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Integrated Thermal Treatment Systems Study

U.S. Department of Energy Internal Review Panel Report

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INTEGRATED THERMAL TREATMENT SYSTEMS STUDY
INTERNAL REVIEW PANEL REPORT
EXECUTIVE SUMMARY

The U.S. Department of Energy's (DOE's) Office of Technology Development (OTD) commissioned two studies to uniformly evaluate nineteen thermal treatment technologies. These studies were called the Integrated Thermal Treatment System (ITTS) Phase I and Phase II. With the advice and guidance of the DOE Office of Environmental Management's (EM's) Mixed Waste Focus Group, OTD formed an ITTS Internal Review Panel, composed of scientists and engineers from throughout the DOE complex, the U.S. Environmental Protection Agency (EPA), the California EPA, and private experts. The Panel met from November 15-18, 1994, to review and comment on the ITTS studies, to make recommendations on the most promising thermal treatment systems for DOE mixed low level wastes (MLLW), and to make recommendations on research and development necessary to prove the performance of the technologies on MLLW.

The ITTS evaluated thermal treatment technologies integrated into systems that could likely be implemented as regional treatment facilities for MLLW typical of that in the DOE complex. The Panel's primary observations are:

Thermal Treatment Technologies

- The integrated systems that appear to have the most versatility (capability to treat a wide variety of waste) include variations of the rotary kiln, plasma arc, and direct vitrification.

  -- These systems accommodate coarser shredding, bulk metals, and are insensitive to wide variations in waste composition. These features were viewed as positive and important attributes for DOE processing needs.

  -- Rotary kilns are based on extensive industrial experience, while the plasma arc technology is still under development. The slagging rotary kiln offers the advantage of a "one-step" process with extensive industry experience. Industrial slagging kiln experience with hazardous waste indicates considerable versatility, but information is lacking on the limits for MLLW compositions that could be processed to maintain slagging and production of a suitable final waste form.

  -- Direct vitrification needs further development to confirm the degree of its perceived versatility on combustible wastes.

  -- The Panel is keenly aware of the current public debate concerning incineration vs non-incineration. While it feels in many respects that incineration is still the best method to treat DOE MLLW, it strongly recommends that non-thermal systems be analyzed with the same degree of rigor as were the thermal systems in the ITTS studies.

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- The systems using molten metal, molten salt, fixed hearth incineration, and steam reforming are more limited in versatility are presently developed because of the need for waste shredding to smaller-sized particles (e.g., 1/4 inch).

  -- The limited capability of molten salt, fixed hearth incineration, and steam reforming to handle inorganic wastes or large quantities of noncombustibles, caused uncertainty regarding acceptance of wide variations in waste feed composition, especially wastes with high ash content.

  -- Molten salt and steam reforming systems will likely require significantly more waste sorting than many of the other systems considered in the study.

- Molten salt oxidation (MSO), Mediated Electrochemical Oxidation (MEO), and supercritical water oxidation (SCWO) appear to be potentially suited for special waste streams rather than applicable to the broad mix of DOE solid wastes.

- Although energy costs vary among the systems from about $20 to $400 per hour, the energy costs for most of the best systems are not significant when compared to the overall total life cycle cost (TLCC).

Air Pollution Control and Monitoring

- The ITTS study used a dry/wet reference air pollution control (APC) system with high efficiency particulate air (HEPA) filters as the off-gas control component for most of the systems.

  -- The Panel noted that this may be a better APC system than has been typically used in DOE thermal treatment systems or in the hazardous waste industry and should perform very well.

  -- Uncertainty exists on the extent of dioxin generation and optimal location of wet scrubbing in such a system. The system as specified is worthy of detailed engineering analysis and operations testing.

    -- Alternate systems using wet scrubbing have kept dioxin production low but have sludge and corrosion problems. Uncertainty exists on the reliability, longevity, or cleanability of HEPA filters depending on the dust loading that may be imposed on them.

    -- Radioactive dust and associated personnel exposure during maintenance of fabric filter baghouses is a concern. The acceptability of bag filter use in an alpha radiation environment needs verification. APC system maintenance in a radioactive environment will be problematic.

- Although large reductions (factor of 10) in the amount of effluent gases are achievable among the 19 systems evaluated, (e.g., 25,000 to less that 2500 pounds per hour), this is not considered to be a major consideration in comparing systems or affecting emissions. Reduction in gas flow does, however, reduce the size of the APC and its costs and allows for more innovative off-gas management techniques.

