE-1236 Explosive-Waste Incinerators at the AAPs cannot reach the temperatures required (1800°F or more).

Thermal deactivation by moderate heating to, say, 600°F could potentially remove enough explosive to permit the carbon to be landfilled as a non-hazardous waste. Tests at the Mississippi and Iowa AAPs indicate that the APE-1236's are satisfactory for this purpose. To date, the deactivated carbon has not been "de-listed," however.

Cost estimates indicate that, because of the saving of more than 400,000 lb/year of carbon (at \$1.00/lb) for reuse, thermal reactivation is the lowest-cost alternative. Because of economies of scale, this is most economically carried out at a commercial reactivator (one is currently available) at a cost of \$470,000/year. It could also be carried out at a central Army reactivation plant which would cost some \$937,000 to build, and would require \$580,000/year to operate. Deactivation using existing APE-1236's involves no new investment, but might cost \$710,000/year to operate.

All of the above assumes that a number of key questions, presently unanswered, can be addressed. These relate to the continuing transportability of explosive hazardous wastes (spent carbons), the explosion hazards of their thermal treatment, and the suitability of reactivated product for reuse.

It is concluded that, while thermal reactivation at an existing commercial installation (not explosion-proof) is potentially the lowest-cost option, it is desirable for the Army to characterize those parameters which can lead to explosions when handling explosive-laden carbons in furnaces and those which can lead to undesirable weakening of the carbon's structure.

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1.0 SUMMARY AND CONCLUSIONS

Several of the U.S. Army's manufacturing facilities use activated carbon columns to remove 2,4,6-trinitrotoluene (TNT) and cyclotrimethylene-nitramine (RDX) from the plant wastewater effluents. The eight principal generators of explosive-laden waste carbons from those columns utilize about 466,000 lb/year of such carbons, according to questionnaires completed by them (see Section 2.0). Disposal of the spent (i.e., explosive-saturated) carbon from these installations has classically been accomplished by open burning, but this is no longer allowed in many areas. This report investigates three other alternatives, described in Section 3.0:

- Thermal Reactivation for Re-use
- Oxidative Incineration and Ash Burial
- Thermal Deactivation and Carbon Burial

Explosive-laden spent carbons from four Army Ammunition Plants (AAP's) have already been processed by a commercial reactivator. Thermal reactivation for re-use was accomplished with about 90% yield (weight basis), but the product was sometimes structurally weak and thus liable to crumble, forming undesirable fines. The only experience with reactivating explosive-laden carbons to date is in rotary kilns; other processing techniques are discussed in Section 3.0.

There is no experience in the incineration of these carbons to an ash, as the APE-1236 Explosive-Waste Incinerators at the AAP's cannot reach the temperatures required (1800°F or more).

Thermal deactivation by moderate heating to, say, 600°F could potentially remove enough explosive to permit the carbon to be landfilled as a non-hazardous waste. Tests at the Mississippi and Iowa AAP's indicate that the APE-1236's are satisfactory for this purpose. To date, the deactivated carbon has not been "de-listed," however.

Cost estimates (Section 4.0) indicate that, because of the saving of more than 400,000 lb/year of carbon (at \$1.00/lb) for re-use, thermal reactivation is the lowest-cost alternative. Because of economies of scale, this is most economically carried out at a commercial reactivator (one is currently available) at a cost of \$470,000/year. It could also be carried out at a central Army reactivation plant which would cost some \$937,000 to build, and would require \$580,000/year to operate. Deactivation using existing APE-1236's involves no new investment, but might cost \$710,000/year to operate.

All of the above assumes that a number of key questions (Section 5.0), presently unanswered, can be addressed. These relate to the continuing transportability of explosive hazardous wastes (spent carbons), the explosion hazards of their thermal treatment, and the suitability of reactivated product for re-use.

It is concluded that, while thermal reactivation at an existing commercial installation (not explosion-proof) is potentially the lowest-cost option, it is desirable for the Army to characterize those parameters which can lead to explosions when handling explosive-laden carbons in furnaces and those which can lead to undesirable weakening of the carbon's structure.

2.0 BACKGROUND AND OBJECTIVES

2.1 General Statement of the Problem

Several of the U.S. Army's manufacturing facilities use activated carbon columns to remove TNT and RDX from the plant wastewater effluents. When a carbon column becomes spent (i.e., saturated with explosive), the carbon is removed as a water slurry and must then be disposed of. Historically, the disposal method was to spread a bed of the damp carbon out in a burning trench, douse it with fuel oil, and "open-burn" it. Open burning is no longer allowed in most areas, and it is necessary to consider other options. This report investigates three such options:

- Thermal Reactivation for Re-use
- Oxidative Incineration and Ash Burial
- Thermal Deactivation and Carbon Burial

2.2 Magnitude of the Problem

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) identified the eight principal Army installations generating explosive-laden spent carbons, to which we sent specially-prepared questionnaires (see Appendix). The principal results of this survey are summarized in Table 2-1. The table shows that:

- The present potential generation rate of explosive-laden spent carbons from the eight AAP's is about 1332 lb/day, or 466,300 lb/year.
- Radford AAP, at 175,000 lb/year, would generate about 40% of the explosive-laden spent carbon from this eight-plant group, at present levels of mobilization.
- No two of the plants use the same type of carbon.
- The explosive content ranges from 0.04 to 0.3 lb/lb carbon, with a median of about 0.2 lb/lb carbon.
- Five of the eight sites have explosion-proof rotary kilns, Type APE-1236 or equivalent.

The location of the eight plants is shown in Figure 2-1. They are all in the eastern U.S.; the Milan, TN location would be the geographically central one.

2.3 Objectives

The objectives of our program were four-fold:

- (1) to survey the U.S. Army installations recognized as the largest generators of explosive-laden spent activated carbon;

