Paper Presented at the:

Twenty-Fifth DoD Explosives Safety Seminar
Anaheim, California

SOIL REMEDIATION METHODS

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ABSTRACT

Remediation methods, problems and optimization techniques for removal of propellants, explosives and pyrotechnics in soils are discussed. Process flow sheets to select best soil remediation methods plus an example of optimization are presented. Many parameters which effect remediation are discussed.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1992**	2. REPORT TYPE	3. DATES COVERED **00-00-1992 to 00-00-1992**

4. TITLE AND SUBTITLE **Soil Remediation Methods**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Safety Consulting Engineers, Inc,2131 Hammond Dr,Schaumburg,IL,60173**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA260984, Volume I. Minutes of the Twenty-Fifth Explosives Safety Seminar Held in Anaheim, CA on 18-20 August 1992.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**17**	

INTRODUCTION

In the past, waste propellants, explosives and pyrotechnics (PEP) would be burned in open pits or recovered if economically feasible. In many manufacturing, loading and end use applications, residual and scrap was landfilled, placed in leaching ponds for separation from water and other chemicals, or accidentally spilled or deposited onto adjacent land. Within the last fifteen years, great emphasis was placed on removal of the hazardous PEP from the soils and ground for safety (potential fires or explosions) and environmental protection (chemicals in water system). Each propellant, explosive or pyrotechnic in the soil presented different issues regarding soil remediation. Much emphasis today is on incineration to destroy the PEPs at significant cost and effort. In this paper, we review the issues related to soil remediation and present optimization methods.

PROBLEM DEFINITIONS

When it is known that propellants, explosives or pyrotechnics are in the ground, various ways to remediate the situation are possible as follows:

- Leave it and treat it
  - neutralize
  - decompose
- Dig it out and
  - burn it
  - decompose it
  - recover it
- Wash it out and
  - burn it
  - decompose it
  - recover it
- Add diluent to soil to reduce hazardous concentrations

Before any remediation is attempted, study is necessary to identify the seriousness of hazard and ways to remedy the situation. A flow chart showing the remediation optimization process is illustrated in Figure 1. Basically, the process steps are as follows:

1. Characterize and locate hazardous material and soil.
2. Remediation method study.
3. Selection of best method.
4. Follow through.

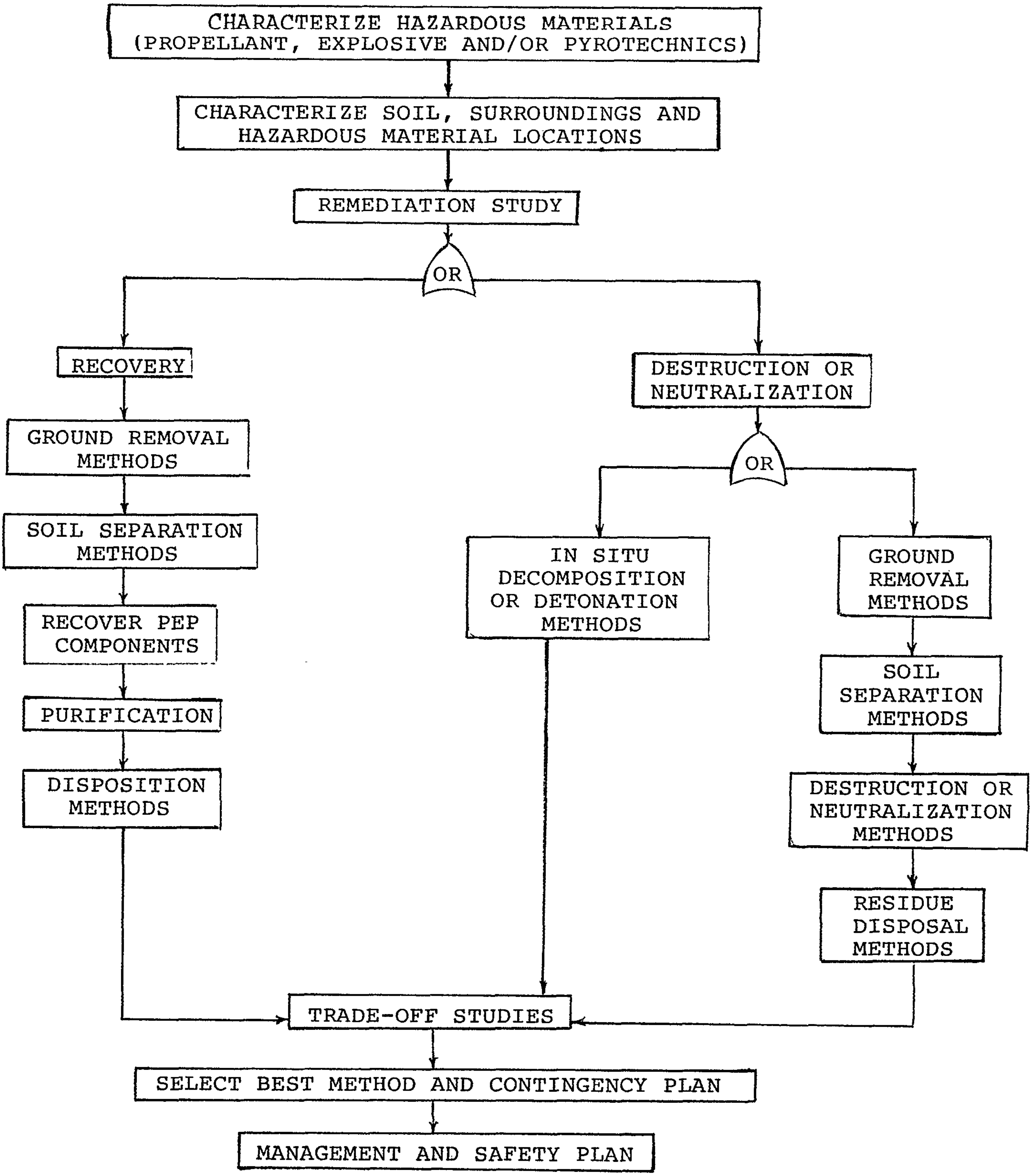

Figure 1. Soil remediation optimization process.

