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**ISSUES RELATED TO UNCERTAINTY IN PROJECTIONS
OF HAZARDOUS AND MIXED WASTE VOLUMES
IN THE U.S. DEPARTMENT OF ENERGY'S
ENVIRONMENTAL RESTORATION PROGRAM***

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ISSUES RELATED TO UNCERTAINTY IN PROJECTIONS OF HAZARDOUS
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ABSTRACT

Projected volumes of contaminated media and debris at U.S. Department of Energy (DOE) environmental restoration sites that are potentially subject to the hazardous waste provisions of the Resource Conservation and Recovery Act are needed to support programmatic planning. Such projections have been gathered in various surveys conducted under DOE's environmental restoration and waste management programs. It is expected that reducing uncertainty in the projections through review of existing site data and process knowledge and through further site characterization will result in substantially lowered projections. If promulgated, the U.S. Environmental Protection Agency's Hazardous Waste Identification Rule would result in potentially even greater reductions in the projections when site conditions are reviewed under the provisions of the new rule. Reducing uncertainty in projections under current and future waste identification rules may be necessary to support effective remediation planning. Further characterization efforts that may be conducted should be designed to limit uncertainty in identifying volumes of wastes to the extent needed to support alternative selection and to minimize costs of remediation.

INTRODUCTION

Identifying quantities of contaminated environmental media that are subject to hazardous waste regulations under the Resource Conservation and Recovery Act (RCRA) is an issue confronted at most hazardous waste sites being addressed under either RCRA corrective actions or under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). At U.S. Department of Energy (DOE) sites, the further presence of radioactive contaminants in such media adds the prospect that media may be considered both hazardous and radioactive waste, or mixed waste. The administration of the hazardous waste regulations for a given site, including DOE sites, is usually the province of the environmental protection agency of the state in which the site resides. Authority over radioactive wastes, on the other hand, has traditionally been the responsibility of federal agencies, principally DOE and the U.S. Nuclear Regulatory Commission (NRC). With the 1992 passage of the Federal Facility Compliance Act (FFCA) amending RCRA to bring federal facilities into compliance with applicable federal and state laws, the administration of mixed waste is conducted jointly under both federal and state authorities.

Identifying and quantifying hazardous and mixed wastes is an important activity within DOE's waste management (WM) program and within the environmental restoration (ER) program, in particular. Such activities have major implications regarding the cost of remedial activities and regarding waste management and waste treatment decisions within the program.

This paper discusses the general nature and sources of uncertainties in projections of volumes of environmental media and debris (i.e., contaminated equipment and structures) potentially requiring

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management as hazardous or mixed wastes within the ER program and suggests means for reducing them. Hazardous and mixed wastes have been singled out for evaluation because of the inherent difficulty in estimating quantities of such wastes in environmental media and debris, because of the large number of technologies available for the required treatment of such media, and because of the high costs associated with treatment and management. In addition to evaluating the nature, sources, and general level of uncertainty in the volume estimates, the nature of impacts of uncertainty on various waste management options are suggested. Lastly, recommendations are made as to what relative levels of uncertainty may be acceptable for supporting various action alternatives and how such levels may be attained through reevaluating current information and through conducting further characterization.

MANAGEMENT OPTIONS FOR HAZARDOUS AND MIXED WASTES

Application of Waste Regulations to Contaminated Environmental Media

Under RCRA, states with authority can classify contaminated environmental media as hazardous waste under two basic provisions of the rules (40 CFR 261): 1) the medium is a characteristic hazardous waste because it has failed a specific characteristic test; or 2) the medium is a hazardous waste under the mixture rule. The mixture rule provides that any product of the mixing of a listed hazardous waste with another solid waste is itself a hazardous waste (not to be confused with mixed waste, i.e., waste that is both hazardous and radioactive). Listed hazardous wastes are derived from specific industrial processes and activities and include many of the substances that often contaminate environmental media, including, for example, spent solvents. Consequently, under the mixture rule, regulations for listed wastes can, in certain circumstances, be extended to environmental media. Given these two provisions, states have had, and continue to have, broad authority to classify contaminated media as hazardous waste. Similarly, by extension, such authority also applies to the classification of media contaminated with mixed waste.