TABLE 2-1
EXPLOSIVE-LADEN CARBON GENERATION RATES
RESULTS OF QUESTIONNAIRE

	RADFORD AAP	MILAN AAP/LAP	LONE STAR AAP/LAP	MISSISSIPPI AAP	KANSAS AAP/LAP	LOUISIANA AAP	IOWA AAP/LAP	JOLIET AAP/LAP	
Location (State)	Virginia	Tennessee	Texas	Mississippi	Kansas	Louisiana	Iowa	Illinois	
Carbon Rate, Frequency	500#/D	31200#/5M	70000#/Y	8.3#/H	10800#/110D	1000#/15D	9600#/180D	(No Carbon	
Lbs/Day	500	214	200	200	98	67	53	Columns in	
Lbs/Year	175000	74900	70000	70000	34400	23300	18700	Operation)	
Carbon Bed Vendor	AM Kinney	Silas-Mason	Day&Zimm'n	?	Various	Hydro-Pure	In-House	AM Kinney	
Year Installed	1978-9	1980-1	1976-85	?	1980	1984	Various	1969/1978	
Carbon Vendor	Calgon	Carborundum	?	?	?	Calgon	Calgon	Witco/Calgon	
Carbon Type	FS 400	GAC 30	HD 4000	?	?	FS 200	FS 300	718/FS 400	
Carbon Mesh	12x40	8x30	12x40	?	8x30	12x40	8x30	8x30/14x20	
Carbon Price, \$/Lb	.95	.68	?	?	.85	1.08	.96	?	
Explosive Con- tent, Lb/Lb C	.19 TNT/DNT	.035 TNT .050 RDX	.125 TNT .090 RDX	(RDX)	.300 RDX	(TNT)	(TNT) (RDX)	.041 TNT	
Incinerator	Rotary Kiln	None	None	APE 1236	APE 1236	APE 1236	APE 1236	None	
Capacity, Lb/Hr	380			?	200-400	1200	360-600		
Fuel, GPH #2 Oil	60			?	6 to 13	23	3 to 13		
Notes	Ship Spent Carbon to Reactivator in PA	Ship Spent Carbon to Haz Waste Landfill; 23000-Lb Test of Re- act'v'd C in Progress	Ship Spent Carbon to Reactivator in PA		Store Spent Carbon On- Site	Ship Spent Carbon to Haz Waste Landfill; 12-Drum Test of React'v'd C Gave Fines in Re-use	Deactivate C and Ship to Haz Waste Landfill		

Source: Arthur D. Little, Inc., based on data provided in AAP questionnaires.

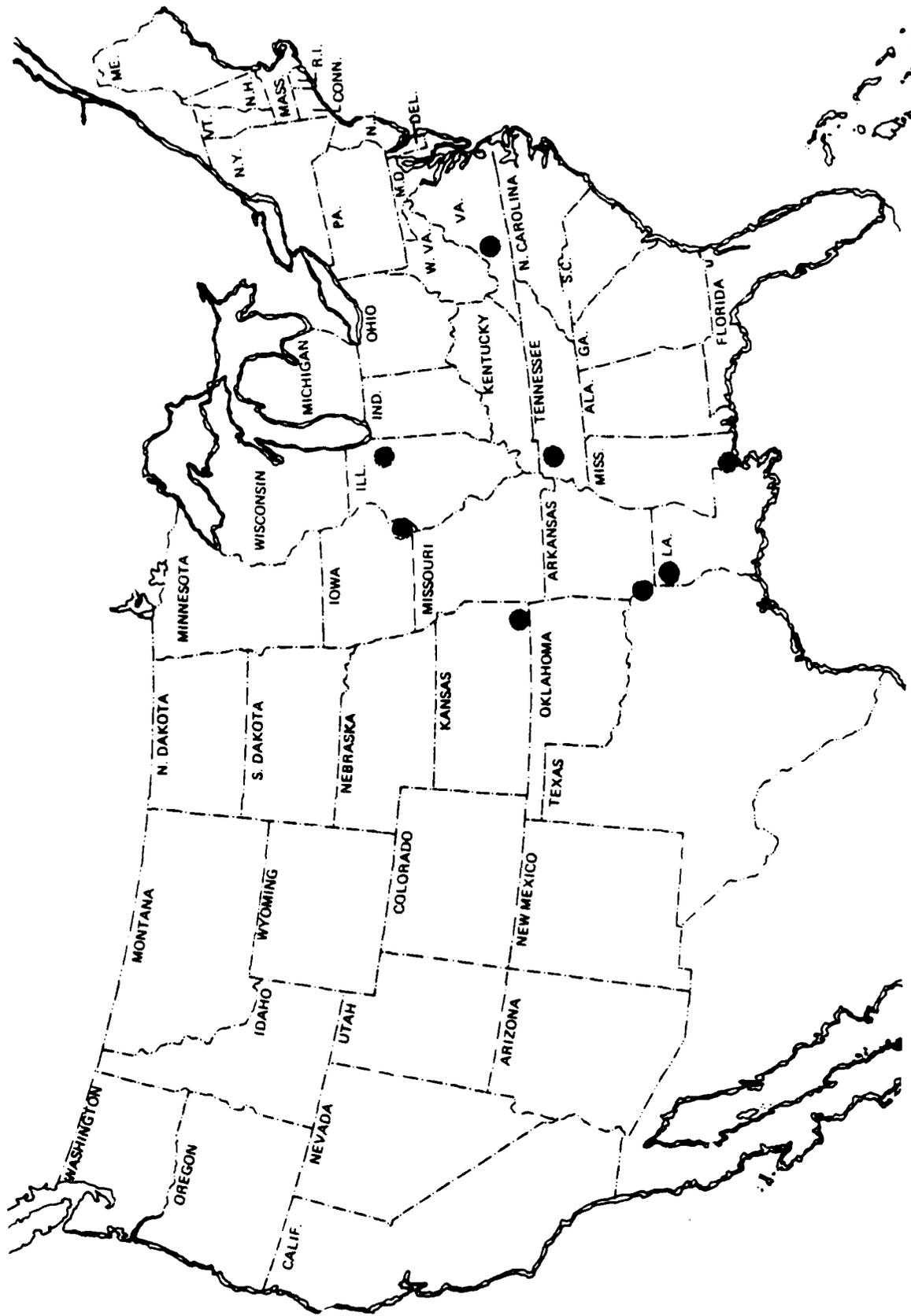


FIGURE 2-1
 LOCATION OF AAP'S GENERATING EXPLOSIVE-LADEN SPENT CARBONS

- (2) to identify the major technology options currently available for treating, reactivating and/or disposing of said carbon;
- (3) to evaluate the most promising technological options on both a technical and cost basis, to the extent practicable; and
- (4) to identify data gaps which would require future work.

3.0 TREATMENT ALTERNATIVES

3.1 Technological Options

Three alternatives for treating explosive-laden spent carbons will now be addressed in more detail.