The PEP characterization consists of identifying its physical, chemical, thermal, electrical and ignition sensitivity properties (see Figure 2). Since the hazardous material may be mixed with other explosives, propellants, or pyrotechnics and/or other chemicals, PEP compatibility analysis is necessary to identify the effects on sensitivity to initiation, stability and quality.

Soil sampling is usually necessary to determine location and condition of the PEP in the ground. Core samplers can sometimes give erroneous results especially if used in sandy soils, i.e., the core can plug up with sample sufficiently to permit soil to flow by the core as it descends into the ground. If large pieces of PEP are present, soil coring may be very dangerous causing impact or friction initiation of the PEP which may propagate into a fire or explosion. Sometimes, if PEP distribution in the soil is very non-uniform, mapping from soil sampling can be very deceiving.

Seismic analysis techniques can be used to identify PEP locations provided that the seismic signals are not great enough to initiate the PEP. If large areas are contaminated with PEP, seismic methods may be more cost effective and will produce better definitions of PEP locations. Some core sampling will still be necessary to identify PEP physical and chemical conditions. Also, initiation sensitivity testing will be necessary to identify effects of changes of state, conditions and contamination of ignition sensitivity and quality. See Figure 3.

Soil remediation can be accomplished by destroying or decomposing PEP in situ or by removing PEP from the soil and recovering or destroying/decomposing it.

In situ destruction or decomposition can be accomplished by detonation, bulk decomposition or separation of components (e.g., pyrotechnics). See Figure 4. Methods to verify completion of destruction (e.g., soil borings and lab tests) may be costly, time consuming and dangerous. This in situ destruction approach may be ineffective and too costly.

Removing the PEP and soil from the ground by earth-moving equipment and/or water washout techniques will depend on its concentration and ignition sensitivity. Water washout techniques (like river dredging) could facilitate water separation of PEP from soil via hydroclones. Also, the PEP may be much safer to handle if in water-wet conditions rather than in dry conditions.

Earth removal by earth-moving equipment may be very hazardous especially if the PEP or mixture is very impact, friction or electrostatic discharge ignition sensitive. Water washdown can be used during excavating to render the PEP-soil mixture safe to handle. If high concentrations of PEP in soil (enough to cause soil to be detonable) are found, special ways to dilute or inert the PEP may be necessary. If the PEP concentration is low enough, or is brought low enough by adding more soil, (concentration below 10% of detonable limits), the soil mixture can be destroyed by

