Summary of Comparative Results
Integrated Nonthermal Treatment
and
Integrated Thermal Treatment
Systems Studies

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EXECUTIVE SUMMARY

During the first quarter of FY 1996, the U.S. Department of Energy's (DOE) Office of Science and Technology (OST) commissioned an Integrated Nonthermal Treatment Systems Study (INTS). The INTS study was initiated as the result of recommendations that came from a DOE Peer Review Panel that looked at the previous Integrated Thermal Treatment Systems (ITTS) study, and as a direct response to recommendations from the Mixed Waste Working Group (MWWG) of the Federal Committee to Develop Onsite Innovative Technologies (DOIT). This document summarizes the INTS and the process used by DOE to conduct the study. It also contains major findings of a July 15, 1996 draft INTS/ITTS Comparison Report.

The INTS study began with the development of a set of functional requirements restricted to operating temperatures less than 350° C for systems to separate, decontaminate, oxidize, immobilize, and dispose the various physical matrices and contaminants associated with DOE Mixed Low Level Waste (MLLW). The major difference between methodologies of the INTS and ITTS studies was the participation of a Tribal and Stakeholders Working Group (TSWG) in the INTS study. The TSWG was made up of tribal and stakeholder representatives from tribal, state, and local governments; universities; regulatory agencies; public and environmental interest groups; and business and industry. The TSWG provided the opportunity for technical and non-technical stakeholders to work together in the early, pre-decision stages of criteria development, assessment, and selection activities related to the study. The TSWG worked with the technical staff to produce a set of "principles" which expanded, and in great part complemented, the set of technical criteria used to evaluate and select five integrated nonthermal treatment systems. The tribal and stakeholder "principles" were consistent with good engineering practice and environmental stewardship.

In the summer of 1996, the DOE organized a peer review group, the Independent Peer Review Panel, to study the documents prepared in these systems studies and to make recommendations to the DOE Mixed Waste Focus Area and the Office of Science and Technology on their findings. Among other things the Panel found: 1) DOE should continue assessing the scientific and engineering advances in both thermal and nonthermal treatment technologies; 2) there are potential critical flaws with nonthermal technologies due to their inability to remove enough organic material to ensure that nonthermal physical or chemical stabilization will adequately provide long term safe disposal, particularly in grout; 3) there is a potential advantage in using nonthermal technologies which can batch process waste material in a closed loop configuration until a predetermined level of destruction is achieved; 4) high temperature thermal vitrification should be incorporated into INTS to achieve more effective stabilization, and further recommended that vitrification be the preferred stabilization technology for

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both INTS and ITTS; and 5) a modified version of grout debris (nonthermal System NT-1) and the acid digestion (System NT-4) should be considered for further development effort.

The ITTS study had compared the cost and performance of 20 thermal treatment systems, conceptually designed to treat a representative heterogeneous mixture of DOE MLLW from their entrance to the treatment facility until final disposal. The costs were spread over 20 years for a DOE-owned, contractor-run system operating at 40 weeks/year, 7 days/week, and 24 hours/day at 60 percent availability, treating 2,729 lbs/hour. These ITTS assumptions were duplicated as the basis for the INTS.

All of the nonthermal technologies studied in the five systems were either at bench scale or limited pilot scale except ultraviolet (UV) oxidation of organic contaminants in an aqueous waste stream. The low volume of offgas was found to be the most positive aspect of the nonthermal systems' estimated performance. However, the concentration of toxic contaminants in the offgas or wastewater can only be approximated without further system tests at pilot scale on real, complex wastes. Concept designs of the air pollution control subsystem was selected to decrease contaminants in the offgas to below current standards.

Analyses show that total life cycle costs (TLCC) to treat an identical amount of representative MLLW by the nonthermal systems are roughly 40 to 60 percent higher than the thermal systems (roughly \$3.5 billion as compared to \$2.5 billion over 20 years). This is due to greater operation and maintenance (O&M) costs and the larger final waste volumes produced with nonthermal stabilization processes resulting in increased disposal costs. Unit treatment costs range from around \$8/lb for most ITTS systems to more than \$14/lb for catalyzed wet oxidation and acid digestion INTS systems. The thermal system unit cost may be reduced further by approximately a dollar per pound because, unlike nonthermal systems, thermal systems can use contaminated soil for formulation of the "vitrified" or glass ceramic final waste form. Treatment of soil through nonthermal systems was not considered advisable. Energy costs for INTS and ITTS systems were less than one percent of treatment costs. However, nonthermal system energy costs, on average, were approximately one-tenth or less than average thermal system energy costs.

The percentage of TLCC for various subsystems in the nonthermal systems was as follows: (1) approximately 25 percent of the total for characterization and preparation; (2) approximately 20 percent for disposal costs; (3) approximately 12 percent for certification and shipping costs; and (4) about 12 percent for stabilization costs. Air pollution control costs were only about 2 percent of the TLCC for nonthermal systems, approximately one-half that for thermal systems, because of the much lower offgas

volumes from nonthermal systems. O&M costs were roughly 50 to 60 percent of TLCC in both studies.

Final INTS system waste form volumes sent to disposal were approximately 80 to 100 percent of incoming waste volume, whereas the final ITTS system waste form volumes were approximately 20 to 30 percent of incoming waste volumes, with the exception of the rotary kiln options, in which the final waste form was grout. Thus, the volume of solid wastes produced by the nonthermal systems was roughly three times the volume produced by thermal systems. One way to improve the final waste form volume performance of the nonthermal systems would be to create a hybrid system that combines a nonthermal primary organic destruction subsystem with vitrification, a subject of future studies.

The conclusions reached in the INTS were 1) it may be technically feasible to develop and implement an effective treatment system utilizing nonthermal technology units that can operate at 350° C or less, 2) a nonthermal concept would probably entail high developmental and operating costs, high waste disposal volumes, high schedule risks, and uncertain compliance with regulatory requirements (This is understandable given the small amount of development work done for nonthermal technologies in contrast with thermal technologies to date.); and 3) the nonthermal technologies applicable to DOE MLLW have limited performance data available. This INTS report lays out the areas where development needs to be pursued to gain more knowledge and, in turn, more confidence, in the performance of nonthermal technologies when applied to DOE MLLW. For example, destruction efficiency (DE) and process throughput under real waste stream conditions where multiple contaminants are present in very complex mixtures need to be known.

Tribal and Stakeholder review of the INTS indicated a preference to continue the development of non-thermal systems rather than thermal systems even though the thermal systems treat waste effectively at high temperatures and produce vitreous or glass-ceramic final waste forms for disposal. Although high temperature processing effectively destroys organic materials and places the residuals in a stable immobilized form, the greatest stakeholder concern was associated with assurance that air quality and water quality were not threatened by waste treatment operations. This concern exists for either thermal or non-thermal systems.

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This report is not intended as a comparative information report and is not intended to reflect or reestablish policy or consistency with planning documents.

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The study was directed by Carl Cooley, EM-50, assisted by Floyd DesChamps, EM-53, and Emile Bernard, SNL.

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An internal review panel (comprised of DOE headquarters and field personnel, EPA regulators, and related contractors) reviewed the ITTS in 1994, and in 1996 both an Independent Peer Review Panel and a DOE users panel review and made findings on the ITTS and INTS studies.

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
Ag	silver
APC	Air pollution control
BDAT	best demonstrated available technology
°C	degrees Celsius (or Centigrade)
CAB	citizens advisory board
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Register
CO	carbon monoxide
CO ₂	carbon dioxide
COG	council of governments
CWO	catalytic wet oxidation
D&D	Decontamination and Decommissioning
DE	destruction efficiency (for nonthermal systems)
DETOX	Catalytical Chemical Oxidation(Delphi Process)
DOE	U.S. Department of Energy
DOIT	demonstration of innovative technologies
DRE	destruction removal efficiency (for thermal systems)
EH	Office of Environment, Safety and Health (DOE)
EM	Office of Environmental Management (DOE)
EPA	U. S. Environmental Protection Agency
°F	degrees Fahrenheit
Fe	iron
FFCA	Federal Facilities Compliance Act
g	gram or gallon
GAC	granulated activated carbon
GPCR	gas phased corona reactor
gpm	gallons per minute
H	hydrogen
HCl	hydrochloric acid
ID	DOE's Idaho Operations Office
INEL	Idaho National Engineering Laboratory
INTS	Integrated Nonthermal Treatment Systems Study
ITTS	Integrated Thermal Treatment Study
kg	kilogram
l	liter
LDF	legal defense fund
LANL	Los Alamos National Laboratory

LMITCO	Lockheed Martin Idaho Technology Company
LLW	low-level waste
m	meter or micro
MEO	Mediated Electrochemical Oxidation
mg	milligram
MK	Morrison Knudsen Environmental Services, Inc.
MLLW	mixed low-level waste
MWFA	Mixed Waste Focus Area
MWIR	Mixed Waste Inventory Report
NA	not applicable
NaCl	sodium chloride
NM	New Mexico
O&M	Operation and Maintenance
OR	DOE Operations Office in Oak Ridge
ORNL	Oak Ridge National Laboratory
OST	Office of Science and Technology (DOE)
PICs	products of incomplete combustion
psia	pounds pressure per square inch absolute
psig	pounds pressure per square inch gauge
RAB	restoration advisory board
R&D	research and development
RCRA	Resource Conservation & Recovery Act of 1976
RDDT&E	Research, Development, Demonstration, Testing and Evaluation
SNL	Sandia National Laboratory
SRS	DOE's Savannah River Site
TCLP	Toxicity Characteristic Leaching Procedure
TLCC	Total Life Cycle Cost
TRU	transuranic
TS	toxic substances
TSCs	Technical Support Contributors
TSG	technical support group
TSWG	tribal and stakeholders working group
UTS	universal treatment standards
UV	ultraviolet
VOCs	volatile organic compounds
WGA	Western Governors Association
WPI	Waste Policy Institute

1.0 INTRODUCTION

1.1 Background

In July 1994, the Idaho National Engineering Laboratory (INEL), under a contract from U.S. Department of Energy's (DOE) Environment Management Office of Science and Technology (OST, EM-50) published a report entitled "Integrated Thermal Treatment System Study - Phase 1 Results" (EGG-MS-11211). This report was the culmination of over a year of analysis involving scientists and engineers within the DOE complex and from private industry. The purpose of that study was "to conduct a systematic engineering evaluation of a variety of mixed low level waste (MLLW) treatment system alternatives." The study also "identified the research and development, demonstrations, and testing and evaluation needed to assure unit operability in the most promising alternative system." This study evaluated ten primary thermal treatment technologies, organized into complete "cradle-to-grave" systems (including complete engineering flow sheets), to treat DOE MLLW and calculated mass balances and 20-year total life cycle costs (TLCC) for all systems. The waste input used was a representative heterogeneous mixture of typical DOE MLLW.

The INEL published an "Integrated Thermal Treatment System (ITTS) Study - Phase 2 Results (INEL-95/0129) in August 1995 (Note: Report was Revised in February 1996). This study conducted similar evaluations for an additional nine primary thermal treatment technologies, including advanced technologies presently being considered for research funding by OST. INEL's Phase 1 and Phase 2 reports were the subject of a November 1994 internal DOE peer review panel review (DOE/EM-0268, April 1995). This panel found that the systems analyses were extremely useful in helping DOE headquarters program managers and field personnel evaluate costs and performances for candidate treatment systems. While two nonthermal technologies were included in the Phase 2 study the panel "strongly" recommended:

... inclusion of other nonthermal organic destruction and thermal technologies not yet studied in order to put EM in the position of having carefully considered an appropriate range of treatment technologies on a comparable basis. *Additional nonthermal studies would be helpful for stakeholder considerations and could form the basis for later selection of specific technologies.* (Italics added) "Integrated Thermal Treatment Systems Study," (DOE/EM-0268), April 1995

Moreover, in its 1994 Annual Report, the Mixed Waste Working Group of the Western Governors Association gave the following advice:

D. STAKEHOLDER CONCERNS ABOUT THERMAL TECHNOLOGIES NEED TO BE ADDRESSED.

Thermal technologies, important treatment options for mixed waste, are controversial among many tribal representatives, public interest groups, and other stakeholders. The concerns about DOE's consideration of "thermal" technologies, including alternatives, should be addressed. A diverse group of stakeholders should be involved in a study of available and/or developing thermal and nonthermal technologies, including closed-loop systems, that address mixed waste treatment, reduction, remediation and disposal. A workshop should be convened to provide education and a forum for the productive discussion of barriers to thermal technologies posed by regulatory issues, laws, and standards and related stakeholder concerns. A forum would provide an opportunity for stakeholders to express concerns and clarify issues related to thermal versus nonthermal technologies. Data needs, technology modifications and other issues could be identified to address tribal and stakeholder concerns to enhance the potential for deployment of such technologies ("Mixed Waste Working Group of the Western Governors Association 1994 Annual Report," p. 26).