3.1.1 Thermal Reactivation for Re-use

3.1.1.1 Early Laboratory Study

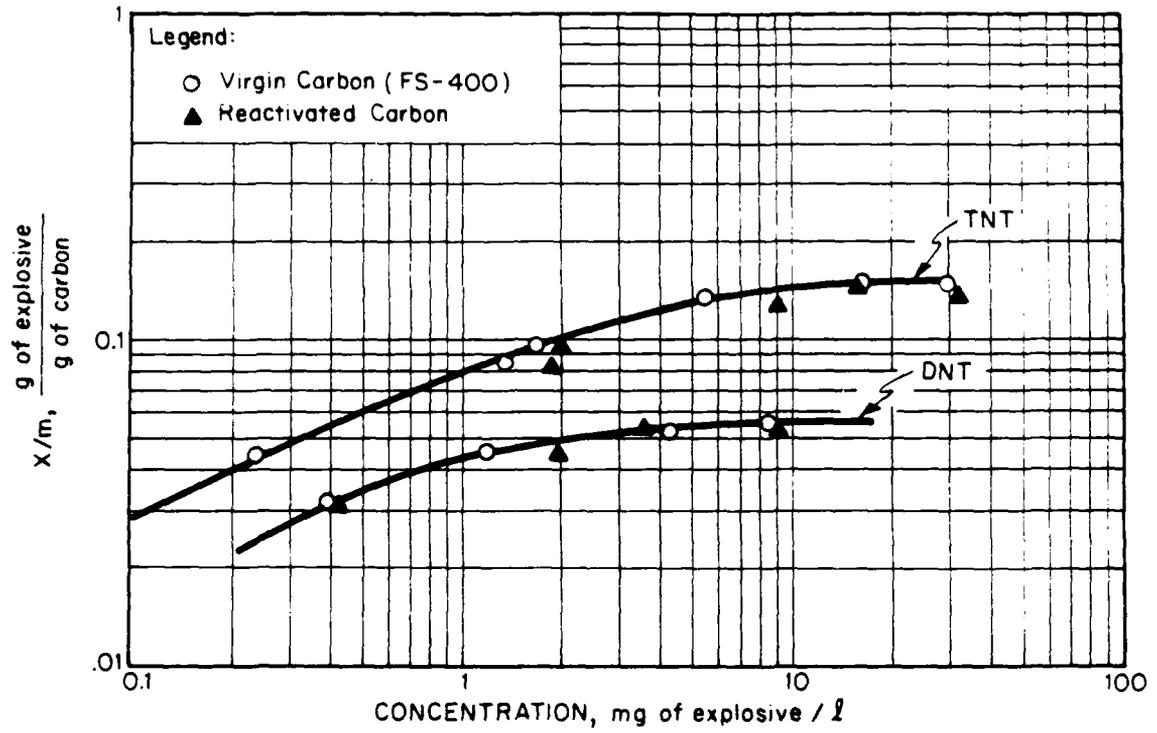
As long ago as 1977, the U.S. Army sponsored a laboratory study utilizing a 6½-inch diameter by 11½-foot long rotary kiln to study the reactivation of Iowa AAP's RDX- and TNT-laden, Calgon FS 300 spent carbon in a deficiency of air, at a rate of 500 lb/day.¹ The conclusions were that, capacitywise, the reactivated carbon was as good as the virgin carbon from which it came when based on isotherm data, but only 87% as good when based on column laboratory breakthrough data; that a temperature of 1580°F was needed for complete reactivation; that rapid heating or the use of temperatures above 1650°F led to particle size breakdown; that carbon yields of 92% were achievable; and that reactivation could be accomplished without explosion.

3.1.1.2 Recent Commercial Experience

There is a commercially-proven technology for reactivating spent carbons, at temperatures as low as 1200°F but more usually at 1600-1800°F, in steam with controlled amounts of air to consume the soot formed in the pyrolysis of organics. Such operations are usually conducted in multiple-hearth or rotary-kiln furnaces, and several 10,000-lb batches of Army explosive-laden carbons have been reactivated at one such commercial location (Envirotrol, Inc. in Sewickley, PA). The batchwise operation at Envirotrol enables them to return to any AAP only the carbon which originated from that AAP.

At Envirotrol's installation, there are three countercurrently-fired rotary kilns (refractory-lined) ranging in size from 4 to about 9 feet in diameter, and from 25 to 50 feet long, with an estimated total carbon capacity probably exceeding 10 MM lb/year. These are followed by indirect-air rotary coolers (no water-quenching). This installation has processed (reactivated) carbons from the Radford, Lone Star, Louisiana, and Milan AAP's. Each batch is tested in a laboratory thermogravimetric analyzer to provide data on process heatup rates. There have been no explosion problems, the carbon yields (weight-basis) approach 90%, and the carbon activity exceeds 90% of that of virgin carbon. This last point was investigated in 1986 by M. Fields of Radford AAP.² Her data on virgin Calgon FS 400 and on the same material after reactivation by Envirotrol have been used to calculate isotherms for TNT and DNT at room temperature, shown in Figure 3-1. Note that the points for the reactivated carbon are almost indistinguishable from those of the virgin carbon. Indeed, Iowa AAP reports no difficulty in using the carbon reactivated for it by Envirotrol.

On the other hand, Louisiana AAP reported difficulty with excessive generation of fines when it tried to re-use carbon which it had sent to Envirotrol for reactivation.³ Envirotrol confirms this with its own steel-ball hardness test, which showed 40% broken material for Louisiana,



Source: Unpublished Data of M. Fields, Radford AAP, Feb. 1986

FIGURE 3-1 ADSORPTION ISOTHERMS FOR TNT AND DNT ON REACTIVATED AND VIRGIN ACTIVATED CARBONS

vs 25% for Milan, 10% for Radford, and 5% for virgin carbon.⁴ More work is being done to determine the causes for such different behavior. This determination may well show that certain carbons can withstand reactivation better than others. It will be recalled, for example, that in the 1977 Iowa work, the FS 300 carbon did not withstand temperatures above 1650°F well.

Aside from rotary kilns, there are two other likely types of equipment for regenerating carbons at the low rates required by the Army--the Shirco Electric Bed Furnace (EBF) and the Marquess and Nell Electric Carbon Regenerator (ECR). We have dismissed the multiple-hearth (Herreshoff) roaster as suited only to much larger applications, and hence unable to process the relatively small batches of Army carbons and still provide assurance that the carbon issuing from the bottom of the furnace at any time actually originated from a particular batch fed some time before.

The smaller rotary kilns, the EBF, and the ECR do have this advantage of batch accountability, important if the reactivated carbons of one AAP are not to appear in the carbon columns of another plant. (Since some AAP's have certain trace metals, e.g., chromium or lead, on their carbons and others do not, those AAP's without these metals do not wish to receive reactivated carbons which might contain them.)

The EBF unit of Shirco Infrared Systems, Inc. consists of a belt which carries carbon through a small-diameter, long electrically-heated tunnel furnace. Such a system can heat the carbon, usually in three zones, to the 1,500-1,800°F required. There are a number of trailer-mounted systems in operation, one of them operating at as high as 100 T/D⁵; the units needed for the Army would be in the range below 1 T/D. While Army carbons contaminated with trichloroethylene (TCE) have been successfully processed at Twin Cities (MN) in an EBF system, there has been no experience to date in handling explosive-laden carbons in such furnaces.

The ECR unit of Marquess and Nell, Inc. is a refractory-lined shaft furnace, electrically heated, operated full of carbon, with a series of expansions and contractions in cross section as the carbon mass slowly descends through a series of ceramic trays, to promote heat transfer. There are presently only two such ECR's in commercial operation, but they are successfully reactivating 1600 and 3600 lb/day of carbon, respectively.⁶ These are somewhat larger than those needed for processing the Army's explosive-laden carbons. The ECR system could be more prone to jam up with solids and would probably contain a larger inventory of carbon (a potential safety consideration) than would the EBF. Again, there is no experience running explosive-laden carbons through the ECR system.