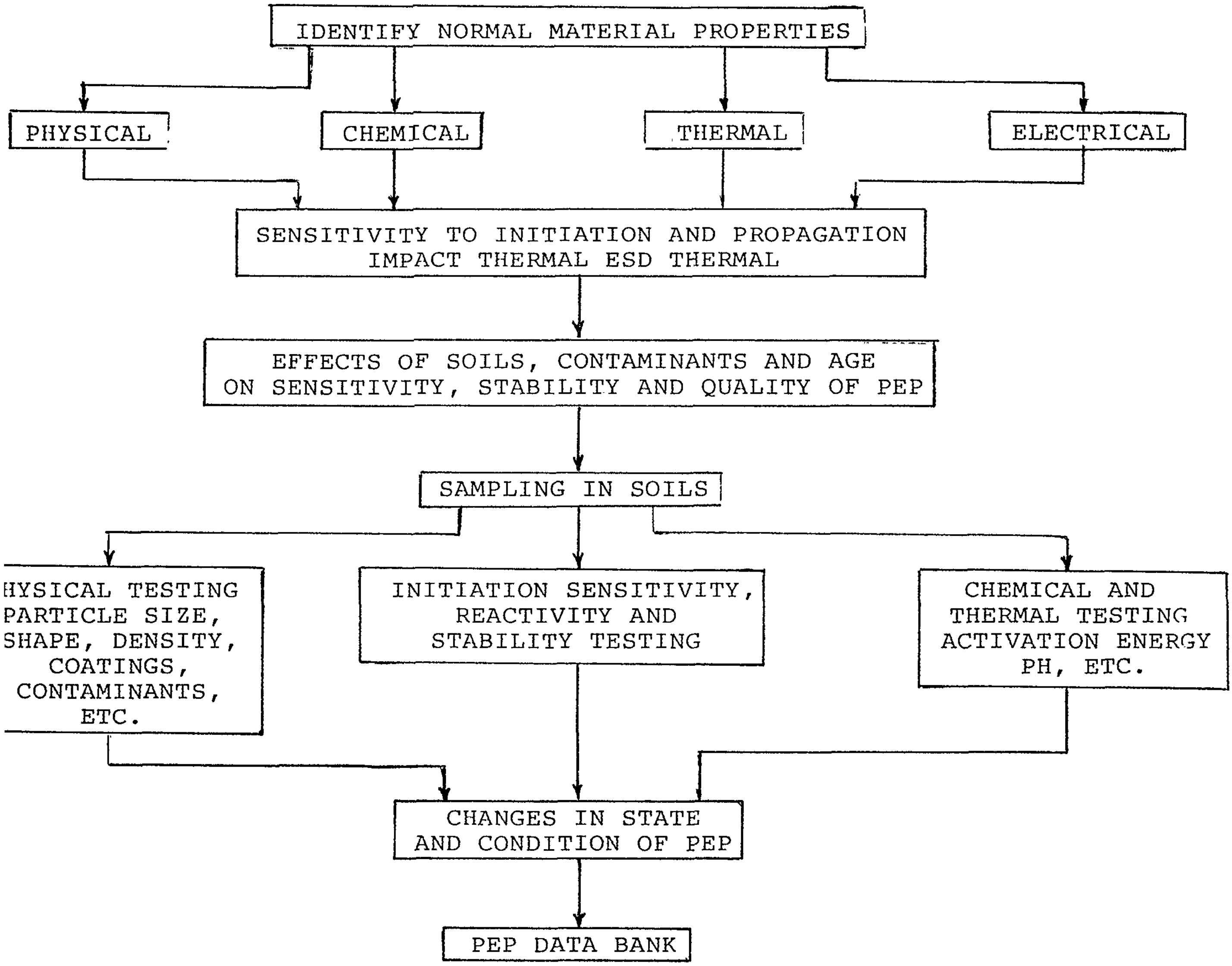

Figure 2. Characterization of prcpellants, explosives and pyrotechnics, (PEP) in soil.

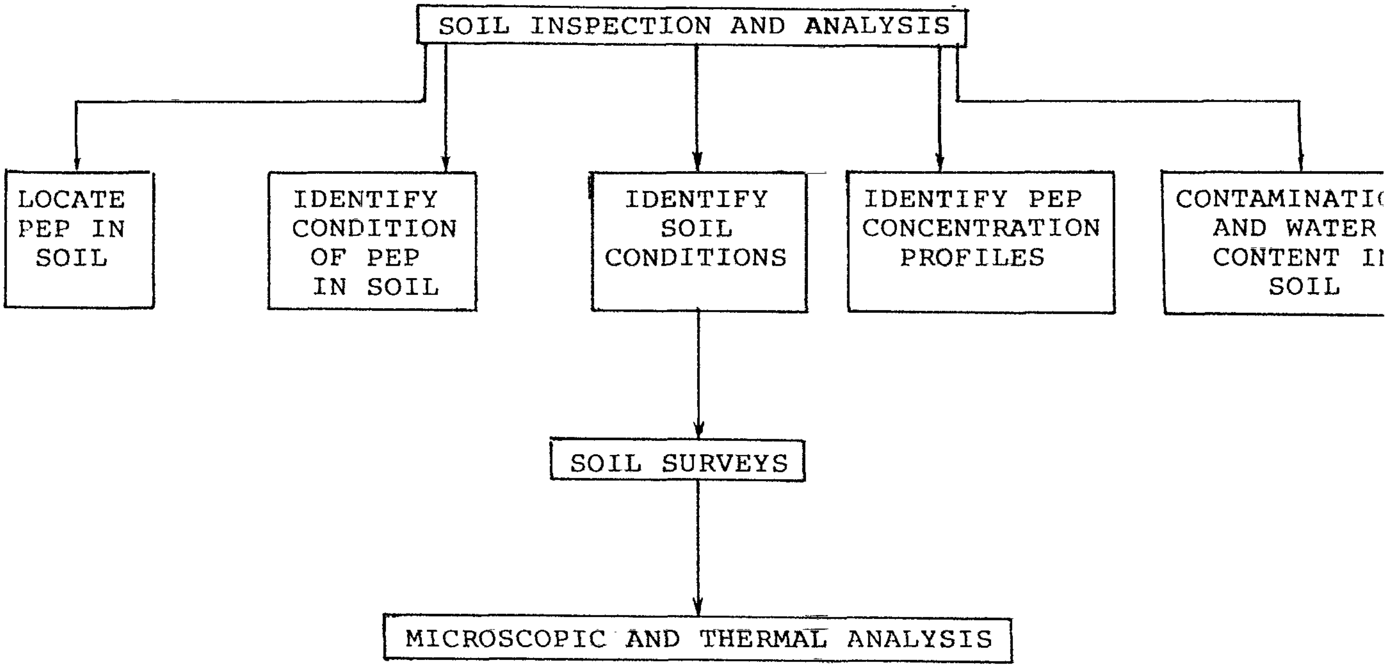

Figure 3. PEP-soil characterization.