Compilation of a summary of nonthermal technologies was the first step in responding to the working group's recommendation. A DOE report, "Overview of Nonthermal Mixed Waste Treatment Technologies" (DOE/EM-0281), summarized more than 250 nonthermal treatment technologies, including technologies for destruction, separation, stabilization, and decontamination. The report also listed available air pollution control technologies described in other OST-sponsored work. The next step was to organize a group of technical experts within the DOE complex to screen technologies for duplication and to recommend technologies that should be included in a series of draft flowsheets based on draft selection criteria, such as the Federal Facilities Compliance Act. This technical group, called the Technical Support Group (TSG), included representatives from the DOE and EPA and two technically-trained members of public and environmental interest groups. To ensure sensitivity to public concerns and needs, DOE hired a stakeholder expert, Ginger Swartz of Swartz and Associates, to attend meetings of the TSG and advise on stakeholder-related issues.

The TSG draft selection criteria and technology recommendations were then reviewed by a diverse tribal and stakeholder working group (the Tribal and Stakeholders Working Group [TSWG]). In May 1995, DOE invited the entire membership of the Community Leaders Network, tribal members active in U.S. DOE-related issues, and the Mixed Waste Working Group of the Western Governors Association's DOIT Committee to participate in the study. About 50 expressions of interest were received, and a representative (in terms of geography, organization, and sphere of influence) group of 20 stakeholder and tribal representatives was selected. The TSWG provided recommendations on stakeholder issues.

Morrison Knudsen Environmental Services, Inc. (MK), a firm used by the private and public sectors to do engineering analysis, design, and costing work, performed a full-spectrum technical analysis. MK included essentially the same assumptions on the formulated nonthermal treatment systems as it had done on the thermal systems in the ITTS study. MK also used a twentieth thermal system as a comparative baseline of existing off-the-shelf technologies, using an air-fired rotary kiln and grout stabilization of the solid residues. Finally, Bill Schwinkendorf of LMITCo produced a summary report comparing the major technical findings of both ITTS and INTS studies in a July 15, 1996 draft INTS/ITTS comparison report.

Both the Technical Support Group and the Tribal and Stakeholders Working Group reviewed MK's work and made recommendations. An independent peer review panel and a DOE Users Panel, comprised of waste type managers from the major DOE sites, have reviewed the INTS and the INTS/ITTS comparison study concurrently with a joint meeting of the TSWG and TSG in August 1996. Although the ITTS and INTS reports cover comparative total life cycle costs and safety and health, public and worker risk needs to receives consideration as a separate subject when technology selections are made for implementation.

DOE held meetings for the TSWG in August 1995 in Denver; in January 1996 in Phoenix; and jointly with the TSG in August 1996 in Idaho. The TSWG gave the INTS technical staff information and guidance regarding "principles" (see Section 2.2) which summarize their priority concerns about treatment technologies. A last meeting of the TSWG was held in November 1996 in Maryland at which time the group finished amending its principles document and shared its views on the five nonthermal systems and the INTS process. This intimate public involvement in evaluating and commenting on complex systems was an experiment for DOE. Separately, a lessons learned paper is being produced to point out to DOE decision makers, technical staff, and the stakeholders the pros and cons of early public involvement in the technology development process. The principles document, the lessons learned paper, an INTS stakeholders process paper, the TSWG views on the five nonthermal treatment systems, a paper prepared by a Native American consultant to DOE, and minority views of stakeholders will be combined into one document to be published by INEL.

1.2 Technical Approach

1.2.1 Integrated Thermal Treatment Systems Study

DOE published Phase 1 of the ITTS study in July 1994 ("Integrated Thermal Treatment System Study - Phase 1 Results", EGG-MS-11211, Volumes I and II). Phase 2 (INEL-95/0129) was published in August 1995 and reissued in February 1996 as Revision 1. Phase 1 covered ten systems; the second phase studied nine. A twentieth system was added to the Phase 2 study in February 1996 (INEL-95/0129, Revision 1). The twentieth system included an "available technology" baseline system consisting of an air-fired rotary kiln with grout for the stabilization of the final waste form. The systems included all facilities, equipment, and methods needed for treating and disposing of existing, stored DOE MLLW (waste receiving, characterization, sizing, thermal destruction of organic wastes, air pollution control, aqueous waste treatment, metal melting and decontamination, and secondary waste residue processing for final disposal).

Phase 1 of the ITTS focused on proven, cost-effective treatment systems that reduce the short- and long-term adverse impacts on workers and public health, environment, and safety. Phase 2 concentrated on innovative, less proven thermal systems.

Phase 1 initially considered twelve treatment systems that included various combinations of the incinerator, air pollution control, and waste stabilization subsystems. Incineration subsystems considered were the rotary kiln, plasma arc furnace, and fixed hearth furnace. Air pollution control (APC) subsystem designs included both wet and dry technologies. The baseline APC system was designed to assure performance so as to exceed current EPA regulations for emission control.

Waste stabilization subsystems considered were concrete, polymer, and glass- or vitrified soil-based waste forms. Hazardous wastes were stabilized to afford not only compliance with Federal law but also to assure long-term isolation of hazardous materials. Mercury, a specialty waste, was amalgamated, and metals (including bulk lead) were removed and recycled after treatment. Many additional options could have been considered; however, due to time and resource constraints a group of DOE science and engineering experts pared down the number of options to ten. The experts preserved options to evaluate different parameters such as incinerator types, oxygen versus air for the combustion gas, carbon dioxide retention, and wet versus dry/wet air pollution control configurations.

Functional and operational requirements, flow sheets, mass balances, and conceptual equipment layouts were developed for each system as part of the *design process*. Mass

balances accounted for all materials treated or used in the processes. All secondary residues were processed according to regulatory requirements. Final waste volumes were estimated for transportation and disposal. Disposal cost estimates were applied to the disposal volume of each system as part of the total costs.

Phase II repeated the same set of analyses described above for an additional set of nine technologies, primarily comprised of more innovative primary treatments such as molten salt oxidation and molten metal technology.

1.2.2 Integrated Nonthermal Treatment Systems Study

1.2.2.1 Problem

Existing and future MLLW generated from remediation and waste treatment operations at DOE require treatment and stabilization by a technically, economically, socially acceptable (from a risk reduction and regulatory standpoint) method before disposal. While thermal technologies have either proven effective or shown promise in treating MLLW, public concern exists over the possible environmental impacts of such thermal systems. Accordingly, DOE needs to compare performance and costs of nonthermal systems on the same waste streams examined in the ITTS study.

1.2.2.2 Mission Statement

The INTS study sought and evaluated nonthermal systems that could process stored MLLW. Hazardous chemical content, radioactive content, and reusable or disposable content must be converted into forms suitable for release to the environment, for reuse, or for disposal in sites typical of those required for commercial hazardous and nuclear waste.

1.2.2.3 Objectives

- Identify known candidate technologies and provide brief descriptions
- Screen the technologies against criteria (e.g., technical, tribal and stakeholder, and Federal Facilities Compliance Act) and document the rationale for application of the technology
- Select and incorporate nonthermal technologies into a conceptual treatment system design and evaluate mass balances, disposal volumes, and costs

- Conceptually, explore specific "attractive" applications where alternative system design could reduce costs and risks
- Identify research and development requirements for the most promising nonthermal systems' technologies

1.2.2.4 Product

The INTS study developed conceptual nonthermal treatment systems designs. The study compared their cost and performance. The study also identified R&D necessary to further the development of the technologies comprising the nonthermal systems to reduce the uncertainty regarding performance and cost estimates.

1.2.2.5 Basis

To maintain comparability between and among nonthermal systems (as well as the primary thermal treatment systems), each system processed the same input waste. Each subsystem processed the portion of the waste for which it was designed at or below 350° C (generally considered in the temperature range at which dioxins and furans are formed during cool down of the offgas containing precursors) and at a total system throughput identical with ITTS (2,927 lbs/hour). INTS total life cycle costs were spread over 20 years at a single facility, DOE-owned and contractor-operated. At this capacity, about 72 percent of the existing inventory would be processed in the 20 year assumed period of operation. Costs included technology development, construction, operation and maintenance, decontamination and decommissioning (of the processing and treatment facility), and disposal of the final waste form.

1.2.2.6 Structure

Technical support contributors (TSCs), sometimes referred to as the INTS technical staff, included scientists and engineers from Idaho National Engineering Laboratory, Waste Policy Institute, BDM Federal, Inc., and Morrison Knudsen (MK) Environmental Services, Inc. Their duties included:

- Preparing proposed bases, draft criteria, technology summaries, and cost estimates.
- Preparing analyses and reports based on recommendations and guidance.
- Evaluating functional flowsheets, organized technologies by function, and screening and recommending technologies and systems of technologies that

should be included in the INTS study. The rationale for selecting or rejecting a technology or system for further analysis was documented.

- Developing evaluation strategies for analysis of the systems in the INTS study that allowed comparison with thermal treatment systems. Systems were compared on effluents, cost, facility size (land use), and resource use.
- Reviewing and commenting on the draft iterations of the INTS report.
- For technologies targeted for further development by the TSG and TSWG, recommended the most likely applications and the associated development work.
- Identified the wastes and percentages of DOE wastes that can be treated by the nonthermal technologies selected for further consideration.
- Served as the technical resource for the independent "peer review."

Technical Support Group (TSG) consisted of headquarters and field representative from DOE EM-30, 40, 50, and 60; the EPA; and technical stakeholder representatives. The TSG:

- Developed and used recommended screening criteria and methodology for technologies and systems of technologies.
- Developed guidelines by which systems of technologies could be evaluated. Guidelines included costs, performances, risks, and maturity.
- Served as the technical resource for meetings with stakeholders.
- Helped resolve stakeholder concerns and issues addressed in the INTS study.
- Developed technical positions on the systems of technologies for tribal and stakeholder consideration.
- Reviewed and commented on the draft iterations of the INTS report.

Tribal and Stakeholder Working Group (TSWG) members represented business, tribes and tribal groups, academia, environmental and public interest groups (both local and national), private citizens, regional bodies, state governments (including both program and regulatory communities).

- Reviewed TSG recommendations on criteria, technologies, and systems and raised concerns and issues to be answered by the study. Reviewed and commented to the TSG and the TSC on technically-recommended systems of technologies to be included in the INTS study.
- From the outset, two technically trained stakeholders participated in the TSG. In response to recommendations from the TSWG, a technically trained Native American Indian consultant was added to the study.

INTS Independent Peer Review Panel

- Reviewed recommendations of TSG, TSWG, and the INTS draft document prepared by the TSCs.
- Recommended significant findings and development work needed to support favored system or systems and the component technologies to OST and the Mixed Waste Focus Area (MWFA).

1.3 Study Organization

The INTS leader was Carl R. Cooley, Senior Technical Advisor to Dr. Clyde W. Frank, Deputy Assistant Secretary for the Office of Science and Technology, EM-50. He was assisted by Floyd DesChamps, EM-53. Throughout the entire study Mr. Cooley was supported by Gary D. Knight, Waste Policy Institute, who organized meetings and logistics, accumulated technical documentation, drafted briefings, wrote progress reports and meeting minutes, and served as the overall study executive secretariat.

William J. Quapp, INEL, directed the conduct of the technical part of the entire thermal, nonthermal, and comparison portions of the study. Mr. Quapp managed a team of INEL colleagues and contractors to ensure that the study's program plan was successfully accomplished on-time and on-budget.

Contractors' contributions included the work of Bill Schwinkendorf, LMITCO, (formerly with BDM Federal), who has studied nonthermal technologies for years, and Morrison Knudsen (MK) Environmental Services, which took the systems crafted by the study participants and performed basic design work, equipment sizing, and cost calculations.

Blaine Brown, INEL, provided mass balances using the ASPEN PLUS computer model. Ginger Swartz, a consultant to the study team, ensured sensitivity to tribal and

stakeholder needs throughout the process and once the TSWG was formed served as liaison to them.