With respect to characteristic wastes, definitive classification requires testing of hazardous characteristics, principally the toxicity characteristic, which is tested using the toxicity characteristic leaching procedure (TCLP; 40 CFR 261, Appendix II). (The characteristics of ignitability, corrosivity, and reactivity can be ruled out for most environmental media and debris.) Preliminary or presumptive classification, on the other hand, can be done on the basis of general information (including process knowledge, spill logs, and material inventories) or even by applying standard assumptions regarding releases from vessels and the like. But definitively establishing that a particular medium is not a characteristic hazardous waste, once brought into question, requires specific characteristic testing.

To establish that a particular medium is hazardous waste under the mixture rule is a less definitive process. The mere presence of a listed hazardous waste constituent may cause a medium to be classified as hazardous (or mixed) waste. No *de minimis* levels exist under the mixture rule. Once a waste (medium) is classified as hazardous waste under this rule, it can only be declassified by petitioning the U.S. Environmental Protection Agency (EPA) to delist the waste, a time-consuming process. Changes to the hazardous waste identification rules are being considered that will offer relief from the mixture rule, as discussed in a later section of this paper.

Regulations under the mixture rule are not explicitly directed to environmental media, e.g., soils or groundwater, but are applied to such media to the extent they can be considered solid wastes. The mixture rule does, however, specifically address contaminated debris, under the so-called debris rule

(40 CFR 268.2[h]). Debris is a significant waste element in the ER program because many restoration projects involve the demolition of buildings and other structures. It is assumed that the mixture rule applies equally to debris and environmental media in the ER program.

In the identification of mixed waste, the above hazardous waste criteria, along with prevailing radioactive waste criteria, are applied independently. Mixed wastes are usually initially established to be radioactive wastes on the basis of NRC regulations and DOE Orders and later determined to be also hazardous wastes under RCRA.

With respect to radioactivity, much of contaminated media at ER sites falls into the category of low-level waste, which is defined as radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in Section 11e.(2) of the Atomic Energy Act (uranium or thorium tailings and waste) (10 CFR 61). Two other classes of radioactive wastes of importance at ER sites are 1) transuranic (TRU) wastes, defined as containing more than 100 nCi of alpha-emitting transuranic isotopes with half-lives greater than 20 years per gram of waste (DOE Order 5820.2A), and 2) 11e.(2) byproduct material (primarily uranium mill tailings), referring to the portion of metal-bearing ore remaining after extraction of uranium (DOE Order 5820.2A). As the identity of such wastes is already well established at most ER sites, details of the application of radioactive waste classification criteria will not be presented here.

Management and Treatment of Generated Waste

Contaminated environmental media are not technically wastes until "generated" through, for example, excavation — as in the case of soils. Once generated, that which is classified as either hazardous or mixed waste is subject to the treatment, storage, and disposal regulations under RCRA (40 CFR 262, 40 CFR 263, and 40 CFR 264). Such wastes that are being considered for disposal are subject to land disposal restrictions (LDR) under RCRA. The LDR rules (40 CFR 268) prohibit the disposal in or on land of wastes that exhibit toxicity or the potential to leach contaminants into groundwater above specific thresholds. Characteristic hazardous wastes are explicitly prohibited from such disposal unless treated to the point that they no longer exhibit the characteristic. Wastes with listed hazardous constituents are subject to treatment standards specific to the constituents or to treatment by a specified technology. Verifying that such treatment standards are met for either waste again requires that the waste be characterized. Often it can be established that wastes, including environmental media, identified through the mixture rule already meet treatment standards in the absence of any treatment.

Alternative Management Strategies

One avenue that has been opened to reduce the administrative burden of LDR rules is the institution under RCRA of the corrective action management unit (CAMU) concept. Under this concept, placing remediation wastes generated at a facility as part of a RCRA corrective action into or within a CAMU is not considered land disposal and such wastes therefore are not subject to LDR (40 CFR 264, Subpart S). Remediation wastes (media) may be excavated within a CAMU, treated in a second CAMU, and redeposited in the excavated area of the original CAMU without triggering LDR. Also, waste disposal units within a CAMU are not subject to minimum technological requirements under RCRA. The responsibility and authority for protecting health and the environment under this approach is assumed under the prevailing RCRA corrective action program. The use of CAMUs is expected to reduce delays in cleanup efforts.