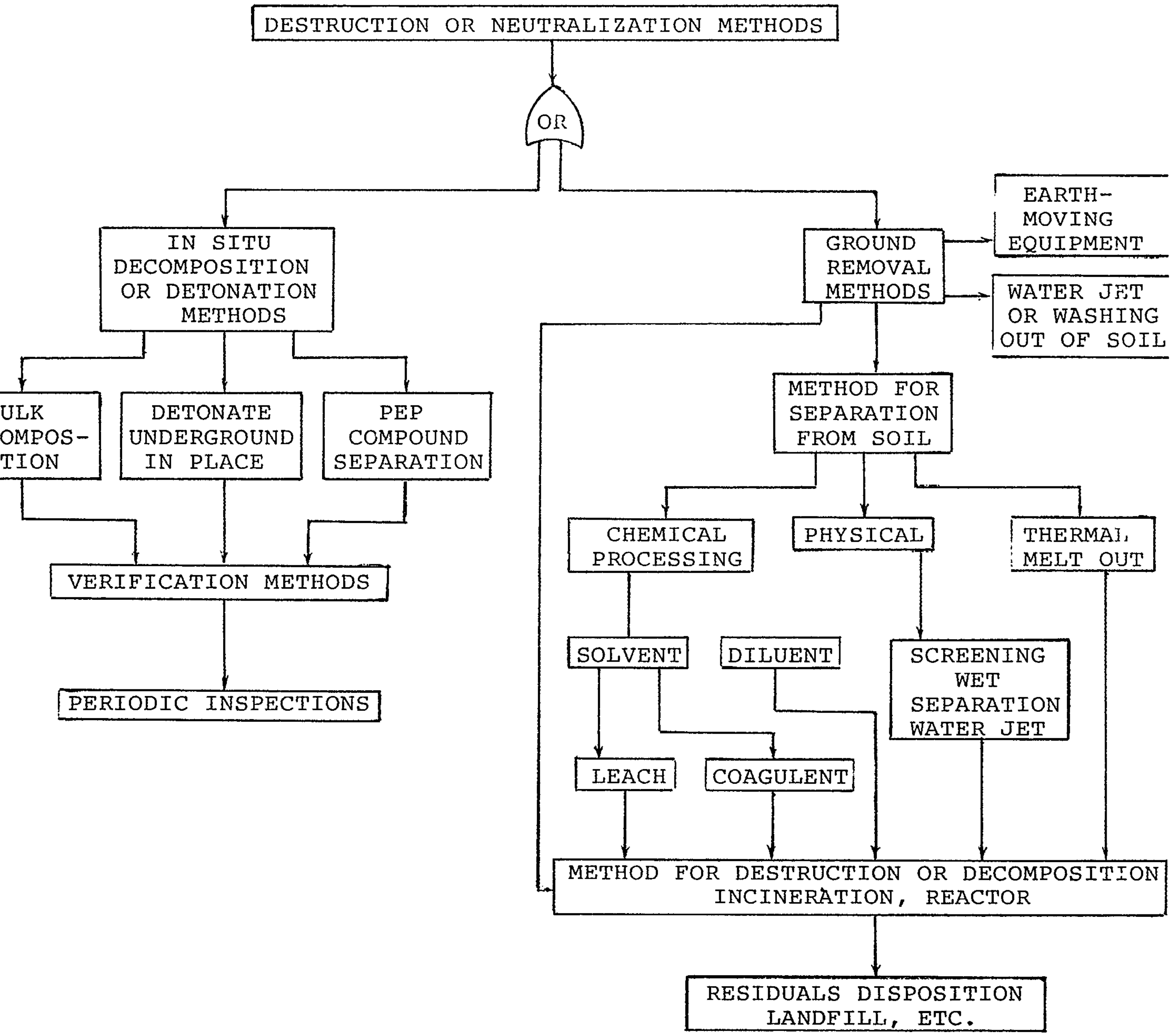

Figure 4. Remediation study - destruction.

incineration (popular today) or decomposition (or neutralization) by chemical reaction.

In either case, residual material must be disposed of properly (landfill if safe or mixing in other safe processes). For direct incineration of the recovered PEP-soil, a massive amount of residual dirt must be disposed of somewhere and extensive tests may be necessary to verify soil environmental safety.

During stockpiling of removed PEP-soil, migration can occur if the PEP particle size and density is greatly different from the soil, or the PEP is water soluble when rains occur.

Once removed from the ground, the PEP-soil mix can be separated prior to destruction by chemical, physical and thermal means. See Figure 4.

For PEP recovery process, the PEP also can be separated out by the same means as listed above. See Figure 5.

Some PEP can be separated from the soil using water soluble solvents (e.g., acetone, etc.) In this case, the solvent added to the PEP-soil mixture causes the PEP to coagulate and cling together. Later, water separation via hydroclone or screening will separate the soil from the PEP. Solvent separation from water could be accomplished by distillation at a later time.

Dry screening can separate PEP from soil, as long as it is of different particle size from the soil. If PEP is dusty, dry screening may not be safe and hydraulic (water) separation may be more appropriate.

Some PEPs can be heated to melting point and the soil can then be screened out from the liquid (e.g., TNT). Caution is necessary to characterize PEP thermal stability as encountered in the soil so that at large scale, runaway reaction can be prevented.

Once separated, the PEP will need to be in a safe condition for handling. Diluents, solvents or inerting agents may be added to assure safety and maintain quality for recovery.

A purification process may be necessary to bring the PEP quality up to standard levels. Recrystalization, solvent purification and chemical treatment may be necessary here.

Packaging and storage of purified PEP should be such that no adverse effect on safety, quality or storage aging will occur.

TRADE-OFF STUDY

The next step in identifying the best remediation method is to conduct a trade-off analysis of important selection parameters. Some typical parameters to be considered (see Figure 6) are as follows:

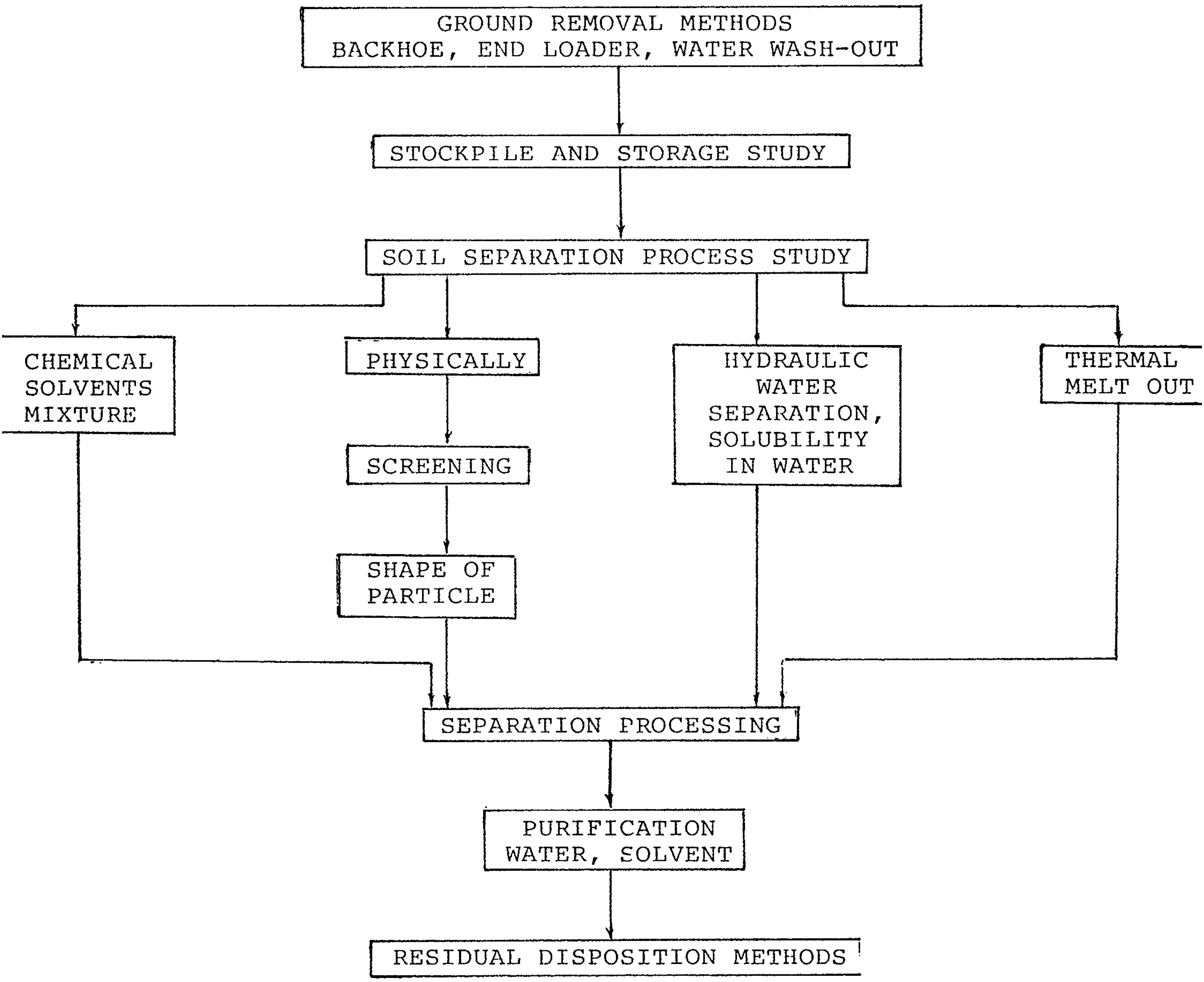

Figure 5. Remediation study - recovery.