The Tribal and Stakeholders Working Group (TSWG) provided invaluable insight and a broader perspective of the MLLW problem. For example, the tribal and stakeholders working group concluded that the five nonthermal systems should be evaluated without using vitrification (a thermal technology) of the final waste form even though the initial focus was to use nonthermal technologies in lieu of thermal technologies as the *primary* treatment subsystem. The tribal and stakeholder's recommendation was adopted.

The Technical Support Group (TSG) included: Leon Borduin, LANL; Jim Cummings, U.S. EPA; Terry Dyches, DOE-SRS; Dave Eaton, LMITCO; Dave Hutchins, DOE-OR; Don Musgrave, BCM Inc.; Steve Priebe (representing the Mixed Waste Focus Area), LMITCO; Jack Watson, ORNL; Carl Cooley, DOE/EM-50; Floyd DesChamps, DOE/EM-53; Michael Torbert, DOE/EM-34; and Paul Strider, DOE/EM-44.

1.4 Regulatory Drivers

The Code of Federal Regulations (40 CFR 61) provides a summary perspective on regulatory standards for volatile metals, dioxins and furans, and products of incomplete combustion (PICs). Guidance provides an order of magnitude "level of destruction" (a percentage reduction of any hazardous constituent) which nonthermal technologies must meet. This figure would allow direct comparison of vendor claims for nonthermal technologies with applicable regulatory standards.

The process and final form chemistry of the particular technology being considered, and the starting chemistry and physical matrix of the DOE wastes, determine the partitioning of hazardous constituents among air emissions and waste waters. Only the wastewater standards directly refer to the concentration of constituents in the final waste. Other standards are given as to quantities of constituents released to the air or in leachate.

Even for waste waters, developing a "level of destruction" goal requires knowledge of waste inputs to the system in greater detail than any information published concerning the ITTS. Table 2.2 in Quantities and Characteristics of the Contact-Handled Low-Level Mixed Waste Streams for the DOE Complex [EGG-MS-11303] (the ITTS "Waste Study"), the most detailed ITTS-related material identified, is still not adequate for such a purpose. The ability of any of these technologies to comply with standards may also remain doubtful until they perform actual tests.

The following paragraphs and tables describe the applicable standards themselves:

(1) Metals: Wastewater and Non-wastewater

Because of a recent court decision, an internal inconsistency exists in the regulatory standards for hazardous metals. Metals in wastes that are declared hazardous because of the toxicity of the metals (certain "D" listed wastes) must be treated by one standard. However, metals in wastes that are hazardous for an entirely unrelated characteristic must comply with "universal treatment standards" (UTS). The Environmental Protection Agency intends to resolve this inconsistency as part of the Phase IV Land Disposal Restriction Rulemaking, which at this writing has not been completed. The INTS was conducted under the assumption that the UTS will be made applicable to all metal wastes.

If the UTS's are made applicable, money expended to develop technologies that could not meet them would be wasted. The control of semivolatile metals in high temperature processes metal's recovery already forms the basis of the UTS, so there is reason to believe that this standard would be applicable to many DOE wastes. In the remaining cases, any successful technology that could meet the UTS would eventually become the "best demonstrated available technology" (BDAT). Finally, in the unlikely event that the EPA maintains less stringent D-waste standards after 1996, development of technologies that could meet D-waste standards could always be resumed.

Certain treatments are required for specific D-waste categories. Radioactive lead solids must be macro encapsulated. Organics with high mercury content (>260 mg/kg total mercury) and inorganics with high mercury content must be incinerated and passed through mercury recovery before treatment according to UTS requirements.

The UTS standards for metals are provided in Table 1. Note that the standards for non-waste waters are given in terms of the toxicity characteristic leaching procedure and therefore are process- and final-form-chemistry dependent.

TABLE 1. UNIVERSAL TREATMENT STANDARDS FOR METAL/INORGANIC CONSTITUENTS

Regulated Hazardous Constituent	Regulatory Level TCLP (mg/l)	Wastewater, total composition (mg/l) ¹	Nonwastewater, TCLP (mg/l) ²
Antimony	NA	1.9	2.1
Arsenic	5.0	1.4	5.0
Barium	100.0	1.2	7.6
Beryllium	NA	0.82	0.014
Cadmium	1.0	0.69	0.19
Chromium (total)	5.0	2.77	0.86
Cyanide (total)	NA	1.2	590 mg/kg ³
Cyanide (amenable)	NA	0.86	30 mg/kg ³
Fluoride	NA	35	NA ⁴
Lead	5.0	0.69	0.37
Mercury (retort residues) ^{5,6}	0.2	NA ⁴	0.20
Mercury (all others) ⁶	0.2	0.15	0.025
Nickel	NA	3.98	5.0
Selenium	1.0	0.82	0.16
Silver	5.0	0.43	0.30
Sulfide	NA	14	NA ⁴
Thallium	NA	1.4	0.078
Vanadium	NA	4.3	0.23
Zinc ^{5,7}	NA	2.61	5.3

Source: *Hazardous Waste Consultant* Volume 12, Issue 6 (November-December, 1994), Table 4.3

NA = not applicable; TCLP = toxicity characteristic leaching procedure.

¹Concentration standards based on composite samples.

²Concentration standards based on grab samples.

³Total concentration standards as analyzed using SW-846 Method 9010 or 9012 instead of TCLP.

⁴Treatment standards not yet determined for this form.

⁵Not regulated hazardous constituent for waste category F039 (multisource leachates).

⁶Applicable to low-mercury subcategory (<260 mg/kg) only.

⁷Zinc not "underlying hazardous constituent" for characteristic wastes.

(2) Dioxins and Furans: Wastewater and Nonwastewater

Standards for dioxin-containing wastes (EPA categories F020-F023 and F026-F028), in which furans and chlorinated phenols are also of concern, are given in Table 2. Universal treatment standards requirements must be met for many organic contaminants prior to nonwastewater stabilization and prior to wastewater discharge.

TABLE 2. STANDARDS FOR DIOXIN-CONTAINING WASTES

Regulated Hazardous Constituent	Wastewater, total composition (mg/L)	Nonwastewater, total composition (mg/kg)
Hexachlorodibenzo-p-dioxins Hexachlorodibenzofurans Pentachlorodibenzo-p-dioxins Tetrachlorodibenzo-p-dioxins Tetrachlorodibenzofurans	0.000063	0.001
Pentachlorodibenzofurans	0.000035	0.001
2,4,5-Trichlorophenol	0.18	7.4
2,4,6-Trichlorophenol	0.035	7.4
2,3,4,6-Trichlorophenol	0.030	7.4
Pentachlorophenol	0.089	7.4

Source: *Hazardous Waste Consultant* Volume 12, Issue 6 (November-December, 1994), Table 6.1.

(3) Products of Incomplete Combustion: Wastewater and Nonwastewater

There are no general standards for products of incomplete combustion (PIC) as a class, in waters and waste waters. The process chemistry of the particular technology would determine whether compounds normally considered PICs were produced and partitioned into these physical forms. Any specific compounds so produced would have to comply with general standards for listed or characteristic wastes. The study provides specific information for the compounds identified. May also need to meet UTS's for specified organics (see Table I in *Hazardous Waste Consultant*).

(4) Metals: Air Emissions

Both air quality standards and emissions standards can regulate air emissions. Emissions standards exist for a few metals that may be applicable to EM activities. Emissions standards are set according to process facility types.

The Code of Federal Regulations (40 CFR 61.32) prohibits incinerators from emitting more than 10 milligrams of beryllium (by weight of elemental beryllium in any compound or in elemental form) over any 24-hour period. Section 61.32 also prohibits the "burning" of beryllium-containing waste, except in incinerators meeting the standard. Thus, the study should address two issues: (1) Do the processes being evaluated in the INTS qualify as burning, despite their nonthermal nature? If so, must they be classified as incinerators to be operated? (2) Even if the beryllium standard does not legally apply, would stakeholders accept systems that do not meet such a standard by "voluntary design?"

A mercury emissions standard also exists for facilities that dry or incinerate wastewater treatment sludge. The Code of Federal Regulations (40 CFR 61.52) prohibits facilities from emitting more than 3,200 grams of mercury (by weight of elemental mercury in any compound or in elemental form) over any 24-hour period.

(5) Dioxins, Furans, and PICs: Air Emissions

No specific national standard is provided in Part 61, 40 CFR for these pollutants. For study purposes it was assumed that the EPA required that systems meet the same emission levels achieved with RCRA-compliant incinerators. Because of public health concerns associated with these compounds and the resistance by many stakeholders to incinerators, the EPA is unlikely to accept more lenient requirements for nonthermal systems than for incinerators. A well-designed incinerator can have nondetectable dioxin and furan emissions.

2.0 TRIBAL AND STAKEHOLDERS VIEWS

Section 1.2 outlines the selection process for membership in the Tribal and Stakeholders Working Group (TSWG).

2.1 List of Tribal and Stakeholder Participants

1. Jim Bierer, Ross Local Schools, Hamilton, Ohio
2. Richard Brusuelas, Bernalillo County, NM, Env't. Dept., Albuquerque, NM
3. Anne Callison, Lowry AFB Restoration Advisory Bd., Denver, CO
4. David Chambers, Sierra Club Legal Defense Fund, Bozeman, MT
5. Terry Escarda, Dept. of Toxic Substances Control, Sacramento, CA
6. Karen Fagg, MSE-HKM, Inc., Billings, MT
7. Critz George, Brown & Root Env'tl. , Inc., Albuquerque, NM
8. Lorna Harrell, OH-KT-IN Regional Council of Governments, Cincinnati, OH
9. Steve Juanico, Pueblos of Acoma, Acoma, NM
10. William F. Lawless, Savannah R. Citizens Advisory Board, Aiken, SC
11. Momi Lovell, Kaho o'lawe Island Res. Commission
12. Tom McBride, Rocky Mountain Peace Center
13. Betsy McBride, League of Women Voters of the US, Chesapeake, VA
14. Toby Michelena, Washington State Dept. of Ecology, Olympia, WA
15. Roy Mink, University of Idaho, Moscow, ID
16. Laura Olah, Citizens for Safe Water, Merrimac, WI
17. Cynthia Sarthou, Heart of America NW, Seattle, WA
18. Momi Lovell, Kaho'olawe Island Res. Com., Honolulu, HI
19. Terry Smith, ID Oversight Program, Boise, ID
20. Stan Sobczyk, Nez Perce Tribe, Lapwai, ID
21. Edwin Tafoya, Eight No. Ind. Pueblos, San Juan Pueblo, NM

TSG Technical Stakeholders:

1. Gary King, New Mexico State Legislature
2. Ross Vincent, Sierra Club, Pueblo, CO

Technical Tribal Consultant

Dr. Mary Jo Ondrechen, Northeastern University, Boston, MA

2.2 Tribal and Stakeholder "Principles"

During the August 8 and 9, 1995 meetings of the Tribal and Stakeholders Working Group, considerable discussion centered on the system attributes systems that meet public concerns. After carefully studying the notes and minutes of the TSWG meetings, the INTS technical staff developed the following Tribal and Stakeholder Principles. The TSWG slightly amended these principles at its November 7 and 8, 1996 meeting.

**Tribal and Stakeholders Principles
for use in Evaluating Technology Systems for
Mixed Low Level Waste Treatment
Developed Jointly by the Office of Science and Technology and
Tribal and Stakeholder Working Group (TSWG)
Mixed Low Level Waste Treatment Systems Studies
January 1997**

FOREWORD

As a complement to the Integrated Thermal Treatment Systems Study (ITTS) completed in August 1995 by the U.S. Department of Energy's (DOE) Office of Science and Technology (OST) of the Office of Environmental Management (EM), OST commissioned an Integrated Nonthermal Treatment Systems Study (INTS). Each study compared the costs and performances of various thermal or nonthermal treatment systems for mixed low level waste. To assist in evaluating the systems, a tribal and stakeholder working group (TSWG) was formed to provide their perspectives. This was the first time that tribal and stakeholder representatives were involved so early in the technology system evaluation process.

The TSWG members represented a broad cross-section of American society. Each person represented an organization (i.e., a local or national environmental group, a state government, a municipality or county, a regional body, a commercial company, an Indian tribe, a citizen's group); however, the views expressed during the course of the INTS study were those of the individuals themselves.

This document is an expression of principles developed by the TSWG, in conjunction with a DOE technical group, to offer guidance to DOE headquarters, field managers, and other tribal and stakeholder groups when evaluating technology systems or making technology selections for waste treatment systems. The principles document is the result of four meetings of the TSWG to consider technology systems and reach agreement on the guiding principles to be used.