A second development currently under way that addresses the issue of identification and management of hazardous waste is EPA rulemaking aimed at reform. The proposed Hazardous Waste Identification Rule (HWIR) (57 FR 21450, May 1992) addresses, among other things, wastes classified as hazardous under the mixture rule, and should benefit environmental restoration efforts. The proposed HWIR would establish an entry and exit system for prospective wastes. The rule would employ health-based, contaminant-specific concentration limits, termed "bright line" numbers, as criteria for entry or exit of the system. The limits could be used to identify hot spots in environmental media that would be subject to RCRA hazardous waste rules, while removing those requirements for media falling below the criteria. The latter media would still, however, be subject to site-specific cleanup standards.

The rule was proposed in 1993, then withdrawn after comments were reviewed. It is expected to be repropounded by September 1995. Large quantities of contaminated media at ER sites currently subject to RCRA regulations, including the mixture rule, could be affected by the new HWIR. Similarly, characterization efforts related to identifying hazardous and mixed wastes in environmental media would have to conform to the new rule, if promulgated, possibly requiring reevaluation of existing data and/or recharacterizing media in light of the "bright line" numbers.

NATURE AND SOURCES OF UNCERTAINTY IN ESTIMATES OF MEDIA VOLUMES SUBJECT TO RCRA

Several surveys of ER sites have been conducted within DOE's environmental management (EM) program, gathering information on estimates of contaminated environmental media and debris that are potentially subject to subject to hazardous waste regulations under RCRA. Surveys include the Contaminated Media/Waste Data Call, the estimates prepared to support the Programmatic Environmental Impact Statement (PEIS), and estimates gathered to support the Baseline Environmental Management Report (BEMR). The surveys relied on site characterization data and process knowledge available at ER sites. The current analysis does not examine any particular estimate but describes the nature and sources of uncertainty in estimates of this type in general. The volume estimates generated are assumed to be inherently conservative, both with respect to the volumes of media that might ultimately be removed for remediation, and thus generate solid waste under RCRA, and with respect to the volumes of solid waste that may ultimately be determined to be hazardous or mixed waste under RCRA. This conservatism arises in general from a desire on the part of waste managers to include all media that will have to be addressed in the future, whether or not it is technically hazardous or mixed waste, and as a result of the generally small amount of characterization data available with respect to current or future hazardous waste criteria.

Many surveys to estimate volumes of contaminated media are conservative by design, often forcing the assignment of suspect media into a particular waste class. Volume estimates, particularly of hazardous and mixed wastes, therefore may start from a conservative base. Moreover, the estimated volumes of contaminated media and debris are often just a first approximation based on limited data or on simple modeling. Such volume estimates are often done in a conservative manner so as to avoid misidentifying any contaminated areas.

With respect to identifying regions within contaminated media that may be potentially hazardous or mixed waste, authoritative data needed to make such identifications are often sparse and, where available, may not have been collected for the purpose of characterizing media according to hazardous waste criteria. Further data needed to define the boundaries of such regions are particularly lacking or may be completely absent. Often, simply the known or suspected presence of a characteristic or

listed hazardous constituent is all the information available as a basis for classifying media and developing volume estimates.

In cases where the mixture rule may apply, a particular medium can be classified as hazardous or mixed waste on the basis of very low levels of hazardous constituents. At many contaminated sites, the mere presence of a listed constituent has been used to preliminarily identify a medium as potentially subject to RCRA without regard to the origin of the constituent. However, if the source of the hazardous constituent was not a listed waste, such as spent solvents, for example, in the case of certain volatile organic constituents, then the medium is not subject to the stringent criteria of the mixture rule. Instead, the quantitative criteria for characteristic hazardous wastes apply. In that regard, data for determining the status of environmental media with respect to hazardous waste characteristic criteria using the TCLP are particularly limited at ER sites.

Because a final determination of the sources of hazardous constituents may not have been fully established at many ER sites, large quantities of contaminated media may be assumed to be subject to RCRA under the mixture rule that in fact are not. The low levels of hazardous constituents in much of this media indicate that the media may be identified as nonhazardous after hazardous characteristic testing using the TCLP.