3.1.2 Oxidative Incineration and Ash Burial

The Army's APE-1236's are not suited to the high temperatures (1800°F or so) of carbon incineration, and the rotary kilns of Envirotrol have not been used for this purpose. The Marquess and Nell ECR system has also never been used for incineration; indeed, there is concern that the hot ash might prove to be "sticky", promoting furnace plugs.⁶

On the other hand, the same Shirco EBF installation has successfully been used at one time as an incinerator and at another time as a reactivator simply by modifying the air flow, at essentially no added cost. Any effect on belt life has not been noticeable.

In general, it is reasonable to expect that once the explosive has been mainly removed by even moderate treatment (see below) there would be no difficulty in pulverizing the carbon and combusting it in any installation already burning coal or coke, if this were desired.

3.1.3 Thermal Deactivation and Carbon Burial

It has been found that a relatively mild treatment of the carbon in the absence of air at, say, 600-700°F will pyrolyze and vaporize the explosive to leave less than a 1% residual level. These tests were done in the Iowa AAP and Mississippi AAP APE-1236 incinerators.

This approach has the potential of converting the spent carbon hazardous waste to a decertifiable ("non-hazardous") waste designation, suitable for ordinary landfilling, either on-site or off-site. It is being pursued actively at Iowa AAP. This approach is well-suited to the low operating temperatures achievable in the APE-1236's; indeed, these units could not be used to achieve the higher temperatures required for carbon reactivation (1500-1800°F) because of materials constraints.

3.2 Other Considerations

For all of the above alternatives, it is desirable to be able to perform them at various locations, not only at the point of origin, to take advantage of the economies of scale. This depends on the ability to transport explosive-laden spent carbons. It is possible to transport such carbons, provided they contain at least 10% water by weight, as Class A High Explosive. In general, they contain about 50% water as received at the reactivation plant of Envirotrol. As mentioned earlier, several tonnage-scale interstate shipments of explosive-laden spent carbons have already been made from AAP's in Virginia, Texas, Louisiana, and Tennessee to Envirotrol's plant at Sewickley, PA (near Pittsburgh).

In reactivation, it is also desirable to maintain the identity of a batch so that it can be returned to the same installation from which it came, to avoid cross-contamination of the wastewater streams from the several AAP's. This means equipment with small in-process inventories would in general be preferred, providing easy "cleanout" between runs.

The need for scrubbers following the afterburners associated with all of the above devices is not clear; it will probably depend mainly on the NO_x content of the off-gases.

Lastly, although so far there is indication that explosive-laden spent carbons can safely be thermally treated in any of the devices discussed above, the actual parameters (e.g., temperature vs time, inter-particle impact, furnace atmosphere composition) for safe heating of this material will have to be investigated in controlled laboratory environments.

4.0 COMPARISON OF TREATMENT ALTERNATIVES

4.1 Cost Basis

To develop rough costs for each of the cases to be presented, estimates of capital, shipping, and operating costs were required.

For the capital investment of the furnaces required for regeneration or incineration, we used data for the installed cost of Shirco EBF systems (see Table 4-1 and Figure 4-1), obtained from several bids to Radford AAP, and information supplied by Shirco directly. The data on Figure 4-1 have been fitted by a dashed line with a slope of 0.4; on a log-log plot, this means that the price is proportional to the carbon rate raised to the 0.4 power. The prices shown are for the complete installation, including feeder, cooler, afterburner, and scrubber. Indications are that the costs for Marquess and Nell systems might be somewhat less, perhaps 15% or so.

For shipping costs, it was necessary to determine the distances between the various AAP's and from them to the Pennsylvania (Envirotrol) reactivator site. For unit costs, we determined, from the Radford AAP experience of shipping an explosive hazardous waste (the carbon) to Sewickley, PA, a unit cost of \$.38/T (wet)-mile, and about \$.28/T-mile for the return carbon. We assume shipment (out) of 2.2 lb of wet explosive-laden carbon per 1 lb of contained carbon (1 lb of H₂O and 0.2 lb of explosive in addition to every 1 lb of carbon). We assume a return of 0.9 lb of reactivated carbon (and no return of incinerated carbon) per lb of carbon fed to a furnace.

For the operating costs, we assume one operator being paid for all shifts, 365 days a year for any furnace being run by the Army, and an electrical consumption of 1.25 KWH/lb of carbon introduced to the furnace with a unit charge of \$.045/KWH. Allowance for supervision, but not for overhead, has been made, on the basis that one operator for running a furnace would not affect the plant overhead structure. Capital-based charges are taken at 15% of capital investment per year, with another 6% for maintenance.

For those cases involving utilization of a commercial reactivator or incinerator, we have taken Envirotrol's quote of \$.51/lb of reactivated carbon plus \$.03/lb for bagging in 50-lb bags. With a yield of 90%, this translates to a processing cost of $(0.9)(0.54) = \$.49/\text{lb}$ of entering carbon.

For the costs associated with deactivation of spent carbons in existing APE-1236 Explosive-Waste Incinerators, we used the fuel oil/waste ratios supplied in the AAP questionnaires, and we estimated the fraction of a year required for those large units to process the comparatively small amount of spent carbons indicated in the completed questionnaires.

4.2 Alternatives Considered

In this section, we consider the costs of the various approaches to treatment of the Army's explosive-laden spent carbons.

TABLE 4-1

SHIRCO REACTIVATION SYSTEM
 1987 CAPITAL INVESTMENT ESTIMATES
 (INSTALLED, WITH AFTERBURNER AND SCRUBBER)

Operating Rate Lbs C/Day	Capital Investment	Notes	Source
160	1.25* x 330,000 = \$ 412,500	45-foot Trailer-mounted	Army Bid
300	1.25* x 250,000 = 312,500	Skid-mounted	Army Bid
500	600,000		Rough Shirco Est.
833	1.25* x 495,000 = 618,750	55-foot Trailer-mounted	Army Bid
2,000	1,000,000		Rough Shirco Est.

*Correction applied because Radford AAP has indicated a 25% increase in Shirco's prices since the original bids of mid-1986.