INTRODUCTION

Background

The Tribal and Stakeholder Working Group (TSWG)¹ assisted the U.S. Department of Energy (DOE), Office of Science and Technology (OST, EM-50) with its study and evaluation of treatment systems for Mixed Low Level Waste (MLLW). To supplement the technical criteria of the Technical Support Group (TSG), representatives of the TSWG and the TSG identified their social, cultural, and spiritual concerns in the form of six tribal and stakeholder principles. These principles were used concurrently with the technical criteria to study and evaluate treatment systems and are intended for that purpose.

Earlier versions of these principles were developed, discussed, and reviewed by the tribal and stakeholder representatives. Their comments have resulted mainly in the addition of clarifying explanations to most of the principles.

The principles are intended to be a continuing reference that can be used by tribal and stakeholder representatives, technical staffs, and by state, tribal, and Federal officials in the study and evaluation of a broad scope of systems.

Objective

Involvement of stakeholders and tribal representatives at every stage of the evaluation and selection of treatment systems and vendors will lead to better, more defensible selections and expedite clean up of the contaminated sites. Within the restrictions set by Federal regulations, DOE's objective should be to integrate stakeholder involvement into all of its processes, including procurement and performance evaluation.

The Six Principles

The six tribal and stakeholder principles are:

1. Minimize Effluents
2. Minimize Effects on Human Health and the Environment
3. Minimize Waste Generation
4. Address Social, Cultural, and Spiritual Considerations

¹ The term "Tribal and Stakeholder" is used throughout the text to represent interested individuals from any ethnic, cultural, religious, or other special background who want to be involved in assuring that system analysis adequately considers and evaluates their issues related to future research and development.

5. Provide Adequate and Understandable Information
6. Incorporate Tribal and Stakeholder Involvement into the DOE Procurement Process and the Performance Evaluation of Contractors on Stakeholder Participation.

These principles and their associated subprinciples are identified and explained in the following main sections.

In some cases the tribal and stakeholder representatives have suggested considerations to satisfy a particular principle or subprinciple. If there are suggested considerations, they follow the explanations that are applied to each principle.

TRIBAL AND STAKEHOLDER PRINCIPLES **General System Concepts**

Because some concepts apply to more than one principle, these concepts are explained here. They apply, as applicable, throughout the principles and subprinciples.

- ***Minimization²***

Minimization is viewed by the tribal and stakeholder representatives as a two part process:

1. Avoid adverse conditions (effluents, effects, waste generation, etc.), if practicable.
2. When avoidance is not practicable, reduce remaining adverse conditions to their lowest practicable levels.

For each principle or subprinciple where minimization is addressed, both avoidance and reduction of adverse conditions should be considered. Research should be expedited to minimize adverse health and environmental impacts from effluents and waste streams. Releases and impacts should be minimized.

- ***Reliance on Regulatory Standards***

Several principles and subprinciples deal with conditions limited by regulatory standards (e.g., operational releases of radioactive and hazardous materials, worker exposures, releases from dis-posed final waste forms). From the tribal and stakeholder perspective,

²While the goal of minimization may be zero release, it is recognized that this goal is often impossible to achieve, in practice.

mere conformance with these standards may provide less than adequate human health and environmental protection. Indeed, mere conformance with regulatory standards does not mean that a proposed system will gain widespread public acceptance. The regulatory standards represent minimum protective values. Actual exposures and releases should be reduced to their lowest possible³ levels, i.e., well below regulatory standards, in order to increase the level of public and environmental protection and enhance public acceptance. Requirements for monitoring over exposure to human population or flora and fauna should be identified and included in Total Life Cycle Costs (TLCC).

- ***System Selections***

A general way of satisfying tribal and stakeholder principles is to select system elements and designs that best comply with these principles. This includes appropriate choices of (a) equipment, technologies and processes, (b) system design configurations, (c) construction and process materials, (d) operating practices (construction, operations, transportation, storage/disposal, facility closure and environmental restoration), and (e) continuous monitoring of effluents. In some cases the selections may contribute directly to satisfying a particular principle. In other cases, the selections may facilitate the use of specific methods needed to satisfy a particular principle.

- ***Procurement Process***

Stakeholder and tribal representatives should be involved in procurements and the selection process. Tribal and stakeholder representatives should participate in the performance evaluation of agencies and contractors.

Principles and Subprinciples

1. Minimize Effluents

1a. Minimize airborne and wastewater effluents that can carry hazardous materials or substances capable of causing adverse human health and environmental consequences.

Operational releases of radioactive and hazardous pollutants contained in airborne and wastewater effluents should be kept to minimum levels, and below regulatory

³ The term "lowest possible" is used throughout the text to describe the desire to reduce the release of radioactive and hazardous substances and their impact to as low as reasonably achievable as contained in DOE Order 5480.11 (12/21/88). This term can cause confusion. It is incumbent upon people to define what they mean when they use this term.

standards, from construction through facility closure and decommissioning. Release of pollutants should be minimized by avoidance and reduction methods. Expected pollutant and effluent releases should be publicly specified. By minimizing these releases, exposures to the general population, the ecology, and the environment should be minimized. Both the number of pollutants and the pollutant concentrations in effluents should be minimized.

Among the specific measures taken to minimize pollutant and effluent releases, consideration should be given to (a) applying newly developed pollution prevention and waste reduction methods, (b) recovering hazardous materials and byproducts, (c) built-in recycling or reuse of potential effluent materials, (d) post-treating internal effluents before they are released, (e) monitoring and controlling airborne and wastewater effluents, (f) diverting pollutants from airborne and waste water effluents into the solidified final waste form, and (g) their possible retention to analyze and validate effluent pollutant levels before they are released.

2. Minimize Effects on Human Health and the Environment

2a. *Minimize worker exposures now and in the future.*

Worker exposures should be minimized during construction, operation, shutdown, maintenance, facility closure, and environmental restoration periods. Tribal and stakeholder representatives are concerned with exposures associated with ionizing radiation and the intake of, or contact with hazardous materials. These exposures should be limited to operating areas where access is restricted to workers only and the general public is not affected.

Among the specific measures taken to minimize worker exposures beginning with the highest risks, consideration should be given to (a) minimizing the use of hazardous reagents and additives; (b) using confinement, containment, and shielding systems to reduce worker exposures; (c) making appropriate choices of operating and maintenance procedures to avoid or reduce worker exposures; (d) maximizing reliance on automated processes where hazardous equipment, reagents, and additives are involved; (e) using protective clothing and equipment appropriately, (f) using monitoring and alarm systems and emergency procedures to protect against abnormal exposures and environmental and public health hazards, and (g) involving worker representatives at each stage of planning.

2b. *Minimize the potential for release of hazardous and radioactive materials from final storage/disposal products.*

Future exposure of humans and the environment to ionizing radiation and hazardous and radioactive material released from final waste forms, whether in an interim storage or

disposal configuration, should be minimized. By minimizing these releases, future effects on human health and the environment may be minimized.

Among the specific measures taken to increase waste form stability and minimize releases from disposed or stored final waste forms, consideration should be given to the following: (a) optimum combinations of final waste forms, the hazardous and radioactive materials and other waste that are stabilized in the final waste forms, and the selection, design and construction of storage/disposal facilities; (b) use of natural and engineered protective barriers at storage/disposal facilities to provide additional protection against releases; (c) use of personnel access control, physical security, and environmental monitoring systems at storage and disposal facilities; and (d) availability of a retrieval strategy to recover stored/disposed final waste forms, if adverse releases occur.

2c. *Minimize the potential for accidents and incidents in the system.*

The probability that an accident or incident associated with physical, chemical, radiological, and electrical hazards will occur should be minimized. Should an accident or incident occur, appropriate safety features to limit and mitigate accident/incident consequences should be provided or readily available. Accident/incident risks, the combination of probabilities and consequences, should be minimized when both accident/incident probabilities and accident/incident consequences are minimized.

Among the specific measures that can be taken to minimize accident/incident probabilities and limit and mitigate the consequences should they occur, the following should be given consideration: (a) appropriate choices of operating practices (transportation, operations, storage/disposal and facility closure); (b) minimization of physical, chemical, electrical, and radiological hazards; (c) appropriate reliance on automated process control equipment to reduce accident probabilities; (d) specification of adequate safety margins for system operations; (e) use and availability of protective clothing and equipment; and (f) use of emergency shutdown, confinement, containment, shielding and recovery systems, as appropriate, to limit and mitigate accident/incident consequences.

3. Minimize Waste Generation

3a. *Minimize creation of new hazardous material by treatments.*

The generation of new hazardous and/or mixed hazardous and radioactive wastes as byproducts of the treatment process should be kept to the minimum.

Among the specific measures taken to avoid or minimize waste generation, consideration should be given to the following: (a) application of newly developed pollution prevention and waste minimization methods, (b) implementation of waste segregation techniques, (c) recycle and reuse of appropriate waste materials, (d) use of techniques

not requiring utilization of hazardous reagents, and (e) cost credits for recycle, reuse, and recovery of resources and materials.

3b. *Minimize the volume of final waste forms for storage/disposal.*

The volume of final waste compared to the initial waste volume should be minimized. Among the measures taken to minimize the volume of final waste forms for storage/disposal, consideration should be given to: (a) making appropriate choices of waste pre-treatment, treatment, post-treatment, and stabilization processes that minimize the volume of final waste forms compared to the volume of initial wastes, (b) maximizing waste loading with respect to final waste form options, (c) minimizing the volume of non-hazardous waste matrix materials that is solidified in the final waste form, and (d) maximizing recycle giving cost credit for recycling and reuse (including the credit in the TLCC).

4. Address Social/Cultural/Spiritual Considerations

Social, cultural, and spiritual concerns, values and perceptions must in some way be factored into the entire technology system assessment process. Although many cultural concerns will generally be addressed on a site-specific basis, it is important that the consideration of cultural concerns be done on a global basis, as well. A relevant generic set of social concerns should be identified and addressed for systems studies. Most importantly, the site-specific concerns can be linked to those identified from the system studies. There is a need to develop cultural protocols for both R&D decisions and also for use at specific sites.

A major consideration relates to the environment. Everything revolves around the environment and encouragement of practices that might benefit the whole of humanity and future generations. Continuing damage to the environment should be minimized. To fully address environmental considerations, facility design, development, operations, and closure processes must be conducted with careful sensitivity to protecting environmental health.

Regulatory realities will need to be considered. Examples are: regulatory barriers, insufficient regulatory resources (manpower, equipment, training), and undeveloped or underdeveloped regulatory standards.

4a. *Minimize land use for storage /disposal*

Land use commitments, in terms of acreage and time, should be minimized. This includes land use for disposal and storage facilities and for the treatment facility itself. Contamination of soil and water (both surface and ground water) that occurs while the land is in use should be kept to the lowest possible levels. Commitments should be made regarding land cleanup and reuse, e.g. to restore the land to its original state upon completion of its use where feasible. When not

restoring the land to its original state, institutional controls should be used to ensure the protection of future generations.

Among the measures taken to minimize land use requirements and soil and water contamination while in use, consideration should be given to: (a) avoiding natural habitats and culturally important locations; (b) using pollutant confinement, containment, and retention systems to avoid soil and water contamination; (c) limiting the type and amount of soil contaminants and water pollutants to those that are amenable to cleanup with available remediation technologies; and (d) initiating an environmental restoration program upon completion of facility closure operations (including pollution prevention).

4b. *Minimize transportation from one site to another.*

Added traffic along public roads in the vicinity of the treatment facility due to plant operations should be minimized. Tribal and stakeholder representatives are concerned that all sources of traffic be addressed and impacts identified. This includes traffic related to construction and closure activities, employee commuting, delivery of goods and services, delivery of process materials and reagents, delivery of wastes to be treated, and shipment of storage and storage/disposal products.

Among the measures taken to minimize transportation requirements, consideration should be given to work force minimization, reduced reliance on process additives and reagents, minimization of final waste form volume, and access roads that avoid populated areas.

4c. *Reflect special considerations for specific sites.*

Identification and response to special considerations at specific sites is critically important to local acceptance of treatment technologies. The representatives strongly encourage the Department of Energy to include site specific considerations as an integral part of future treatment system studies.

4d. *Waste should be disposed in a retrievable manner.*

Final waste forms must be disposed in a manner that allows the waste to be retrieved, if pollutant releases prove to be unacceptable. Retrieval may also be required if future land use considerations dictate its relocation. In line with this position, contingency plans for waste retrieval should be addressed as part of the waste storage/disposal process. Furthermore, a solid final waste form, with long-term stability, should be used to facilitate retrieval, if retrieval is required.