Current estimates of waste volumes potentially subject to regulation as hazardous or mixed (hazardous and radioactive) waste under RCRA may therefore be considered to represent a reasonable upper bound on hazardous and mixed wastes that may be generated in the ER program. The level of uncertainty varies from site to site and from medium to medium according to the level of information available. The greatest volumes as well as the greatest relative uncertainties are probably associated with groundwater and soil.

The volumes of media that will ultimately have to be addressed in the program, however, are probably substantially less than these upper bound projections, even if changes in waste identification rules are not forthcoming. Efforts to refine the boundaries of contaminated areas will surely reduce volumes. Given the economic incentives, characterization efforts to support such refinements will be easily justified. Much greater reductions in volumes are possible, however, under scenarios that provide relief from the mixture rule, such as under the proposed HWIR described above. Some forms of rule changes are to be expected over the multiyear course of the ER program. With respect to some mixed waste, volume reductions would in fact reflect reclassification from mixed waste to the prevailing radiological waste class, although refinement of the volumetric extent of the radiological component through further characterization or monitoring during excavation is certainly also possible.

MANAGING UNCERTAINTY IN VOLUME ESTIMATES

Impacts of Declining Volume Estimates on Action Decisions

If existing volume estimates of hazardous and mixed wastes represent an upper bound, as asserted above, then reductions in uncertainty in these estimates will correspond to declining estimates of volumes. As volume estimates decrease, management decisions addressing the wastes may change.

There are three major factors influencing any scenario under which hazardous and mixed waste cleanup actions might proceed under the ER program: 1) the extent to which the current action plan under current RCRA waste rules is carried out, 2) the extent to which the CAMU concept can be applied to additional ER sites, and 3) and the extent to which proposed revised hazardous waste

identification rules affect the ER program. Declining volume estimates will have impacts on cost estimates and associated action decisions under the various possible scenarios.

Under any scenario, significant reductions in hazardous and mixed waste volumes from current estimates will impact the budgeting of remedial actions, the selection of action alternatives, and the selection of treatment technologies and process options. Table I presents the nature of impacts of declining volume estimates on these activities in terms of the three scenario factors. The impacts increase according to the degree that volume reductions are realized through improved characterization and to the extent that the CAMU concept and revised hazardous waste rules apply to a given scenario.

Insert TABLE I here

Preliminary selection of both the general alternative actions and specific treatment processes at various ER sites may be expected to change in the directions suggested in Table I as cleanups progress and requirements change.

Reducing Uncertainty in Volume Estimates

Refinements to volume estimates will be required on a continual basis as the ER program is carried out. For initial planning purposes, current volume estimates may have to be evaluated and revised before major planning decisions are made. That is, the uncertainty in current estimates may be too high to support a comprehensive action plan relative to an environmental medium that is potentially hazardous or mixed waste. In general, reducing uncertainty to support planning will require 1) reexamining existing data available at the sites with the expressed purpose of improving volume estimates and 2) conducting further characterization to improve estimates where existing data are insufficient. The extent to which these activities need to be carried out varies from site to site.

Several measures can be taken to reevaluate existing site data. First, if characterization data are available, those data should be evaluated for representativeness. The inferences drawn from the data can then be applied to the volume of medium represented by a given sample. Second, it is very important that in cases where RCRA characteristic hazardous waste criteria are being applied, rather than the mixture rule, this fact be firmly established and characterization data applied according to the applicable concentration criteria. In such cases, a particular medium can be classified on the basis of available TCLP data or, lacking that, to a great extent on the basis of direct analysis of the medium. In the latter case, a solid medium can be determined to be nonhazardous if contaminant concentrations in the medium do not exceed 20 times the TCLP criteria. (This criterion ensures that TCLP leachate could not possibly exceed the criteria.) For instance, if all soil samples representing a given volume of medium have no concentrations exceeding 20 times TCLP criteria, it may be inferred that none of that volume is hazardous or mixed waste. In cases where wastes are identified on the basis of the mixture rule, improvements in estimates may be accomplished through careful review of sample locations.