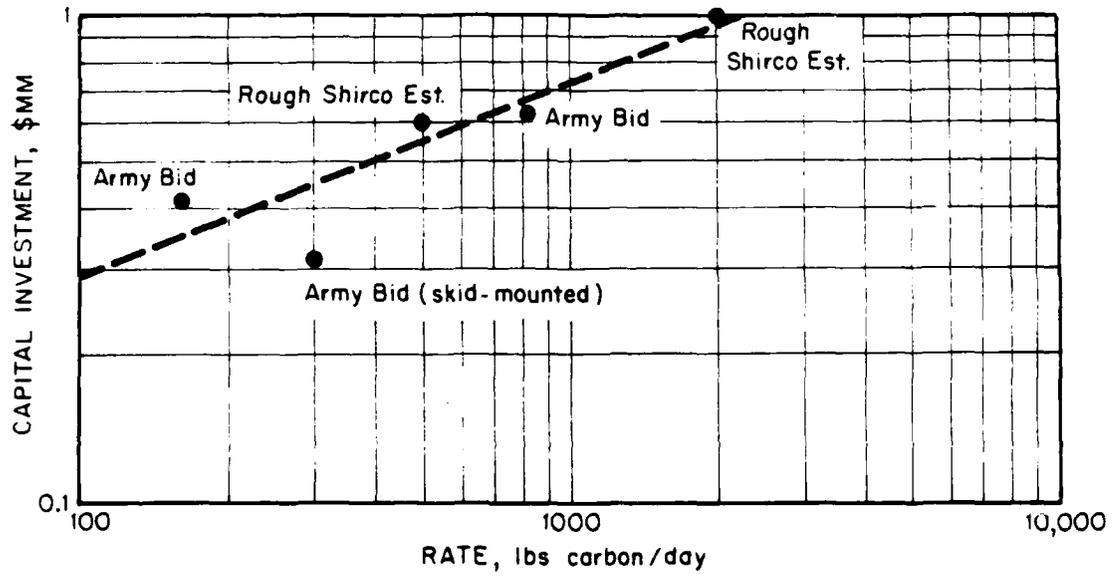


FIGURE 4-1 MID-1987 CAPITAL INVESTMENT FOR SHIRCO REACTIVATION SYSTEM (Installed, with Afterburner and Scrubber)

We have considered the following cases:

- Options 1R through 4R: Thermal Reactivation for Re-use.
In these four cases, we consider new reactivation furnaces at one, two, or three AAP's, and, lastly, the possibility of using an existing facility in Pennsylvania for reactivation.
- Options 1I through 4I: Oxidative Incineration and Ash Burial.
In these four cases, we consider new incineration furnaces at one, two, or three AAP's, and, lastly, the possibility of using an existing commercial facility in Pennsylvania for incineration.
- Option 1D: Thermal Deactivation and Carbon Burial.
In this case, the deactivation is performed in the existing APE-1236 Explosive-Waste Incinerators (or an equivalent rotary kiln in the case of Radford).

In Table 4-2, we summarize the results for these nine cases. For each is shown the Government's additional capital investment, the annual operating cost, and the excess cost over that of sending the carbons to a commercial reactivator in Pennsylvania.

The nine cases of Table 4-2 are then shown more completely in Tables 4-3 through 4-11. Each of these tables is in turn accompanied by its own detail table showing the calculation of the shipping cost component; the shipping detail tables are Tables 4-3A through 4-11A.

We shall now describe the nine cases shown in summary Table 4-2.

4.2.1 Reactivation (Four Options)

Options 1R through 4R (detailed in Tables 4-3 through 4-6) represent the results of our cost estimations for reactivation. In Option 1R we show what would be involved if one were to set up a furnace at Milan AAP (because of its centrality) to reactivate material for all eight of the AAP's. From Table 4-2, the Government would have to invest \$970,000 for such a plant. The annual costs are given as \$580,000 (of which the shipping component is \$112,000). The total annual cost is compared with that of sending all the carbon to a commercial reactivator (Option 4R), in which there is no capital investment to the Government, and the annual charges for commercial reprocessing are only \$470,000, given the huge economies of scale enjoyed by the commercial unit. Commercial reactivation, then, is the standard against which all cases are compared. In Options 2R and 3R, we save on shipping costs by installing one or two more reactivation furnaces at different sites, but we find in each case that the total cost increases because of the added labor to run more furnaces and the added capital charges. Because of the 0.4-power price dependence discussed above, two small furnaces will always cost more than one large one of equal total capacity.

4.2.2 Incineration (Four Options)

In Options 1I through 4I (detailed in Tables 4-7 through 4-10) we present the results of our cost estimation for incineration. The results summarized in Table 4-2 again show the same effect of increased cost when one disperses the incineration capacity among several AAP's. In addition,

TABLE 4-2

SUMMARY OF COSTS OF PROCESS ALTERNATIVES FOR EXPLOSIVE-LADEN SPENT CARBONS

<u>Option</u>	<u>Detailed in Tables</u>	<u>Title</u>	<u>Additional Gov't Cap. Investment \$000's</u>	<u>Annual Cost \$000's/Yr</u>	<u>Annual Cost Above Comm'l Reactivation \$000's/Yr</u>
1R	3-3 and 3-3A	Carbon Reactivation at One Central AAP	970	580	110
2R	3-4 and 3-4A	Carbon Reactivation at Two AAP's	1450	812	343
3R	3-5 and 3-5A	Carbon Reactivation at Three AAP's	1854	1066	596
4R	3-6 and 3-6A	Carbon Reactivation at Comm'l Facility	0	470	0
1I	3-7 and 3-7A	Carbon Incineration at One Central AAP	970	973	504
2I	3-8 and 3-8A	Carbon Incineration at Two AAP's	1450	1220	750
3I	3-9 and 3-9A	Carbon Incineration at Three AAP's	1854	1478	1008
4I	3-10 and 3-10A	Carbon Incineration at Comm'l Facility	0	844	375
1D	3-11 and 3-11A	Carbon Deactivation at Existing APE-1236's	0	710	241

however, despite some lower shipping costs (because of no returns), there is now the very large added cost of replacing some 466,300 lb/yr of incinerated carbon at about \$1.00/lb, so that each of these four options show annual costs some \$400,000 more than the corresponding reactivation cases.

4.2.3. Thermal Deactivation (One Option)

In Option 1D (detailed in Table 4-11), we show our estimate of the cost of utilizing the existing APE-1236's (or equivalent) at five of the sites to heat the carbon enough to deactivate it. Here Table 4-2 indicates no additional capital investment, but even this option is some \$241,000 more expensive than commercial regeneration, mainly because of the cost of purchasing replacement carbon.

The results summarized in Table 4-2 clearly show that commercial reactivation (Option 4R--Table 4-6) is by far the lowest-cost alternative. If this is not available, for any reason, then the next lowest-cost alternative is to set up a central reactivator at one AAP (Option 1R--Table 4-3). If the capital investment money for this (\$937,000) cannot be found, then the next lowest-cost alternative is the deactivation at existing APE-1236's (Option 1D--Table 4-11).

There are, however, a number of uncertainties which should be clarified before any of these alternatives is chosen. These will be discussed in Section 5.0.