4e. *Respect cultural values.*

At least two approaches are available to assure that cultural values are properly respected in studying, siting, constructing, operating, and closing treatment facilities:

1. Assignment of scientists and engineers from diverse cultural backgrounds to the technical staff supporting the study to assist in identifying and addressing cultural value issues, e.g., Native Americans.
2. Integration of a meaningful tribal and public participation process into site systems management and planning models for site specific studies. This includes participation that provides identification of issues and timely responses regarding estimated impacts.

In both cases, it is important to the tribal and stakeholder representatives that early and meaningful involvement be achieved. Provisions should be made for tribal and stakeholder involvement in studies, assessments of treatment technologies and systems, and for planned treatment system demonstrations or implementations at DOE sites. DOE management should take appropriate action to ensure that both approaches are implemented.

Involvement, e.g., Indian Tribal representation, allows appropriate consideration of the impact of technologies on food, medicine, religious ceremonies, and other features essential to Native cultures. Similar issues have been addressed by the Development of On-site Innovative Technologies (DOIT) program in issuing "A Guide to Tribal and Community Involvement in Innovative Technology Assessment."

4f. *Minimize noise.*

Noise due to traffic is addressed in subprinciple 4b above. Additional sources of noise and vibrations, whether in facility construction, operations, or closure activities must be identified and addressed.

Among the measures taken to minimize these sources of noise, consideration should be given to elimination of noise sources if practicable, installation of sound-barrier walls or other mitigating measures where appropriate, and selection of remote locations for proposed systems.

4g. *Protect local vistas.*

Some sites have intrinsic value because of their panoramic views of distant mountains, bodies of water, and scenic landscape. These vistas need to be protected. A particular concern is the obstruction of vistas and visual impact upon the horizon by "dotting the landscape" with assorted treatment facilities, power lines, effluent stacks, and other supporting requirements.

Among the measures than can be taken to protect local vistas, consideration should be given to minimizing above-ground structures, using facilities that can be powered by underground electrical systems, and carefully siting facilities so that existing vistas are

not disturbed. Permanent massive structures that dominate an otherwise attractive vista are to be avoided, as they may compromise religious use of such sites. All should be considered as part of the evaluation of systems.

4h. *Include Costs of Complying with Intergovernmental Agreements*

Compliance agreement and MOU-related costs such as monitoring, technical assistance, and third party review should be included in Total Life-Cycle Costs.

5. Provide Adequate and Understandable Information

Detailed, timely, and accurate information should be provided to stakeholders in accessible formats and locations. The written language should be understandable to a general audience, and examples or analogies should be used for explanation.

- 5a. *Provide technology screening and down-selection, and system description and cost information, including details of the process and how unsuccessful systems could become viable .***
- 5b. *Provide information about systems hazards and risks, and the safety features provided to avoid or reduce these hazards and risks.***
- 5c. *Describe the processes that govern the conduct of the study:***
- Treatment study decision-making
 - DOE decision-making
 - Tribal and stakeholder involvement
 - Planned documentation and outcomes
 - Likely pollutants in gas or water effluents
- 5d. *Provide system and technology information within the framework of Tribal and Stakeholder Principles and Technical Criteria.***
- 5e. *Integrate or "bridge" thermal, nonthermal and other applicable treatment systems studies for overall systems comparisons.***
- 5f. *Focus on existing stored waste and then add projected impact of future waste generation.***

- 5g. *Keep the Tribal and stakeholder representatives involved and informed throughout the evolution of systems studies.***
- 5h. *Provide information on qualitative and quantitative analysis and monitoring of hazardous and radioactive components in effluents.***
- 5i. *Independent advisory resources should be made available to review the information and respond to those supplying the information.***

6. Incorporate Tribal and Stakeholder Involvement into the DOE Procurement Process and the Performance Evaluation of Contractors on Stakeholder Participation

Stakeholder and tribal representatives should be involved in procurements and the selection process. Tribal and stakeholder representatives should participate in the performance evaluation of agencies and contractors.

CONCLUSIONS AND PROPOSALS

Conclusions

These principles, reflecting the concerns of Tribal and stakeholder representatives, are applicable to evaluations of mixed low level waste treatment systems and may be applicable to selection of other systems. They augment conventional technical criteria by introducing additional considerations that technical staffs, possibly assisted by technically trained tribal and stakeholder representatives, should address in order to make treatment systems more acceptable to the general public. The principles are generic and can be applied to a broad range of systems studies in planning future research and development.

The principles are qualitative in nature. They provide no quantitative limits that can be used to delineate between acceptable and unacceptable systems. They are goals toward which technical staffs should strive in studying treatment systems including siting, design, development, implementation, and closure processes. They are goals which, when better satisfied, should enhance public acceptance.

Uncertainties regarding public acceptance of mixed waste treatment systems will always exist. These uncertainties can be reduced, preferably on a site-specific basis, by timely and meaningful involvement of tribal and stakeholder representatives from the beginning of technology development processes. Doing so will promote early identification of significant issues, joint resolution of these issues, and "real time" concurrence about public acceptance of the proposed treatment system.

Tribal and stakeholder representatives place great importance on being kept informed whenever a treatment system is planned or proposed for implementation. Means to identify appropriate representatives and keep them informed are recommended.

Proposals

It is proposed that tribal and stakeholder principles be applied in future mixed waste treatment systems studies and implementation activities. There should be community involvement in the analysis and selection of storage and disposal technologies. Based on the favorable results of discussion of these principles, affected communities should be involved in analysis of storage and disposal technologies intended for use at specific sites.

It is proposed that technically trained tribal and stakeholder representatives be available to technical staffs and Tribal and stakeholder representatives responsible for future systems studies to assist in evaluation of treatment system options with respect to tribal and stakeholder principles.

3.0 NONTHERMAL TREATMENT SYSTEMS STUDY BASIS

3.1 General Description

DOE MLLW consists of a heterogeneous mixture of soils, organic and inorganic sludges, organic and aqueous liquids, and both combustible and noncombustible debris. The commercial sector treats hazardous organic compounds by thermal treatment. Because of stakeholder concerns in the communities surrounding DOE sites and current Administration policy, DOE has been evaluating alternatives to thermal treatment (normally assumed to be incineration). OST has, therefore, directed its systems engineering analysis program to supplement its study of thermal treatment as *systems* (not as single technologies) with a similar study on nonthermal systems. OST commissioned the Integrated Nonthermal Treatment Systems study to compare the cost and performance of nonthermal systems against the comparative study of thermal systems.

For the INTS, nonthermal means any technology that operates at less than 350° C. The INTS technical staff knew that the Western Governors Association's DOIT Committee was also looking into technologies that were alternatives to incineration. The DOIT Committee's defining point for nonthermal technologies was also technologies operating at less than 350° C. Dioxins and furans are produced only when hot offgas containing precursors and a chlorine source are slowly cooled at temperatures ranging between 250° C to 500° C, and in the presence of particulates that provide recombination sites. It was believed that if process temperatures were kept below a certain temperature (arbitrarily chosen as 350° C) then dioxins and furans would not have an opportunity to return during the offgas cooldown phase. This does not mean to imply that dioxins/furans could not form in the condensed reacting media or be carried into the offgas from the reaction vessel.

3.2 Methodology

The INTS technical staff, working with contractors representing EM-30 who had already begun examining nonthermal technologies, identified promising representative technologies to consider as systems. Simultaneously, the WPI Team, EM-50's headquarters support contractor, undertook an extensive literature search and produced a compendium of some 250 nonthermal technologies that were either being developed or being seriously considered by public and private investigators. This compendium, published as "Overview of Nonthermal Mixed Waste Treatment Technologies" (DOE/EM-0281) in July 1995, also included air pollution control technologies appropriate for inclusion in nonthermal systems. The technology collection was not meant to be a selection document; rather, it was an attempt to bound

the universe of known processes that could be included in a total system for nonthermal treatment of mixed low level waste.

The INTS technical staff took information from these two sources and fashioned representative major nonthermal subsystems required for treatment of DOE MLLW. The subsystems included: low-temperature thermal desorption, washing, chemical destruction of organics, aqueous waste and offgas treatment, metal decontamination, and waste stabilization. The staff then developed preconceptual system designs and presented the ideas to the Technical Support Group (TSG) at a Denver meeting in June 1995. After discussion and approval, the technical staff further developed the suggested concepts into five nonthermal systems. The staff identified one or two candidate technologies for treatment of the major waste components (soils; organic and inorganic sludges; organic and aqueous liquids; soft, complex, and open debris). Soft debris includes, for example, cardboard, plastic, and wood. Complex debris includes contaminated items such as pumps and valves with internal surfaces or cavities that trap contaminants and are not accessible to decontamination agents. Drums, concrete, bricks, glass, and metals with only surface contamination constitute open debris.

In August 1995, the INTS technical staff presented the proposed systems at the first meeting of the Tribal and Stakeholders Working Group (TSWG) in Denver. For two days, the staff made presentations on the study background (focusing on the reasons for the ITTS and the resultant recommendations to complement it by a nonthermal study), the shared bases for the studies, a description of the waste stream and its components, and the recommended systems. The TSWG discussed the proposals and focused heavily on the criteria to be used by the technical staff in evaluating the systems. The TSWG also strongly recommended that the study include other aspects and concerns. They insisted their two technical representatives on the TSG (Gary King of the New Mexico State Legislature and Ross Vincent of the Sierra Club) participate in all discussions of the technical staff. In August, 1995 detailed descriptions of the technologies selected for inclusion in the nonthermal study were published as "Description of Recommended Nonthermal Mixed Waste Treatment Technologies" (DOE/EM-0282).

The INTS technical staff, including Morrison Knudsen Environmental Services (MK), finalized subsystem technologies for inclusion in the five nonthermal systems. MK began the development of equipment size, equipment layouts, building configurations, and life cycle cost data. INTS technical staff met with nonthermal technology vendors to enhance understanding of the performance and capabilities of various technologies included in the study. INEL performed mass balance analyses on each system using the ASPEN PLUS computer model.

The TSG met in Salt Lake City in November 1995 to hear technical staff findings on the systems, to respond to the TSWG input on the systems, to discuss the systems as now proposed by the technical staff, and to agree on the wording of a response to the tribal and stakeholders' criteria principles. During these discussions, the TSG decided to limit the present INTS analysis to the five major nonthermal systems without varying different subsystem options. Sensitivity considerations were deferred to an "enhanced" INTS study to be conducted in the summer of 1996. This resulted in the INTS studying a single technology through all five nonthermal systems for the treatment of aqueous waste and vapor phase organics in the offgas. This would minimize the variations between and among systems to allow a less confusing and more direct comparison. On October 31, 1995, a panel of chemical experts from DOE sites was convened to ensure that no chemical deficiencies or incompatibilities were overlooked when designing these systems. The panel recommended several technical changes that were adopted.

MK then completed the conceptual designs and produced costs and flow sheets. INEL produced more definitive mass balances. The TSCs presented these preliminary results to the TSWG in Phoenix in January 1996. The TSWG offered more information regarding issues to be considered in evaluating the systems' performance. Following this meeting, MK revised process flow diagrams, facility layouts, equipment lists, and costs. INEL completed the mass balances. The final INTS designs were completed, data were produced, and briefings were prepared.

3.3 Major Assumptions

Figure 1 depicts the DOE MLLW systems design for both thermal and nonthermal systems.

Figure 1. Integrated Thermal and Non-Thermal Systems

Figure 1. 88-0312

3.3.1 Common Assumptions

- Facility designed to meet DOE and RCRA standards for processing radioactive and hazardous materials (no delisting)
- Operation for 20 years at 4,032 hours per year (2,927 lbs/hour)
- Constant waste profile to permit direct comparison of systems. Source data was Interim Mixed Waste Inventory Report (IMWIR) 93. Changes in MWIR 95 will not affect comparison of systems
- Represents the average composition of MLLW in the DOE complex (less Hanford tank waste and Rocky Flats pondcrete)
- All waste must be treated in the facility – no diversions to other facilities
- Facility to be DOE-owned, contractor-operated

3.3.2 ITTS-Only Assumptions

- 50 percent of waste received requires sorting
- Organic destruction is 99.99 percent to 99.9999 percent

3.3.3 INTS-Only Assumptions

- Nonthermal operations at 350° C or less
- Efficiencies, reaction rates, and decontamination factors are based on vendor or developer data where available
- 75 percent of waste received requires sorting
- No vitrification of final waste form

Figure 2 is a pie chart depicting the incoming waste fractions and the percentage of each type of waste comprising the total.