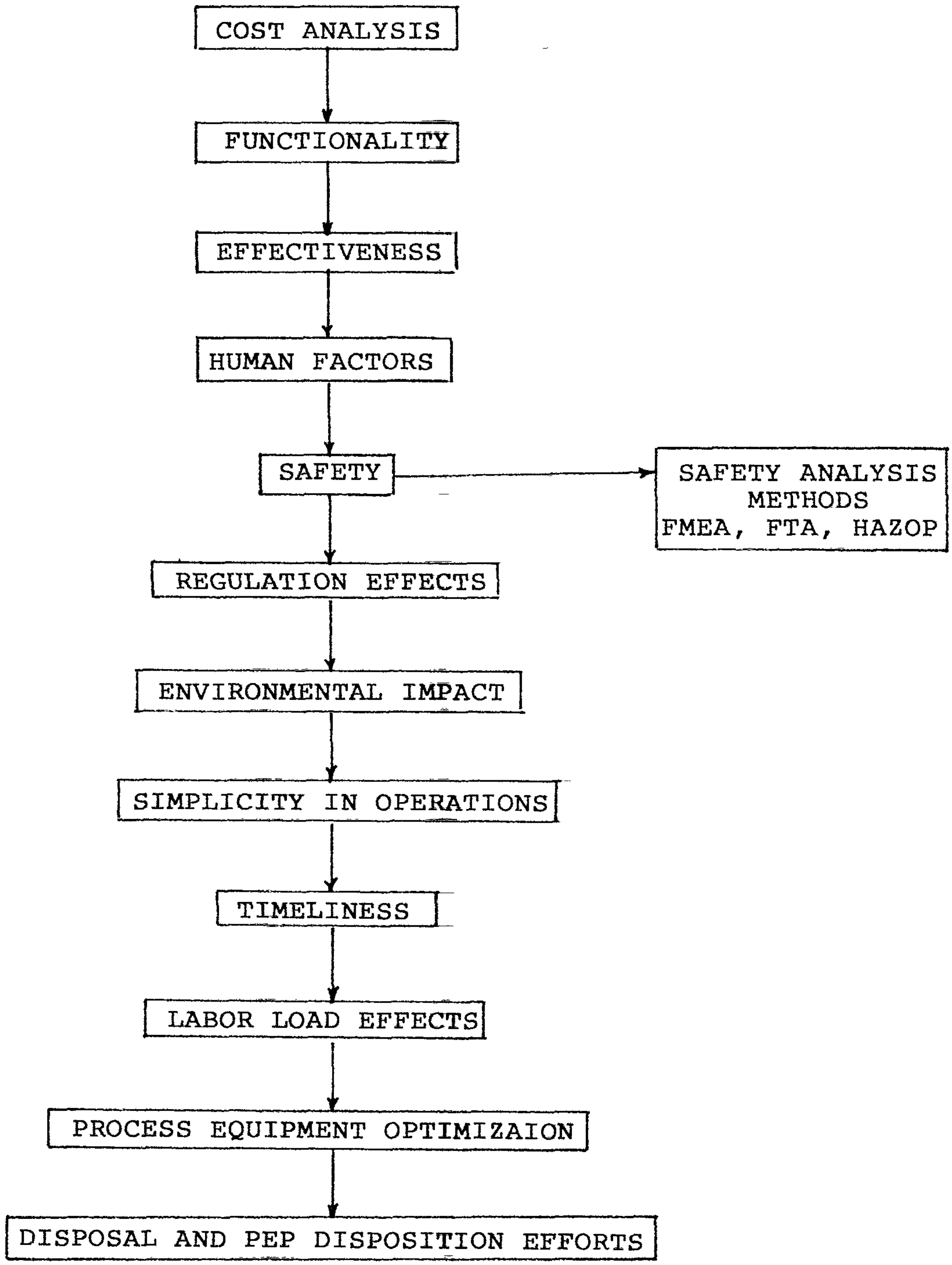

Figure 6. Trade-off study.

- Cost
- Functionality and simplicity
- Cleanup effectiveness
- Safety
- Time to complete
- Process equipment availability
- Environmental impact and regulations
- Labor availability
- Disposal or recovery ease

For each remediation method considered, estimates on cost, safety and availability of equipment and labor should be made. Preliminary hazards analysis should be conducted for each viable method to identify major safety restrictions prior to completion of the trade-off analysis. Thus, remediation methods which are too hazardous can be removed from consideration.

The relative importance of each remediation method selection parameter should be agreed upon early in the study. See Figure 7. A typical ranking multiplier for explosives in soil is shown in the following table:

TYPICAL RANKING MULTIPLIERS

PARAMETER	MULTIPLIER
Cost	10
Safety	10
Functionality and Simplicity	7
Effectiveness of Cleanup	5
Availability of Equipment	2
Availability of Labor	4
Time to Complete	5
Environmental Impact and Regulations	3

Next, each parameter is assigned a relative ranking scale to assist in evaluating its level for each remediation method. Some examples are as follows:

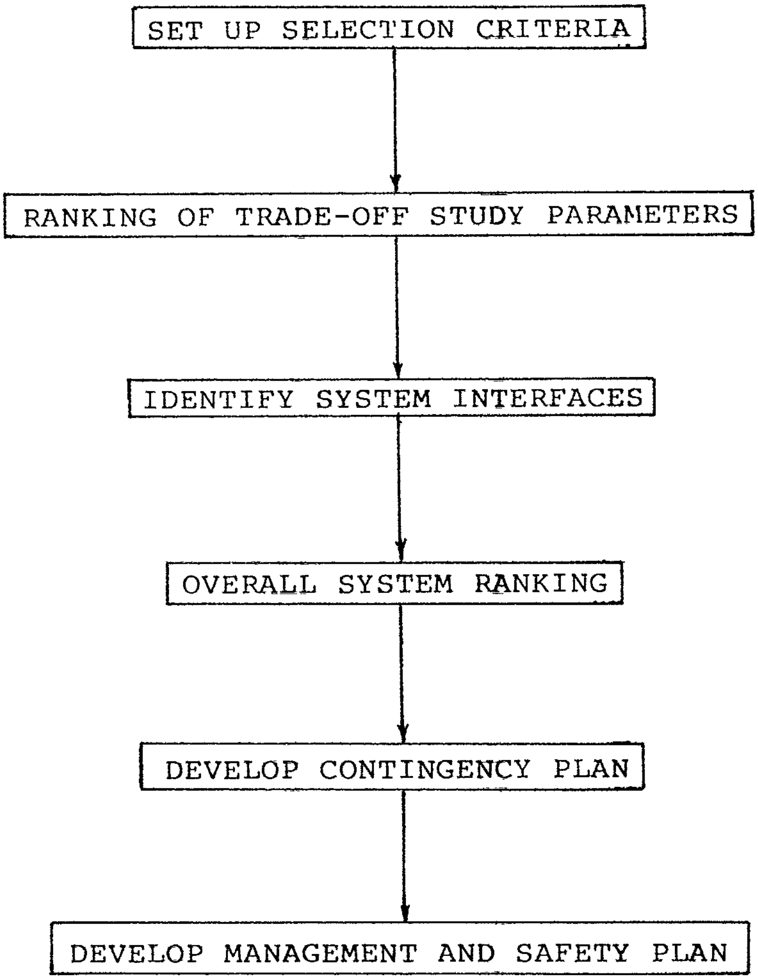

Figure 7. Selection of best method.