TABLE 4-3
 OPERATING COST - OPTION 1R
 CARBON REACTIVATION AT ONE CENTRAL AAP

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
Central Furnace at Milan	1,332	2,000	970,000
Totals	----- 1,332	----- 2,000	----- 970,000

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Electricity	582875	KWH	0.045	26,229
Replacemt Carbon	46630	Lb	1.00	46,630
Direct Labor	8760	M-H	15.00	131,400
Sup'v'n	45% of DL			59,130
Maintenance	6% of CI			58,200
Other Capital	15% of CI			145,500
All Shipping	See Table 4-3A			112,457
				----- 579,546
Added Cost Relative to Comm'l Reactivation:				109,942

TABLE 4-3A
 SHIPPING COST - OPTION 1R
 CARBON REACTIVATION AT ONE CENTRAL AAP

Shipment Out of Hazardous Waste = 2.2 Lb/Lb Dry C
 Return of Non-Hazardous Product = 0.9 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Milan	615	175,000	58,548
Milan	Milan	0	74,900	0
Lone Star	Milan	400	70,000	15,232
Mississippi	Milan	500	70,000	19,040
Kansas	Milan	500	34,400	9,357
Louisiana	Milan	490	23,300	6,211
Iowa	Milan	400	18,700	4,069
Joliet	Milan	440	0	0
			466,300	112,457

TABLE 4-4
 OPERATING COST - OPTION 2R
 CARBON REACTIVATION AT TWO AAP'S

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
Dedictd Furnace at Radford	500	750	650,000
Central Furnace at Milan	832	1,250	800,000
 	-----	-----	-----
Totals	1,332	2,000	1,450,000

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Electricity	582875	KWH	0.045	26,229
Replacemt Carbon	46630	Lb	1.00	46,630
Direct Labor	17520	M-H	15.00	262,800
Sup'v'n	45% of DL			118,260
Maintenance	6% of CI			87,000
Other Capital	15% of CI			217,500
All Shipping	See Table 4-4A			53,909

				812,328
Added Cost Relative to Comm'l Reactivation:				342,724

TABLE 4-4A
SHIPPING COST - OPTION 2R
CARBON REACTIVATION AT TWO AAP'S

Shipment Out of Hazardous Waste - 2.2 Lb/Lb Dry C
Return of Non-Hazardous Product - 0.9 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Radford	0	175,000	0
Milan	Milan	0	74,900	0
Lone Star	Milan	400	70,000	15,232
Mississippi	Milan	500	70,000	19,040
Kansas	Milan	500	34,400	9,357
Louisiana	Milan	400	23,300	6,211
Iowa	Milan	400	18,700	4,069
Joliet	Milan	440	0	0
			466,300	53,909

TABLE 4-5
 OPERATING COST - OPTION 3R
 CARBON REACTIVATION AT THREE AAP'S

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Cap'tl In- vestm't, \$
Dedictd Furnace at Radford	500	750	650,000
Central Furnace at Milan	365	550	570,000
Central Furnace at Lone Star	467	700	634,000
Totals	----- 1,332	----- 2,000	----- 1,854,000

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Electricity	582875	KWH	0.045	26,229
Replacem't Carbon	46630	Lb	1.00	46,630
Direct Labor	26280	M-H	15.00	394,200
Sup'v'n	45% of DL			177,390
Maintenance	6% of CI			111,240
Other Capital	15% of CI			278,100
All Shipping	See Table 4-5A			31,829
				----- 1,065,619
Added Cost Relative to Comm'l Reactivation:				596,014

TABLE 4-5A
 SHIPPING COST - OPTION 3R
 CARBON REACTIVATION AT THREE AAP's

Shipment Out of Hazardous Waste	=	2.2 Lb/Lb Dry C
Return of Non-Hazardous Product	=	0.9 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Radford	0	175,000	0
Milan	Milan	0	74,900	0
Lone Star	Lone Star	0	70,000	0
Mississippi	Lone Star	450	70,000	17,136
Kansas	Milan	500	34,400	9,357
Louisiana	Lone Star	100	23,300	1,268
Iowa	Milan	400	18,700	4,069
Joliet	Milan	440	0	0
			-----	-----
			466,300	31,829

TABLE 4-6
 OPERATING COST - OPTION 4R
 CARBON REACTIVATION AT COMMERCIAL FACILITY IN PA

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
None			

Totals			None

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Reactivation	466300	Lb	0.49	228,487
Replacemt Carbon	46630	Lb	1.00	46,630
All Shipping	See Table 4-6A			194,488

				469,605

TABLE 4-6A
 SHIPPING COST - OPTION 4R
 CARBON REACTIVATION AT COMMERCIAL FACILITY IN PENNSYLVANIA

Shipment Out of Hazardous Waste - 2.2 Lb/Lb Dry C
 Return of Non-Hazardous Product - 0.9 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Pennsylvania	450	175,000	42,840
Milan	Pennsylvania	760	74,900	30,967
Lone Star	Pennsylvania	1100	70,000	41,888
Mississippi	Pennsylvania	1000	70,000	38,080
Kansas	Pennsylvania	1050	34,400	19,649
Louisiana	Pennsylvania	1100	23,300	13,943
Iowa	Pennsylvania	700	18,700	7,121
Joliet	Pennsylvania	550	0	0
			466,300	194,488

TABLE 4-7
 OPERATING COST - OPTION II
 CARBON INCINERATION AT ONE CENTRAL AAP

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
Central Furnace at Milan	1,332	2,000	970,000
Totals	----- 1,332	----- 2,000	----- 970,000

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Electricity	582875	KWH	0.045	26,229
Replacemt Carbon	466300	Lb	1.00	466,300
Direct Labor	8760	M-H	15.00	131,400
Sup'v'n	45% of DL			59,130
Maintenance	6% of CI			58,200
Other Capital	15% of CI			145,500
All Shipping	See Table 4-7A			86,410
				----- 973,169
Added Cost Relative to Comm'l Reactivation:				503,565

TABLE 4-7A
 SHIPPING COST - OPTION 1I
 CARBON INCINERATION AT ONE CENTRAL AAP

Shipment Out of Hazardous Waste	-	2.2 Lb/Lb Dry C
Return of Non-Hazardous Product	-	0.0 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Milan	615	175,000	44,987
Milan	Milan	0	74,900	0
Lone Star	Milan	400	70,000	11,704
Mississippi	Milan	500	70,000	14,630
Kansas	Milan	500	34,400	7,190
Louisiana	Milan	490	23,300	4,772
Iowa	Milan	400	18,700	3,127
Joliet	Milan	440	0	0
			-----	-----
			466,300	86,410

TABLE 4-8
OPERATING COST - OPTION 2I
CARBON INCINERATION AT TWO AAP'S

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
Dedictd Furnace at Radford	500	750	650,000
Central Furnace at Milan	832	1,250	800,000
Totals	----- 1,332	----- 2,000	----- 1,450,000

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Electricity	582875	KWH	0.045	26,229
Replacem Carbon	466300	Lb	1.00	466,300
Direct Labor	17520	M-H	15.00	262,800
Sup'v'n	45% of DL			118,260
Maintenance	6% of CI			87,000
Other Capital	15% of CI			217,500
All Shipping	See Table 4-8A			41,423
				----- 1,219,512
Added Cost Relative to Comm'l Reactivation:				749,907

TABLE 4-8A
SHIPPING COST - OPTION 2I
CARBON INCINERATION AT TWO AAP's

Shipment Out of Hazardous Waste	-	2.2 Lb/Lb Dry C
Return of Non-Hazardous Product	-	0.0 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Radford	0	175,000	0
Milan	Milan	0	74,900	0
Lone Star	Milan	400	70,000	11,704
Mississippi	Milan	500	70,000	14,630
Kansas	Milan	500	34,400	7,190
Louisiana	Milan	490	23,300	4,772
Iowa	Milan	400	18,700	3,127
Joliet	Milan	440	0	0