Figure 2. Incoming Waste Fractions Sent to Various Subsystems

Figure 2. 98-0312

4.0 TECHNICAL CRITERIA

The INTS technical staff used the following technical criteria when examining more than 250 nonthermal technology candidates to present to the TSG and the TSWG for approval:

(1) *Process Performance*

- Applicability
- Flexibility
- Versatility
- Availability
- Reliability
- Maintainability
- Hazardous Waste Generation
- Byproducts and Residuals
- Volume Reduction
- Final Waste Form Volume and Contaminant Loading
- Effectiveness

(2) *Environmental Impact*

- Airborne Releases
- Wastewater Releases
- Final Waste Form Performance
- Ecological Effects

(3) *Worker Health and Safety*

- Hazardous Reagents
- Hazardous Operating Conditions
- Hazardous Process Equipment

- Process Controls
- Maintenance Exposures
- Off-normal Conditions, and their Probabilities and Consequences
- Upset and Accident Conditions, and their Probabilities and Consequences
- Process Containment

(4) *Costs*

- Research and Development
- Total Life Cycle

(5) *Acceptability*

- Complexity/Simplicity
- Technology Development Status
- Site Expanse
- Resource Utilization
- Schedule
- Facility Closure
- Environmental Restoration

5.0 NONTHERMAL TREATMENT SYSTEMS

Five distinct nonthermal systems were developed using some of the more than 250 candidate technologies available to the INTS technical staff. All systems required extensive up-front characterization and sorting of the waste for treatment.

Each of the five systems has identical or very similar systems for metal decontamination, mercury amalgamation, lead recovery, "special" waste treatment (e.g., mercury recovery and amalgamation), air pollution control, aqueous waste treatment, and polymer stabilization. Many of these are similar to those used in the ITTS. The INTSAPC subsystems were much smaller than the corresponding ITTS APC subsystems. The INTS APC subsystems used dry filtration and wet offgas scrubbing and organic destruction in the gas phase corona reactor. The aqueous treatment subsystem used photo-oxidation for organic destruction, supplementing the standard neutralization, precipitation, filtration, and evaporation techniques.

Figure 3 shows an illustration of the waste flow and subsystem configuration for one of the five nonthermal systems (System 4 -Acid Digestion). Figure 3 also shows the percentage of the overall incoming waste stream going to each subsystem.

Table 3 shows the specific technology chosen for each of the subsystems in the five nonthermal systems studied.

Figure 3. Acid Digestion Non-Thermal System

Figure 3. 99-0312

TABLE 3
NONTHERMAL SYSTEMS AND SUBSYSTEMS

SUBSYSTEM	GROUT DEBRIS	DESORPTION	WASH	ACID DIGESTION	CWO
	SYSTEM 1	SYSTEM 2	SYSTEM 3	SYSTEM 4	SYSTEM 5
ADMINISTRATION	As Needed	As Needed	As Needed	As Needed	As Needed
RECEIVING & PREPARATION	Extensive Sorting	Extensive Sorting	Extensive Sorting	Extensive Sorting	Extensive Sorting
ORGANIC DESTRUCTION	Mediated Electrochemical Oxidation (MEO)	Catalytic Wet Oxidation (CWO)	MEO	Acid Digestion	CWO
PROCESS RESIDUE TREATMENT	Vacuum Desorption	Vacuum Desorption	Aqueous Wash	Vacuum Desorption	Vacuum Desorption
SOIL TREATMENT	Vacuum Desorp. w/ Process Residues	Vacuum Desorp. w/ Process Residues	Aqueous Wash	Aqueous Wash	Aqueous Wash
SOFT DEBRIS	Grout	Included w/ Process Residue	Low Pressure Wash	Acid Digestion	Catalytic Wet Oxidation
OPEN DEBRIS	Grout	Included with Process Residue	High Pressure Wash	High Pressure Wash	High Pressure Wash
COMPLEX DEBRIS	Grout	Included with Process Residue	Included with Open Debris	Grout	Grout
LEAD RECOVERY	Decontamination	Decontamination	Decontamination	Decontamination	Decontamination
MERCURY STABILIZATION	Amalgamation	Amalgamation	Amalgamation	Amalgamation	Amalgamation
OFFGAS TREATMENT	Gas Phase Corona	Gas Phase Corona	Gas Phase Corona	Gas Phase Corona	Gas Phase Corona
AQUEOUS	Photo Oxidation	Photo Oxidation	Photo Oxidation	Photo Oxidation	Photo Oxidation
PRIMARY STABILIZATION	Grout/Polymer	Grout/Polymer	Grout/Polymer	Phosphate Cement	Grout/Polymer
SECONDARY STABILIZATION	Polymer	Polymer	Polymer	Polymer	Polymer
BULK METAL	Decontamination	Decontamination	Decontamination	Decontamination	Decontamination

5.1 Nonthermal System Waste Flows

Figures 4 through 8 depict the distribution of waste sent to the various subsystems of the five integrated nonthermal treatment systems.

Figure 4. Grout Debris Waste Flows

Figure 4. 98-0312

Figure 5. Thermal Desorption Waste Flows

Figure 5. 96-0312

Figure 6. Wash Case Waste Flows

Figure 6. 95-0312

Figure 7. Combination with Acid Digestion Waste Flows

Figure 7. 95-0212

Figure 8. Combination with CWO Waste Flows

Figure 8. 96-0312

5.2 Comparative Emissions Summary

Solid residues produced from nonthermal systems have far greater volume than thermal systems. Thermal systems with a vitrified final waste form produce the lowest final volume. For the standard ITTS/INTS system input at 2,927 lbs/hour, the thermal vitrified waste forms generally produced solid stabilized final waste forms at a rate of less than 2,000 lbs/hour. Only the rotary kiln/grout case exceeded 2,000 (actually 3,700 lbs/hour). However, the five nonthermal systems ranged from 3,600 lbs/hour for System 4 (acid digestion) to over 4,700 lbs/hour for System 1, grout debris.

In contrast, gaseous emissions for nonthermal systems with offgases (primarily carbon dioxide [CO_2]) were less than 1,500 lbs/hour for all five systems. For thermal systems where offgases are primarily carbon dioxide and nitrogen, offgas emissions ranged from 6,000 to 27,000 lbs/hour.

Aqueous effluents from both thermal and nonthermal systems vary significantly. Water output for thermal systems ranged from minus 500 lbs/hour (e.g., water consumption) for steam gasification to 900 lbs/hour water generation for the slagging rotary kiln. For nonthermal systems, water effluents varied from 50 lbs/hour for System 1 (debris grout) to 800 lbs/hour for acid digestion, System 4.

5.3 Waste Volume

Waste volume can be related to land use. For both thermal and nonthermal systems, a site of 50 to 57 acres is required for the treatment facility. The accompanying disposal facility requires at least 150 acres. The treatment facility land use requirement is only about 5 to 7 percent of the total treatment site area requirement. The greatest impact in land use is inclusion of a buffer zone around treatment and storage buildings. Parking, outbuildings, and utilities comprise 30 percent of site area. The disposal facility size depends on the volume of 1 to 4 million cubic feet of waste produced (depending on the system chosen). Waste is disposed of in 31 foot cells. Total land usage ranges from 149 to 214 acres.

5.4 System Evaluation Against Stakeholder Principles

This section compares each of the following five nonthermal systems as evaluated by the INTS technical staff with the five stakeholder "criteria principles" listed in Section 2.2.

For reference purposes, the five nonthermal systems are again listed:

- System 1: Grout Debris
- System 2: Thermal Desorption
- System 3: Wash
- System 4: Acid Digestion
- System 5: Catalyzed Wet Oxidation (see Table 3).

5.4.1 Minimize Effluents

This principle seeks systems that minimize effluents into either the air (offgases), water (discharged wastewater), or ground (stabilized solids for disposal).

Offgas. Air emissions (most of which is carbon dioxide produced when organic wastes are oxidized and decomposed by the systems) range from 700 lbs/hour for System 1 to 1,440 lbs/hour for System 5. System 1 has the least amount of offgas because debris waste is not oxidized but is sent directly to grout stabilization. Systems 2 and 3 have more offgas due to removal of organics and subsequent oxidation. Systems 4 and 5 have the most offgas because of additional oxidation of soft debris. We should note, however, that all systems have sufficiently robust and redundant components in the offgas (APC) system to more than meet existing (and likely future) emission standards. Because the offgas in these systems, unlike thermal systems, is at low temperature, the potential for toxic contaminants (e.g., volatilized metals and radionuclides in the offgas) is significantly reduced. However, the presence or absence of partialized contaminants is unknown.

Wastewater. Treated water leaving the aqueous treatment subsystem is recycled in all five systems to minimize water discharge. However, more water is produced by the oxidation of organic contaminants in the waste stream than is required to operate each system. Water discharge ranges from 50 lbs/hour for System 2 to about 800 lbs/hour for System 4. Rather than discharging to surface water, excess water could be evaporated and discharged into the air as water vapor. However, this would increase the offgas rate, put a larger burden on the air pollution control system, and increase energy usage. All systems meet all current and proposed discharge requirements.

Solid Effluents. Waste is stabilized in either grout (cement and polyethylene) in Systems 1, 2, 3, and 5, or polyethylene and phosphate bonded cement in System 4. Grout is also used in System 4 to stabilize complex debris. Mercury is stabilized by amalgamation. The stabilized residue mass flow rates (3,600 to 4,700 lbs/hour) are high (about 300 percent compared to wastes from thermal treatment). Polymer or phosphate cement requires one pound of polymer or phosphoric acid for every pound of waste stabilized. Grout stabilization requires twice this amount. The largest amount of solid waste generated is from Systems 1, 2, and 3 the systems that do not oxidize soft debris.

5.4.2 Minimize Effects on Human Health and the Environment

This principle has three components: (1) worker and environmental exposures, (2) release of hazardous and radioactive materials from final disposal or storage products, and (3) the potential for accidents.

5.4.2.1 Minimize Worker Exposures Now and in the Future

Proper system and facility design minimize worker exposure to hazardous and radioactive materials. In fact, since the systems and facilities were designed for alpha MLLW treatment capability, they are over designed for non-alpha MLLW. Alpha MLLW treatment uses airtight cells for three separate levels of confinement. The greatest exposure risk is in the sorting operations at the front end of each system where waste containers are opened and dumped. Exposure risk is reduced in Systems 1 and 3 using MEO because (1) reagents are less aggressive, and (2) the process is at atmospheric pressure and only slightly above room temperature. Exposure risk is higher for the more aggressive processes such as acid digestion (System 4) and CWO (Systems 2 and 5) which operate at higher temperatures and pressures than MEO. However, proper design and control procedures will minimize the potential for accidents and exposure.

Volatilized metals and radionuclides should not be released into the offgas from nonthermal treatment processes. Formation of dioxins in the offgas is not anticipated as operating temperatures are, by design, kept below the temperature at which they form by recombination in the offgas. Oxides of nitrogen will be formed by using nitric acid as the oxidizing agent in the MEO and acid digestion processes). The resulting NO_x will be recovered as nitric acid or converted to nitrogen. Other acid gases are removed in the APC and neutralized.

Wastewater contains spent acids and dissolved heavy metals, radionuclides, and organics. Contaminated water is treated by standard wastewater treatment technologies such as precipitation and filtration, evaporation, ion exchange, and

activated carbon. Treated water is recycled or discharged through a system that meets applicable water discharge standards.

Long-term environmental exposure may occur due to leaching of contaminants from the final waste form at the disposal site. It is assumed that the stabilized waste will meet all regulatory requirements; however, there is a higher risk of release from the untreated, grout stabilized debris from System 1. The long-term performance of grout, especially grout containing debris and residual organics, needs to be verified. Phosphate bonded ceramic (cement) and polyethylene are thought to have greater long term stability than grout, but this also requires verification.

5.4.2.2 Minimize the Potential for Release of Hazardous and Radioactive Materials from Final Storage/Disposal Products

Solid waste intended for disposal is stabilized to minimize releases harmful to the environment. Different stabilization forms may prove more effective for stabilization of different waste residue streams. All systems use a polymer for stabilizing salts. Grout was used for debris and soils in all systems, except System 4 (which used phosphate bonded ceramic and grout). All systems were designed to meet all EPA requirements.

System 1 has the maximum release potential because untreated debris and metal- and radioactive-laden desorbed soils and sludges are simply encapsulated in grout. System 3 washes the material, removing organics and soluble compounds of heavy metals and radionuclides, which reduces the release potential. Systems 4 and 5 chemically destroy soft debris reducing disposal volume. Additionally, acids solubilize inorganic contaminants that are subsequently precipitated as salts or oxides and stabilized in polymer or phosphate bonded ceramic.