Beyond these steps, where data are sparse, the application of process knowledge may improve volume estimates. Such knowledge might include spill logs, area use patterns, chemical inventories, or a mass balance analysis. In some cases, site-specific contaminant transport modeling, in which existing data and process knowledge are applied, may be appropriate to refine volume estimates of contaminated media.

In cases where additional characterization is required, either to support planning or implementing an action, a focused and efficient sampling and analysis plan should be developed with well conceived data quality objectives. In such development, the sampling problem and action decisions should be well defined and measurement uncertainty goals set accordingly. The first step in this process is to identify the leading action alternative for the affected media. Next, consideration of costs per volume of media and total volumes of media affected should be used to indicate the levels of uncertainty in volume estimates that may be acceptable and thus the level of characterization required. Table II presents a qualitative ranking of uncertainty as driven by overall costs that might be acceptable under various action alternatives for a given volume of waste.

Insert TABLE II here

The general observations shown in Table II would further be a function of the total volumes of waste ultimately identified. For example, percentage uncertainties in media volumes acceptable at a 1,000 m³ level may be unacceptable at a 100,000 m³ level. An additional factor to be considered relative to uncertainty in volume estimates of mixed waste is whether further characterization will result in reducing volumes of the media that are either potentially hazardous or radioactive, or both.

Another factor that will affect characterization requirements is the extent to which new hazardous waste identification rules are adopted in the future. Given concentration-based criteria, increased levels of characterization will be required to define areas of media above and below the criteria. The levels of uncertainty attained in these efforts will depend on a balance of the costs of characterization versus those of treatment and/or disposal of excess media.

SUMMARY AND CONCLUSIONS

Contaminated environmental media at DOE ER sites are subject to the provisions of RCRA and may be classified as hazardous or mixed waste on the basis of characteristic testing or the mixture rule. Estimated volumes of such media that are potentially hazardous or mixed waste are large and are assumed to be conservative because 1) surveys are generally based on first-order approximations of the boundaries of contaminated regions, 2) current levels of characterization do not support identification of subregions, or hot spots, of media exceeding RCRA criteria, and 3) some media may be classified as hazardous waste on the basis of a misapplication of the mixture rule. It is expected that improving media characterization and reviewing RCRA criteria will result in declining volume estimates. Reduced waste volumes, in turn, will have impacts on cost estimates and on the selection of remedial action alternatives. Improved volume estimates, therefore, may be necessary to support remedial action planning. Such improvements may be effected through review of existing characterization data and process knowledge, or through further characterization of contaminated media. The levels of uncertainty acceptable in further characterization efforts will depend on the nature of the contamination, the volume of contaminated media involved, the type of remedial alternative selected, and the overall costs of the remedial actions.

TABLE I
Impacts of Declining Waste Volume Estimates and Associated Characterization Requirements

Planning Activity or Characterization Requirement	Impacts and Characterization Requirements Relative to the Three Major Scenario Factors		
	Current Conditions with Volume Refinement	Additional CAMUs	Adoption of Revised Waste Identification Rules
Planning Activity			
Costs/Budgeting	Cost reductions proportional to volume reductions; increases in characterization costs	Cost savings from reductions in paper work and other delays	Treatment and/or disposal costs greatly reduced with corresponding volume reductions
Alternative selection	Toward lower volume facilities	Consistent with on-site treatment and/or disposal	Toward significantly lower volume facilities
Technology selection	Toward lower volume technologies with lower capital costs	Technologies to be available on site	Toward much lower volume technologies with lower capital costs
Characterization Requirement	To refine volumes of contaminated media under current waste identification rules	To support waste identification under prevailing rules	To identify contaminated hot spots in excess of "bright line" values

TABLE II
Relative Acceptable Uncertainty in Waste Characterization

Action Alternative	Relative Costs per Volume of Affected Medium	Ranking of Acceptable Uncertainty in Waste Characterization (1 = lowest)
Collect and treat off-site	Moderate to very high	1
Collect and treat on-site	Moderate to high	2
Collect and dispose of off-site (meets LDR)	Low to moderate	3
Collect and dispose of on-site (meets LDR or employs CAMU)	Low	4