			466,300	41,423

TABLE 4-9
 OPERATING COST - OPTION 3I
 CARBON INCINERATION AT THREE AAP'S

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Cap'tl In- vestm't, \$
Dedictd Furnace at Radford	500	750	650,000
Central Furnace at Milan	365	550	570,000
Central Furnace at Lone Star	467	700	634,000
	-----	-----	-----
Totals	1,332	2,000	1,854,000

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Electricity	582875	KWH	0.045	26,229
Replacemt Carbon	466300	Lb	1.00	466,300
Direct Labor	26280	M-H	15.00	394,200
Sup'v'n	45% of DL			177,390
Maintenance	6% of CI			111,240
Other Capital	15% of CI			278,100
All Shipping	See Table 4-9A			24,457

				1,477,917

Added Cost Relative to Comm'l Reactivation: 1,008,312

TABLE 4-9A
 SHIPPING COST - OPTION 3I
 CARBON INCINERATION AT THREE AAP's

Shipment Out of Hazardous Waste = 2.2 Lb/Lb Dry C
 Return of Non-Hazardous Product = 0.0 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Radford	0	175,000	0
Milan	Milan	0	74,900	0
Lone Star	Lone Star	0	70,000	0
Mississippi	Lone Star	450	70,000	13,167
Kansas	Milan	500	34,400	7,190
Louisiana	Lone Star	100	23,300	974
Iowa	Milan	400	18,700	3,127
Joliet	Milan	440	0	0
			466,300	24,457

TABLE 4-10
 OPERATING COST - OPTION 4I
 CARBON INCINERATION AT COMMERCIAL FACILITY IN PA

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
None			
-----			-----
Totals			None

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Incineration	466300	Lb	0.49	228,487
Replacemt Carbon	466300	Lb	1.00	466,300
All Shipping	See Table 4-10A			149,441

				844,228
Added Cost Relative to Comm'l Reactivation:				374,623

TABLE 4-10A
SHIPPING COST - OPTION 4I
CARBON INCINERATION AT COMMERCIAL FACILITY IN PENNSYLVANIA

Shipment Out of Hazardous Waste = 2.2 Lb/Lb Dry C
Return of Non-Hazardous Product = 0.0 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Pennsylvania	450	175,000	32,918
Milan	Pennsylvania	760	74,900	23,794
Lone Star	Pennsylvania	1100	70,000	32,186
Mississippi	Pennsylvania	1000	70,000	29,260
Kansas	Pennsylvania	1050	34,400	15,098
Louisiana	Pennsylvania	1100	23,300	10,713
Iowa	Pennsylvania	700	18,700	5,472
Joliet	Pennsylvania	550	0	0
			466,300	149,441

TABLE 4-11
 OPERATING COST - OPTION 1D
 CARBON DEACTIVATION AT FIVE EXISTING APE 1236's *

Additional Government Facility	Load, Lbs/D	Cap'y, Lbs/D	Government Captl In- vestm't, \$
• None			
-----			-----
Totals			None

Item	Quantity/Yr	Unit	Unit Cost, \$	Annual Cost, \$
Fuel Oil	45000	Gal	0.90	40,500
Replacemt Carbon	466300	Lb	1.00	466,300
Direct Labor	2300	M-H	15.00	34,500
Sup'v'n	45% of DL			15,525
Maintenance	Share of 5 APE's			100,000
All shipping	See Table 4-11A			25,690
Disposal Cost	233	Tons	120.00	27,978

				710,493
Added Cost Relative to Comm'l Reactivation:				240,889

* At Mississippi, Louisiana, Iowa, Kansas, and an equivalent rotary kiln at Radford.

TABLE 4-11A
 SHIPPING COST - OPTION 1D
 CARBON DEACTIVATION AT FIVE EXISTING APE 1236's *

Shipment Out of Hazardous Waste = 2.2 Lb/Lb Dry C
 Return of Non-Hazardous Product = 0.0 Lb/Lb Dry C

Origin	Destination	Distance, Miles	Dry Carbon in Feed, Lbs/Year	Annual Shipping Cost, \$
Radford	Radford	0	175,000	0
Milan	Iowa	400	74,900	12,523
Lone Star	Mississippi	450	70,000	13,167
Mississippi	Mississippi	0	70,000	0
Kansas	Kansas	0	34,400	0
Louisiana	Louisiana	0	23,300	0
Iowa	Iowa	0	18,700	0
Joliet	Iowa	230	0	0
			466,300	25,690

* At Mississippi, Louisiana, Iowa, Kansas, and an equivalent rotary kiln at Radford.

5.0 DISCUSSION OF RESULTS

As shown by the economics developed in the previous section, incineration is a costly solution to the problem; commercial reactivation is the lowest-cost alternative (at \$470,000/year), Army reactivation at a central AAP is the next lowest-cost alternative (at \$580,000/year) and deactivation at existing APE-1236's is the next lowest-cost alternative (at \$750,000/year). On the other hand, the practicality of any of these alternatives depends on the presently unknown answers to some key questions.

While results of reactivation of explosive-laden carbons to date are encouraging, the whole topic of treating these carbons raises these questions:

1. Is it possible to locate other carbon regenerators beside Envirotrol who would be willing and able to routinely process explosive-laden spent carbons on an identified-batch basis? So far only Envirotrol has shown its readiness to do this; would it be wise for the Army to rely on a service with only one supplier?
2. In reactivation of explosive-laden carbons, under what conditions could an explosion occur, and what would the consequences be? (Envirotrol's installation is not explosion-proof.) And under what conditions could particles of neat explosive find their way into the spent carbon (leakage, bypassing, or incorrect backwashing of filters, for example)? What would be the extent of the Army's liability if an explosion occurred under such circumstances?
3. In reactivation, what are the variables which determine why Radford's reactivated carbons remain strong but Milan's and Louisiana's tend to crumble? Are the variables controllable by the reactivator, or must the various AAP's standardize on "reactivable" grades of carbon? And how many times can the same carbon be reactivated and re-used? Will some of it have to be discarded eventually, or will attrition losses at the reactivation facility provide a sufficient "purge" of old carbon?
4. If the Army decides to build its own reactivation furnace, should it be of the Shirco EBF, Marquess and Nell ECR, or rotary kiln design? And will it have to be designed to explosion-proof standards in order to obtain regulatory approval?
5. If the Army decides instead to deactivate this carbon at existing APE-1236's, what are the process conditions that will assure that the residue is converted to a decertifiable non-hazardous waste for landfilling purposes?
6. In all of the above, will the various states and communities continue to allow long-term transit of the explosive hazardous-waste spent carbons for off-site thermal treatment?