5.4.2.3 Minimize the Potential for Accidents and Incidents in the System

By using robust designs to deal with aggressive systems such as acid digestion (System 4) and catalyzed wet oxidation (Systems 2 and 5), the potential for and the consequences of accidents would be reduced. Typically, the detailed design work to preclude or mitigate accidents comes at a later, more detailed design stage than was used for this study.

5.4.3 Minimize Waste Generation

This principle has two parts: (1) minimize creation of new hazardous material, and (2) minimize volume of final waste for disposal or storage.

5.4.3.1 Minimize Creation of New Hazardous Material by Treatments

Extensive recycling of reagents and additives has minimized the use of hazardous chemical reagents. Acids are used in the treatment processes to decompose the organic contaminants. HCl is recycled. Excess acids are neutralized with sodium hydroxides. These acids result from spent acids in the organic destruction processes. Heavy metals and radionuclides are precipitated from solution and stabilized in a polymer or phosphate bonded ceramic (in System 4).

In System 1, the MEO process uses concentrated nitric acid and silver nitrate. Iodine is used in the mercury leaching process after thermal desorption. All are hazardous reagents. Other acids and bases are used to recover silver (99.9 percent recovery in bench tests), a RCRA metal which is used in the MEO process to oxidize organic liquids and sludges.

System 2 (catalyzed wet oxidation or CWO) uses hydrochloric acid, ferric chloride, and metal catalysts to oxidize organics. Iodine is required to remove mercury from soils, sludges, and debris after thermal desorption.

System 3 also uses MEO. The three washing processes use surfactants and additives that the developers claim are nontoxic. The surfactants are recovered and recycled, and spent surfactant is sent to the organic destruction subsystem.

System 4 uses nitric and phosphoric acids as the organic destruction medium. Some of the spent phosphoric acid is incorporated in the phosphate bonded ceramic final waste form, and the remainder is neutralized. The washing processes generate spent surfactants as in System 3. Iodine is also used for mercury removal as in Systems 1 and 2.

System 5 uses CWO in place of acid digestion, generating wastes similar to Systems 2 and 4.

5.4.3.2 Minimize the Volume of Final Waste Forms for Storage/Disposal

All five systems are designed for maximum recycle of reagents to reduce the volume of waste requiring disposal. Solid, stabilized waste is generated from the waste treatment. The volume of waste volume sent to disposal is 5 percent less than Systems 1, 2, and 3 waste volume, and 19 percent less than System 5 waste volume. Lower volumes are sent to disposal from the systems that destroy the soft debris.

5.4.4 Address Social/Cultural/Spiritual Considerations

This principle has eight components: (1) minimize land use for disposal or storage, (2) minimize intersite transportation, (3) special site considerations, (4) dispose of waste in a retrievable manner, (5) reflect cultural/spiritual values, (6) minimize noise, (7) protect local vistas, and (8) help with the costs of complying with intergovernmental agreements. There is also a need to develop cultural protocols for both R&D decisions and also for use at specific sites.

5.4.4.1 Minimize Land Use for Storage/Disposal

This criterion's component was addressed in Section 5.4.3.2.

5.4.4.2 Minimize Transportation from one Site to Another

A basic assumption in the study is that a centralized site is utilized. Therefore, transportation of reagents and MLLW waste to the facility across the complex is assumed. The frequency of waste delivery to the site, assuming 44,000 pounds per truck, is approximately 268 trucks per year.

5.4.4.3 Reflect Special Considerations for Specific Sites

The INTS technical staff strongly agrees with this stakeholder principle; however, this paper engineering study with hypothetical sites could not reflect these considerations. Complex-wide issues, rather than site-specific issues, are addressed in the INTS study.

5.4.4.4 Waste Should be Disposed in a Retrievable Manner

Waste Retrievability depends on both the waste form and the design of the disposal facility. In the INTS, the final waste form was put into steel drums which were put into concrete vault cells, which, when full, are capped in place to protect against long-term intrusion and migration. This approach should support retrieval for a very long time.

5.4.4.5 Reflect Cultural Values

The INTS was an engineering study. Therefore, it deals with neither policy nor site-specific issues. Tribal and stakeholder representatives should make independent assessments of the cultural impact of treating wastes using information and methods described in the INTS. A technically-trained tribal consultant was retained in August 1996 to advise the INTS study team on ways to make future such studies more sensitive to social, cultural, and tribal values.

5.4.4.6 Minimize Noise

Each hypothetical facility site was designed with large buffer areas surrounding the treatment building partially as a means of mitigating the noise impact on surrounding communities.

5.4.4.7 Protect Local Vistas

The INTS technical staff agrees with the importance and necessity of protecting local scenic beauty and amenities. Again, since these were paper studies, the application of this subprinciple to the conduct of the study did not come into play.

5.4.4.8 Costs of Complying with Intergovernmental Agreements

Costs for complying with state and local regulations were included in the systems' TLCCs; however, there were no funds set aside for the new concept of paying for the costs of local communities' monitoring efforts.

5.4.5 Provide Adequate and Understandable Information

This principle has nine components; most do not relate to specific technical issues: (1) better information on cost information and how unsuccessful, but promising systems could gain DOE acceptance (2) better information on system hazards and risks; (3) better information on how technical decisions were made for the INTS and ITTS; (4) provide system and technology information within the framework of the stakeholders principles and technical criteria; (5) bridge ITTS and INTS to combine elements; (6) focus on existing stored waste and projected impacts of future wastes; (7) maintain information flow and stakeholder involvement during the course of systems studies; (8) provide information on qualitative and quantitative analysis and monitoring of effluents; and (9) make resources available to stakeholders' independent advisory resources and respond to their concerns.

5.4.5.1 Provide Technology Screening and Down-Selection, and System Description and Cost Information

The performance on these technologies on DOE MLLW is uncertain because of the early pilot scale and bench-scale development levels of the nonthermal technologies in the five INTS systems. Performance data were used when they were available; however, the technologies are relatively immature and data are scarce. No nonthermal technologies have been tested on MLLW.

5.4.5.2 Provide Information about Systems Hazards and Risks

Health and safety information was developed during evaluation of the technologies used in systems designs. Comparative risk analysis is the subject of another study on thermal and nonthermal systems, although the impact on the environment is not part of the ongoing analysis since that is quite site-specific. This study is currently underway.

5.4.5.3 Describe the Processes that govern the Conduct of the Study

The process is found under "Technical Approach" above in Section 1.2.

5.4.5.4 Provide System and Technology Information within the framework of Tribal and Stakeholder Principles and Technical Criteria

The technical criteria listed in Section 4.0 often had to be applied qualitatively for many facets of the INTS systems. Qualitative analysis tends to be more flexible. In selecting technologies for the five systems, criteria were applied both qualitatively and, where data were available, quantitatively.

5.4.5.5 Integrate or "Bridge" Thermal, Nonthermal and other Applicable Treatment Systems Studies for overall Systems Comparisons

Hybrid systems combining the best thermal and nonthermal technologies is the subject of a subsequent systems study, which is on-going and is expected to be completed early in 1997. One option that is included is a nonthermal primary organic destruction subsystem combined with vitrification (a thermal system) to minimize final waste volume.

5.4.5.6 Focus on Existing Stored Waste and Add Projected Impact of Future Waste Generation

The INTS focused on existing stored waste; however, the technologies and systems are also applicable to future MLLW. The INTS study was conducted assuming all existing MLLW was treated plus that to be generated in the next five years.

5.4.5.7 Keep the Tribal and Stakeholder representatives Involved and Informed throughout the Evolution of Systems Studies

The INTS is an engineering study comparing performance and cost of nonthermal systems. It is not a demonstration project. The TSG selected the technologies included in the five systems to be studied after soliciting input from the TSWG. The TSG includes two technical members of the TSWG. Findings were presented to the TSWG for its concurrence. As part of the INTS study process, progress reports were sent

periodically to the TSWG members. Meetings were held to present and discuss results and to respond to suggestions and comments.

5.4.5.8 Provide Information on Qualitative and Quantitative Analysis and monitoring of Hazardous and Radioactive Components in Effluents

The preliminary plans and documentation for ITTS and the INTS have been presented to the TSWG. Results and complete documentation were presented to the TSWG in August 1996 to share analysis on the comparative INTS and ITTS results and to get TSWG recommendations on systems that DOE might pursue with respect to further R&D. The TSWG shared its views on both the nonthermal systems and the INTS process at its last meeting in November 1996. The ITTS and INTS studies provide information to evaluate candidate treatment technologies and treatment options by DOE's Office of Environmental Restoration (EM-40) and Office of Waste Management (EM-30) managers. Upon the completion of the INTS and the INTS/ITTS comparison studies, more data will become available to both DOE headquarters and site managers and to tribal and local stakeholders.

5.4.5.9 Independent Advisory Resources Should be Made Available to review the Information and Respond to those Supplying the Information

This suggestion, unfortunately, is beyond the scope of the INTS and ITTS studies, but it has been forwarded to DOE management.

5.4.6 Incorporation of Tribal and Stakeholder Involvement into the DOE Procurement Process and the Performance Evaluation of Contractors

This is a belated principle added by the TSWG, so it was not included in the studies; however it is not read as applying to the development of MLLW treatment technologies. Rather, it was meant to apply to the actual selection and implementation of technologies in the field. This point has been shared with DOE management.

5.5 Evaluation Summary

All five nonthermal systems satisfy the technical criteria and the TSWG principles by varying degrees. The more aggressive treatments (Systems 4 and 5) can decrease waste disposal volumes by destroying more organic waste. Wastes that can be converted to a gaseous effluent include organic liquids, organic sludges, and soft or combustible debris. The consequence of oxidizing or destroying more of the organic waste is higher offgas volumes. The more aggressive technologies have less performance risk but require more vigorous and expensive designs to mitigate safety risk. For all systems,

proper system design and operation reduce worker and environmental risk and the potential of contaminant release in the effluent. The long-term stability of the final waste form is dependent on effective stabilization system operation and proper loading factors of stabilizing agents. Long-term stability must be measured after wastes are produced; however, at this stage of design, this information is not available.

6.0 SYSTEMS DESCRIPTIONS AND EVALUATIONS

6.1 Technical Descriptions of Each System

Approximately 75 percent of the incoming waste was assumed to require sorting into homogeneous and heterogeneous wastes and to require size reduction. Debris, bulk metals (especially lead), and elemental mercury are segregated.

The Air Pollution Control (APC) Subsystem is the major common subsystem. The APC uses several unit operations: a sintered metal filter, pre-filter, a gas phase corona reactor (GPCR) unit, a wet gas scrubber, mist eliminator, activated carbon for trace organics removal, sulfur impregnated activated carbon for trace mercury vapor removal, and a system for continuous emissions monitoring — all at or near standard temperature and pressure.

Aqueous waste treatment is also common among all systems. Aqueous wastes were treated to meet RCRA standards, the Clean Water Act, and the Universal Treatment Standards.

6.1.1 System 1 — Grout Debris Case

Organic destruction is by Mediated Electrochemical Oxidation (MEO). Wastes are pumped into a primary reactor containing an electrolyte of silver (Ag II) ions and nitric acid. In this highly reactive environment, the organics are broken down into harmless constituents such as CO₂ and water with a 99.99 percent destruction removal efficiency.

Inorganic sludges and bulk soils are treated in an indirectly heated vacuum desorption dryer to remove volatile organic compounds. Some volatile inorganic compounds (such as mercury) are sent to leaching or ashing operations for remaining trace mercury removal. All three types of debris are grouted without being segregated or treated. In Systems 2 through 5, the debris is treated before grouting.

Metal is sized and then decontaminated in blasting booths. It is then assayed and recycled where possible in the DOE complex. Contaminated liquid is treated and recycled; grit is processed through the residue treatment subsystem.

The grout stabilization subsystem receives treated soil, untreated debris solids, internally contaminated metal waste, lead waste that cannot be decontaminated, and other solid materials from throughout the system. Complex debris is not shredded, but put into drums and grouted in place (macroencapsulation). The process assumes disposal in an earth mound and concrete cell concept in engineered disposal units designed in 1991 by MK and Chem Nuclear Services. RCRA and non-RCRA disposal requirements are essentially the same, except for the double leachate collection system.