COST	
RANKING	DOLLARS
5	10^3
4	10^4
3	10^5
2	10^6
1	10^7

SAFETY	
RANKING	DOLLARS LOST PER YEAR
5	$< 10^3$
4	10^4
3	10^5
2	10^6
1	10^7

FUNCTIONALITY	
RANKING	LEVEL
5	Easy
4	Relatively Complex
3	Complex
2	Very Complex
1	Extremely Difficult

CLEANUP EFFECTIVENESS	
RANKING	PERCENT
5	100
4	92
3	90
2	70
1	20

AVAILABILITY OF EQUIPMENT	
RANKING	TIME
5	Readily
3	Relatively Available
1	Not Available

LABOR AVAILABILITY	
RANKING	LEVEL
3	Readily
2	Relatively Available
1	Not Available

TIME TO COMPLETE	
RANKING	TIME
3	1 Month
2	6 Months
1	2 Years

ENVIRONMENTAL IMPACT	
RANKING	LEVEL
3	None
2	Minor
1	Major

SELECTION OF BEST METHOD

The next step is assigning ranking values of parameters for each remediation method. An example for optimization is shown in Table 1 for nitrocellulose in soil which has slightly decomposed. The process options are shown in Figure 8. This is an example and each situation may require different parameter values and ranking. By multiplying each parameter ranking by the relative importance value and adding up all numerical values, an overall ranking for each method is made. The method is selected based on the highest numerical ranking value.

IMPLEMENTATION

Once the method of remediation has been chosen, management plans for various options as shown in Figure 9, should be undertaken. Contingency plans should also be formulated, since excavation could yield major changes in composition, concentration, contaminants and soil conditions which may require changed remediation methods.

CONCLUSIONS AND RECOMMENDATIONS

Various soil remediation methods have been reviewed and selection criteria and methods were given for PEPs. An example of trade-off analysis and optimization was given.

Soil remediation is very complex and can be very dangerous especially with mixtures of PEPs and other chemicals. If concentrations are high in the soil, potential detonations of PEPs could occur. Chemical, physical, thermal and hydraulic methods can be used to separate PEPs from the soil once excavated. Excavation can be done by mechanical or water washout methods. Depending on the type of PEP, destruction, decomposition or recovery is possible.

It is recommended that thorough study and trade-off analyses be conducted on contaminated soils before remediation is attempted.

Also, soil sampling is essential to be sure what is in the soil and what its condition is.

Detailed ignition sensitivity testing is essential to evaluate the hazards presented by of PEP-soil remediation. Also, detailed hazard analyses must be done on the processes and their contingencies prior to startup to assure safety. For recovery methods, great care must be exercised to be sure that the PEP is pure, free from contaminants and has not aged sufficiently to lose stability.

TABLE 1

TYPICAL TRADEOFF STUDY RESULTS
FOR NITROCELLULOSE

METHOD	(10) COST	(10) SAFETY	(7) FUNCTION	(5) EFFECTIVE-NESS	(2) AVAILABILITY OF EQUIPMENT	(4) PEOPLE	(5) TIME TO COMPLETE	(3) ENVIRON-MENTAL IMPACT	RANKING TOTALS
In situ destruction	(3) 30	(3) 30	(1) 7	(2) 10	(3) 6	(2) 8	(3) 15	(1) 3	109
Dig out and incinerate	(1) 10	(4) 40	(4) 28	(4) 20	(1) 2	(2) 8	(2) 10	(2) 6	124
Dig out and decompose	(3) 30	(2) 20	(4) 28	(2) 10	(3) 6	(2) 8	(2) 10	(2) 6	118
Dig out separate and incinerate	(1) 10	(4) 40	(2) 14	(5) 25	(1) 2	(2) 8	(1) 5	(2) 6	118
Dig out and recover	(2) 20	(2) 20	(2) 14	(4) 20	(1) 2	(2) 8	(2) 10	(3) 9	103