The answers to these questions are not presently known. All but the last are subject to scientific settlement, however. Laboratory muffle furnace,

thermogravimetric, and impact tests on actual explosive-laden carbons from the various AAP's can go a long way toward answering Questions 1 and 4. Tests of actual explosive-laden spent carbons in pilot-scale reactivators, followed by testing of the product in laboratory wastewater treatment columns, can go a long way toward answering Questions 2 and 3.

The importance of these questions merits considerable effort to develop the required answers.

6.0 REFERENCES

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2. Fields, M. (Radford Army Ammunition Plant), Unpublished Data, Hercules Aerospace Corp., 2/10/86 and 2/25/86.
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9. Schuliger, W. G. et al. (Calgon Carbon Corporation), "Thermal Reactivation of Granular Activated Carbon: A Proven Technology." Paper to be Published, 1987.

APPENDIX
SAMPLE QUESTIONNAIRE
ON EXPLOSIVE-LADEN SPENT CARBONS

QUESTIONNAIRE ON EXPLOSIVE-LADEN SPENT ACTIVATED CARBON
TREATMENT AND/OR DISPOSAL PRACTICES AT U.S. AAP/LAP PLANT SITES

July 7, 1987

FACILITY INFORMATION

Plant Name: _____
Plant Type: (circle one): AAP, LAP, AAP/LAP
Plant Location: _____
Plant Address: _____

Operating Company: _____

Name: _____
Title: _____
Company: _____
Address: (If different from the plant address)

Telephone Number: _____
Date: _____

A. WASTEWATER STREAMS TREATED

Activated carbon is used at this plant site to treat the following
wastewater stream(s):

A1. Stream No.: _____
A2. Stream Name: _____

A3. Flow Rate

- Continuous, gpm: _____
- Intermittent, gpm
and hrs/day: _____/_____/_____

A4. Stream Temperature
at Carbon Bed Inlet, °F: _____

A5. Analysis of Wastewater Entering Carbon Bed(s):
(Please specify species and concentration)

<u>Species</u>	<u>Concentration</u>		
• _____	_____	_____	_____
• _____	_____	_____	_____
• _____	_____	_____	_____
• _____	_____	_____	_____
• _____	_____	_____	_____
• _____	_____	_____	_____
• _____	_____	_____	_____

B. ACTIVATED CARBON BED SYSTEM

The activated carbon bed system used at this plant site for treating explosive-contaminated wastewater can be characterized by the following:

B1. Designed by: _____.

B2. Manufactured by: _____.

B3. Year Installed: _____.

B4. Carbon Bed Dimensions: Diameter - _____ ft; Height - _____ ft.

B5. Total Number of Beds: _____.

B6. Number of Beds Piped in Series: _____.

B7. Number of Beds Piped in Parallel: _____.

B8. Materials of Construction: Columns - _____; Piping - _____.

B9. Quantity of Carbon in Each Bed: _____ lbs.

B10. Usual Frequency of Carbon Replacement: _____ lbs/ _____ days.

B11. Type of Carbon Used

- Supplier: _____.
- Grade: _____.
- Mesh Size: _____.

B12. Purchase Cost of Carbon: \$_____/lb in _____ lbs shipment lots.

B13. Method of Loading Carbon into the Adsorber: (please describe or provide sketch)

B14. Method of Unloading Carbon from the Adsorber: (please describe or provide sketch)

B15. Method for Determining Carbon Replacement

- Fixed Time Cycle : _____ operating hours.
- Fixed Wastewater Volume : _____ gallons.
- Effluent Breakthrough : (species) _____
at (concentration) _____.
- Other Method (please specify) :

B16. Please supply the design basis for the carbon adsorbers at this installation. (For example: amount of carbon per gpm of wastewater treated for certain period of time, or amount of carbon per unit weight of key chemical constituent removed.)

B17. The above design basis was established from: (please check as appropriate)

- Bench-Scale Data: _____
- Pilot Plant Data: _____
- Vendor Information: _____
- Operating Experience at This Plant Site: _____
- Operating Experience at Other Plant Sites: (please specify)

B18. Do you anticipate any significant changes in the amount of carbon you now use, if so, how much of a change and why?

C. TREATMENT AND/OR DISPOSAL OF EXPLOSIVE-LADEN SPENT ACTIVATED CARBON

C1. Do you perform chemical analysis to determine the content of explosives and other organics on the spent carbon? If so, please provide a typical analysis.

C2. Explosive-laden carbon is disposed of at this plant site by:
(please check as appropriate)

- Open-pit Burning On-site: _____
- Incinerated in Explosive Incinerator On-site: _____
- Regenerated On-site (please specify): _____

- Temporary On-site Storage (describe containers, storage area):

- Off-site Disposal: _____

Questions C3 - C11 pertain to off-site disposal of spent carbon.

C3. What is the type, size, and cost of container you use for shipping spent carbon?

C4. How much carbon can you actually pack into each of these containers?

C5. Do you go through a dewatering step before packing spent carbon into the shipping containers? If so, please describe.

C6. Please describe the method and equipment you use in packaging the spent carbon into these containers.

C7. Please estimate the man-hour requirement for packaging the spent carbon, in hours per carbon bed, per shipping containers, or any other convenient measure.

C8. Do you use a contractor for the disposal service? If so, who?

C9. What is the off-site disposal cost? In \$/lb or in \$/container.

C10. Does the above disposal cost include transportation from plant site to the disposal site? If not, please indicate estimated cost.

C11. What does the disposal contractor do with the explosive-laden spent carbon? (Please check as appropriate.)

- Secure Landfill: _____
- Incineration: _____
- Other Methods (please specify): _____
- Unknown: _____

Questions C12 - C19 pertain to the explosive incinerator operation in your plant. Please address these questions as appropriate regardless of whether or not explosive-laden spent carbon is incinerated at your plant site.

C12. Is your plant equipped with an incinerator for disposing explosive wastes?

C13. If so, what type of explosive incinerator do you have?

C14. Please list the individual incinerator capacities, in lbs of explosives per 8-hour operation, rated fuel requirement, and the type of fuel used.

C15. Please describe provisions for air emission control and ash disposal as related to the incinerator operation.

C16. How many hours per week is the explosive incinerator in use?

C17. What is the manning requirement to operate these explosive incinerators?

C18. Could you list some of the explosive incinerator design features and operating procedures that are crucial to the safe operation of the system?

C19. Do you have any general comments on these incinerators as to their pros and cons vs. other types of incinerators that you know of?

Questions C20-C23 pertain to the regeneration of spent carbon. Please address these questions as appropriate regardless of whether spent carbon is regenerated at this plant site or not.

C20. Do you currently regenerate explosive-laden spent carbon at this plant site? If so, please describe.

C21. Have you ever considered regenerating these spent carbons on-site?

C22. What do you think are the major issues regarding the regeneration of explosive-laden spent activated carbon?

C23. If you have tried carbon regeneration before, what experience can you share with us in terms of type of equipment used, carbon weight loss, carbon re-usability, and any other comments.

End of Questionnaire

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Thank you very much for your cooperation. Please return this questionnaire in the enclosed self-addressed envelope to:

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