6.1.2 System 2—Desorption Case

This system was studied to explore improved debris treatment through vacuum desorption. The key changes over System 1 are an organic destruction subsystem based on catalytic wet oxidation and debris treatment, along with inorganic sludge, process residue, and soil treatment using a vacuum thermal desorber and mercury removal process. Aqueous treatment, APC, metal decontamination, lead recovery, grout stabilization, and polymer stabilization are the same as System 1.

Organic destruction is accomplished with a catalytic wet oxidation process that uses an iron catalyst to enhance oxidation of organic contaminants. Operations take place at 20 psi above atmospheric pressure and between 300 and 400° F.

6.1.3 System 3—Wash Case

This system has several washing approaches for the treatment of process residue and sludge, soil, and debris. Due to the processing of wet, as opposed to dry, solids outputs from residue, soil, and debris treatment subsystems, these washing approaches have larger mass throughput. Otherwise, this system is identical to System 1.

6.1.4 System 4—Acid Digestion Case

This system is also a variant of System 1. It was selected for study (1) to examine the use of a strong acid medium to dissolve and subsequently destroy organic wastes and soft debris, and (2) to examine the use of phosphate bonded ceramic (often called phosphate bonded cement) as a partial substitute for polymer and grout in the stabilization subsystem.

This system couples acid digestion and 19 other subsystems with the following major differences from Systems 1 to 3: (1) the acid digestion subsystem for organic wastes, (2) the acid digestion subsystem for soft debris, and (3) the phosphate bonded ceramic subsystem for soils, insoluble salts, process residues, and inorganic sludges.

The phosphate bonded ceramic stabilization subsystem treats the process residues from the thermal desorber, the organic and soft debris acid digestion subsystems, and treated soil. A polymer is used to stabilize salts such as sodium chloride (NaCl) to reduce leaching as the ceramic is somewhat porous, and grout is used to stabilize untreated complex debris.

6.1.5 System 5—Catalyzed Wet Oxidation Case

System 5 substitutes catalytic wet oxidation (CWO) for treatment of both soft debris and organics to permit a direct cost and performance comparison with System 4.

This system uses vacuum thermal desorption for process residue and inorganic sludge, aqueous wash for soil, high pressure wash for open debris, and grouting for complex debris. As in System 3, the polymer subsystem has a larger throughput than System 1. As with System 4, a slower reaction time is expected and a larger vessel with a longer residence time is required. Most inorganic components in the soft debris are converted to insoluble oxides of salts that are removed from the acid mixture by filtration and sent to polymer stabilization. Treated soil and inorganic debris are grouted.

6.2 Summary of Technical Evaluations

All five INTS systems provide varying degrees of compliance with both the technical criteria and the tribal and stakeholder criteria principles.

The most aggressive (in terms of organic destruction) treatments can decrease waste volumes by destroying the organic waste. Wastes capable of complete breakdown into gases include organic liquids, organic sludges, and soft or combustible debris. The consequences of oxidizing more of the organic waste is higher offgas volumes. Also, the more aggressive technologies have less performance risk but require more robust and costly designs to reduce safety risks.

The thermal desorption and washing systems may not adequately remove all organics. Effective removal depends on the organic contaminant and surface characteristics of the waste matrix. The vendor demonstrations reviewed did not yield sufficient information to decide definitively whether the systems and technologies will perform as required with modifications to the equipment or operating procedures. It is not known what the reaction byproducts in the aqueous or gas phases will be produced.

For all the INTS systems, worker and environmental risk (while not quantified in the current study), as well as the potential of contaminant release in the effluent, is minimized by proper system design and operation. The long-term stability of the waste

forms is dependent on effective stabilizing operation and proper loading factors of stabilizing agents. At this conceptual design stage, this information is not available. Additional research and demonstration will be required to quantify this parameter.

7.0 DEMONSTRATION, TESTING, AND EVALUATION NEEDS

A production-scale facility for treatment of DOE MLLW must satisfy several objectives: (1) meet current and future regulatory requirements; (2) be responsive to tribal and stakeholder principles; (3) reduce public and worker health risks by minimizing releases to the environment; (4) produce a waste form that ensures long-term isolation from human contact once it is disposed; (5) be an acceptable, available process, and (6) optimize cost. Therefore, a responsive and efficient technology development program would: (1) evaluate initial technologies, (2) perform bench scale testing, and (3) select one or more parallel technologies for prototype demonstration.

Most nonthermal technologies are at the bench or laboratory scale of development (e.g., chemical wet oxidation, acid digestion, and mediated electrochemical oxidation). Some, however, are at the small pilot scale level (gas phase corona reactor [GPCR]; vacuum thermal desorption, and washing technologies). Before a prototype can be considered, these technologies must be developed and tested at a sufficiently large pilot scale to validate laboratory/bench scale results and provide information for scale-up to production capacity. Pilot scale testing must also show applicability to as wide a variety of MLLW as possible, and mitigate safety and environmental risks.

Several subsystems possess uniform development needs, primarily because the same (or substantially the same) subsystems are used for each as below:

Common development needs among all five systems:

- extensively test their operations on mixtures
- establish their ability to meet EPA UTS
- establish kinetics
- resolve corrosion issues
- establish better costs
- resolve waste form issues
- characterize APC performance
- evaluate byproducts and products of incomplete reaction
- evaluate operating conditions and optimal process design

Following are specific development needs for each of the five systems:

System 1 – Grout Debris:

- design of the appropriate thermal desorber as a function of the solid matrix and organic contaminant
- determine the fate of mercury, radionuclides, and organics in the desorber
- test the ability of grout to stabilize organically contaminated debris

System 2 – Desorption:

- determine operating conditions of the thermal desorber for various feed types (plastics, combustibles, process waste)
- feed sorting requirements to reduce upsets

Since catalytic wet oxidation is part of the process, many CWO-related issues must be resolved, e.g., the need to test its destruction effectiveness on organic liquids and sludges, the need to detect best and safest operating conditions, and the need to resolve material compatibility issues.

System 3 – Washing:

- determine extent of waste characterization required
- validate surfactant selection
- evaluate ability to remove different contaminants from varied soil matrices
- determine fate and release of volatile components during washing process

System 4 – Acid Digestion:

Pilot scale testing is necessary to validate bench scale tests to:

- evaluate corrosive properties of acid
- test the destruction effectiveness on organic liquids and sludges and combustible debris

- evaluate fate of RCRA metals and radionuclides
- evaluate methods of recycling acids and metals from the reagent
- develop methods to separate HCl and nitric acid

System 5 – Catalyzed Wet Oxidation:

Pilot-scale testing is necessary to validate total CWO operation:

- evaluate destruction efficiency (DE) for mixtures of organic liquids, sludges, and combustible debris
- evaluate methods to separate precipitated solids from the acid solution
- evaluate methods to recycle acids and catalysts

8.0 CONCLUSIONS

System studies are generally useful to evaluate performance and cost of mixed waste processing options. Since only approximately 20 percent of the DOE MLLW is combustible and treatable by thermal or chemical destruction, other subsystems are needed. The balance of solid matrices requires either: treatment under the debris rule; thermal treatment to destroy organic contaminants, followed by stabilization; or removal of organics by washing or thermal desorption followed by chemical destruction of the organics and stabilization of residual solids. Land use requirements for the treatment system do not vary significantly; land use requirements for disposal vary about 30 percent.

(1) Cost and performance uncertainty for the INTS nonthermal systems is great:

- Few nonthermal technologies are commercially available
 - Only UV photo-oxidation and some soil washing applications are commercialized
 - Most technologies are at laboratory or small pilot scale
 - Minimal operating experience exists with limited contaminants and matrices
 - Waste form recipes for grout and polymer must be validated

- Twenty-five percent cost contingency which was applied to ITTS and INTS systems may be greatly understated for INTS systems
- Little or no volume reduction is produced using nonthermal technologies
 - Low temperature waste forms require large quantities of stabilizing reagents or agents
- Low volume gaseous emissions
- Life cycle costs differences among nonthermal systems are small
- Major cost elements: operations and maintenance, disposal, and capital
- Major subsystem costs: front end handling, certification, shipping, and stabilization of disposal waste

Results of the INTS study show that perhaps a hybrid system study, using the most promising thermal and nonthermal technologies in a complete system, might be in order. Vitrification of the final waste form, for example, would result in lower costs by reducing waste volume. However, offgas volumes could likely increase.

- (2) Nonthermal systems total life cycle cost (TLCC) are higher than thermal systems although there is not as much confidence in the certainty of the numbers:
- TLCC is modestly affected by the choice of primary nonthermal treatment technology (approximately 5 to 10 percent of TLCC). Thus, reliability, performance, and safety are most important features
 - TLCC for nonthermal systems, including disposal, is 40 to 60 percent higher than thermal systems
 - TLCC for nonthermal systems, including disposal, varies by 7 percent; TLCC for thermal systems varies by 20 percent
 - For nonthermal systems, disposal costs are 20 percent of TLCC; for thermal systems, disposal costs are 11 percent of TLCC
 - Process selection should be based on system performance, reliability, and technical risk versus technology cost

- O&M costs are 45 percent higher for the average nonthermal system than thermal – performance uncertainty could further increase these costs
- Energy costs are not discriminators for either type of system – less than 1 percent of TLCC
- The “best” available APC subsystem capital costs are about 5 percent of TLCC for thermal and 2 percent for nonthermal – so why not use the best?
- Where contaminated soil can be used as a glass former during vitrification, processing unit costs are reduced by 10 percent or a 10 percent opportunity cost incentive can be realized
- For both thermal and nonthermal systems:
 - O&M (50 to 60 percent of TLCC) represents the major cost driver
 - Process availability estimate can significantly decrease or increase TLCC estimates
 - major subsystem cost (25 to 30 percent of TLCC) is front-end handling – characterization, sorting, preparation
 - capital costs range from 17 to 24 percent of TLCC (equipment and construction)
 - the 25 percent cost contingency does not properly reflect programmatic risk of the technologies

(3) The relative immaturity of nonthermal systems means far less certainty of the cost estimates:

- nonthermal systems consist of immature process technologies; destruction and removal efficiencies are not well established for all contaminants or waste matrices
- lack of pilot scale experience with nonthermal system operations makes performance and cost estimates highly uncertain
- compliance with applicable UTS regulatory requirements is uncertain

- nonthermal stabilization (grout or polyethylene) generates disposal volumes two to three times the disposal volumes compared to a vitrification process
 - larger number of nonthermal subsystems to operate and maintain
 - potential for system corrosion, larger number of subsystems, sorting, and a higher volume of wastes shipped for disposal results in increased need for operations and maintenance personnel
 - implementation schedule for nonthermal systems would be 5 to 10 years longer than a thermal system due to immature state of development
 - nonthermal offgas volumes are an order of magnitude less than the offgas from the thermal systems
 - liberation of volatile metal compounds in offgas is a non-issue
- (4) Thermal systems are, overall, more mature; therefore costs are better known:
- thermal systems are generally simpler
 - main thermal treatment process can treat a larger fraction of the total DOE waste inventory
 - vitrification of treatment residues maximizes volume reduction
 - thermal systems are expected to meet current and proposed regulatory requirements (UTS and DRE)
 - incineration-based thermal systems are mature:
 - Incineration-based systems are well developed
 - Vitrification of ash from incinerators requires demonstration but is feasible, based on experience
 - innovative thermal systems (plasma, molten metal) present the greatest risks (costs, schedule, health and safety, and environment, plus they have no commercial experience on hazardous or radioactive waste)

- thermal systems produce high offgas volumes and require high performance APC systems to control volatile metals and PICs (however, nonthermal systems may also require complex APC systems due to the chemical complexity of the offgas, although the volume will be less)

(5) Environmental-related observations and conclusions:

- volume of effluent gases (usually inert O₂, N₂, CO₂, H₂O) from nonthermal treatment systems is less by a factor of twenty compared to thermal systems using rotary kiln incineration and air for combustion
- steam reforming and molten metal destruction produce no liquid effluents
- based on bench-scale vendor data, nonthermal systems are expected to have 80 percent to more than 99 percent organic removal efficiency from solid matrices. Thermal systems have a 99.99 percent organic removal and destruction efficiency
- nonthermal treatments produce little volume reduction and the final disposal volume is about three times that from thermal treatment systems using vitrification

(6) General Observations:

- thermal systems operating in a limited air mode to produce carbon monoxide and hydrogen have the potential of being accepted by stakeholders as a non-incineration process method and may be permissible under RCRA Subpart X (e.g., molten metal and steam reforming). However, precautions for potentially explosive gas mixtures is an added concern.

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