Select #2, Dig Out and Incinerate

Situation: Nitrocellulose and cellulose products burned in soil

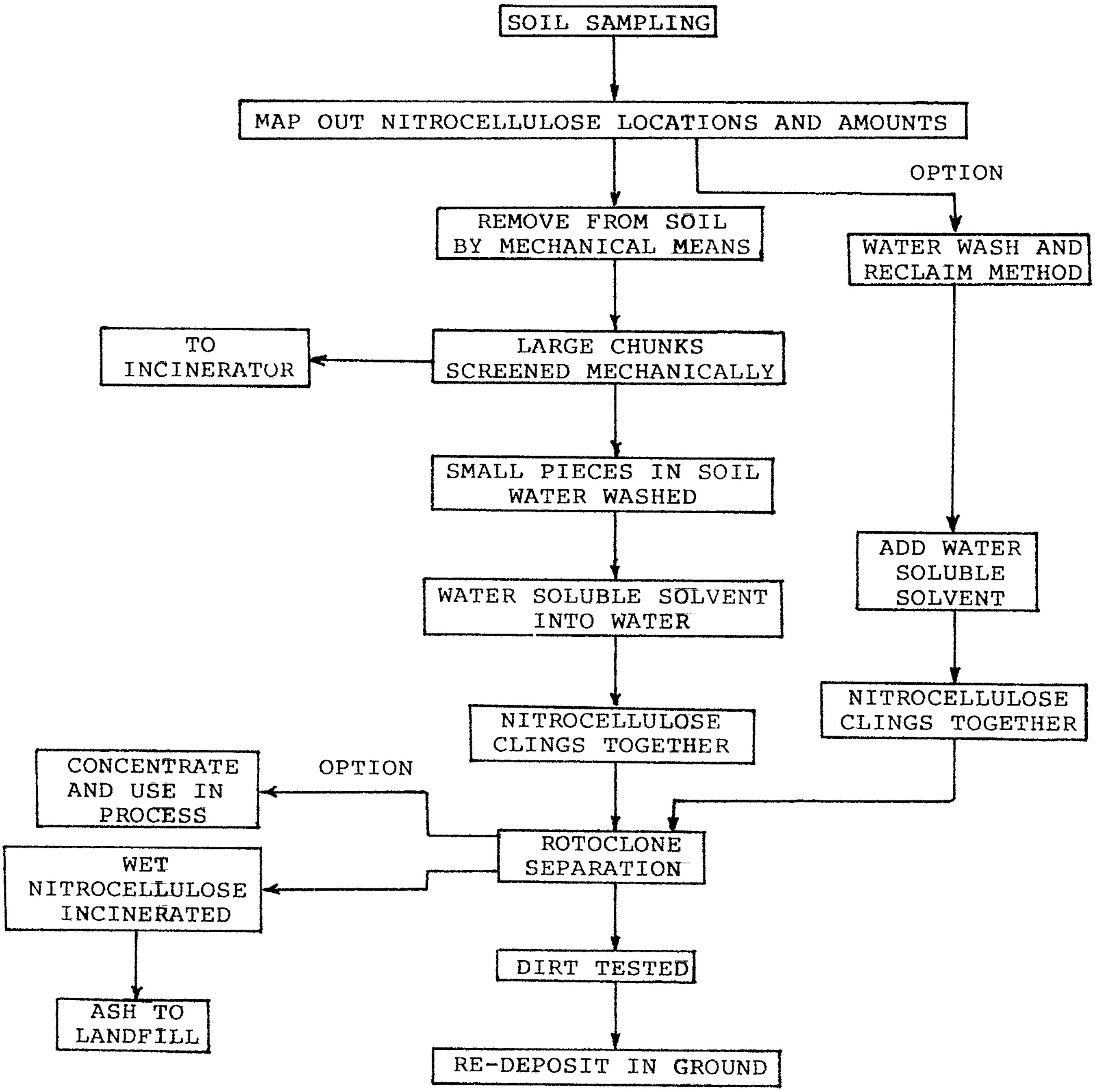

Figure 8. Typical soil remediation process.

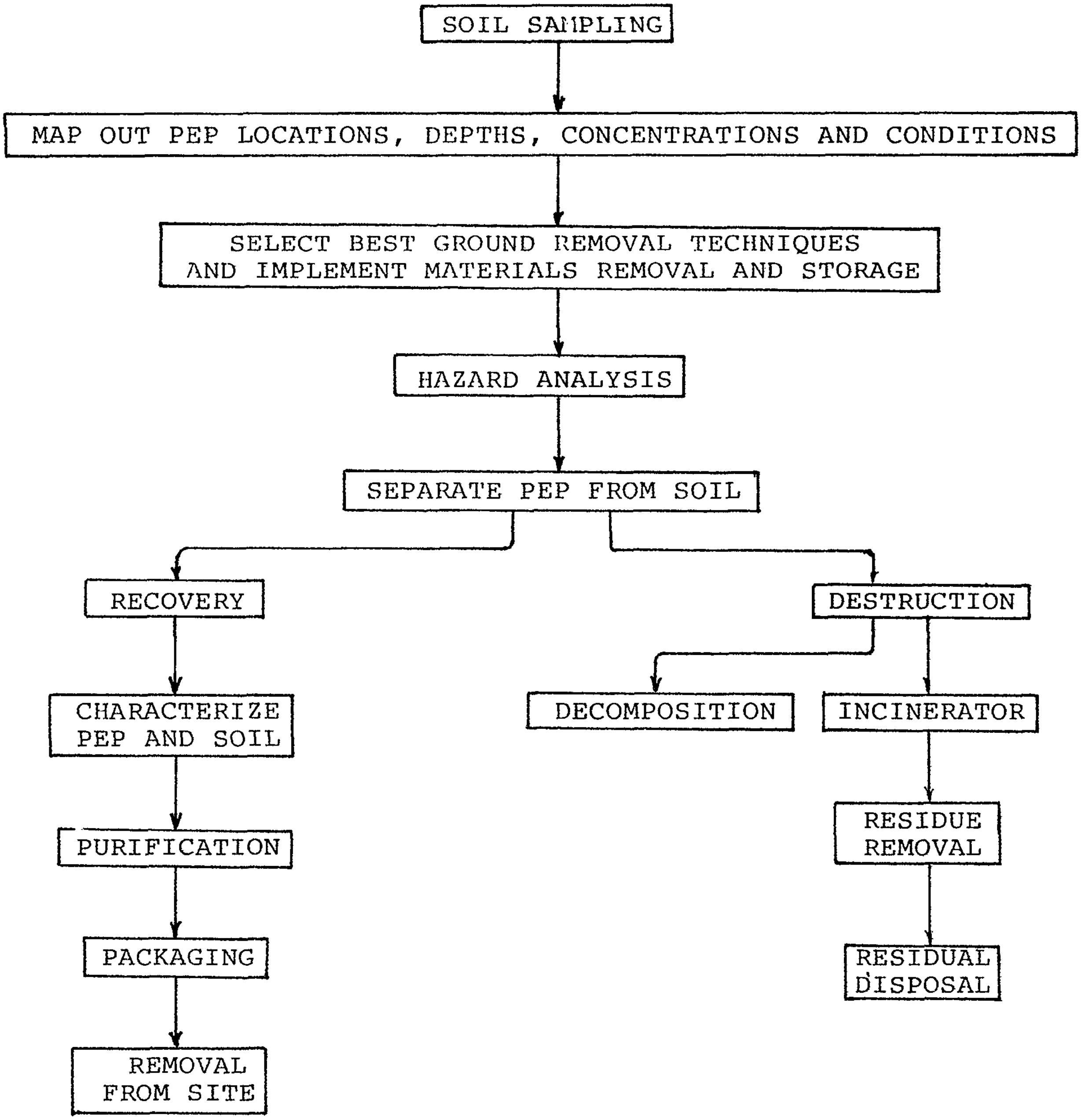

Figure 9. Implementation of plan.