Immobilized Waste Forms

- It is clear that a highly stable and inert solid product would be advantageous. A vitrified or ceramic-like product is the leading candidate for such a waste form. It should reduce costs, reduce risks, be relatively insensitive to future changes in waste acceptance criteria of various disposal sites, and be relatively easy to make with various technologies.

- With high temperature vitrification, attention must be paid to control of volatilization of metals and radionuclides. Consideration of the use of "cold caps" or similar means should be given to reduce volatilization.

Overall Costs

The ITTS study stressed a combination of modular systems to assure efficient processing of all DOE wastes. Cost-related conclusions of the Panel:

-- Cost variations among the systems were not large enough to make Total Life Cycle Costs (TLCC) an overriding consideration; variations should not be simply ascribed to the thermal treatment technology employed

-- 20-year TLCC of a complete system to process 2900 pounds per hour of MLLW (designed to take about 1/4 of the total DOE MLLW in inventory within a period of 20 years) could vary from $2 to $3 billion depending on the process selected. The TLCC's calculated are for fully integrated, complete systems

-- The lowest cost systems used the slagging rotary kiln, plasma arc, molten metal, or direct vitrification for thermal treatment

-- Distribution of costs: 50% of TLCC for operation and maintenance
10% for waste disposal costs
20% for capital costs
30% for other

-- System costs would change if the assumed waste input was changed from what is essentially a DOE complex average to one reflecting other site treatment scenarios

Recommendations

The Panel notes that the ITTS Phase I and II studies were a useful start and for the first time put MLLW thermal treatment technologies on a technically comparable basis. The studies focused predominantly on high temperature thermal technologies, primarily incinerators, and only included two non-thermal technologies, MEO and SCWO.

The Panel strongly urges inclusion of other non-thermal 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 non-thermal studies would be helpful for stakeholder considerations and could form the basis for later selection of specific technologies.* Also, the ITTS study could be used as a reference basis for individual site evaluations of technology options in the future.

Accordingly, the ITTS study should receive wider distribution than it has to date. Discussions of the study with individual DOE sites would be helpful in defining future analyses that are needed. The Panel notes that the ITTS study emphasized costs more than performance or risks and suggests that future studies include information on performance and risks.

Finally, the Panel agrees that the DOE sites are in great need of a DOE repository of comprehensive data on systems costs and risks for thermal treatment including melters. There should be a repository for such data that centralizes all the knowledge from both Principal Investigators and practitioners regarding incinerators and other thermal treatment techniques. The data need to be compiled in a comprehensive enough manner to support permit applications or rule-makings should that be needed in the future.

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ITTS INTERNAL REVIEW PANEL REPORT

Background

The U.S. Department of Energy's (DOE's) Office of Technology Development (OTD, EM-50) started an Integrated Thermal Treatment Systems (ITTS) study in June 1993. The purpose of the study was to evaluate thermal treatment technologies as part of a complete waste treatment system and evaluate the state of development, the probable costs, and the required research and development to implement the technologies. The DOE Office of Waste Management (WM, EM-30) and the Office of Environmental Restoration (ER, EM-40) provided review and guidance during the formulation and progress of the study. Phase I (Reference 1) of the study produced mass balance and flowsheet analysis and comparison of ten incineration and related thermal treatment technologies, together with accompanying documents on the DOE mixed waste data base (Reference 2) and status of waste shredding technology (Reference 3). In November 1994, a draft of Phase II (Reference 4) was issued on nine additional mixed waste thermal treatment alternatives.

From November 15-18, 1994, OTD convened an Internal Review Panel (hereinafter, the "Panel"; see Appendix A for members and qualifications) to: (1) evaluate and comment on the Phase I and Phase II documents, (2) prepare major technical statements on the attributes of the technology systems and their uncertainties relevant to the Federal Facilities Compliance Act (FFCA) criteria (Reference 5, developed by WM), and (3) identify and recommend research and development needs required to implement the most noteworthy technology systems.

The Panel was convened by Carl R. Cooley, EM-54 (now EM-52), the DOE-HQ program manager of the ITTS, and staffed by his support contractor, Gary Knight (also this review's chief editor) of the Waste Policy Institute, which hosted the review. Also contributing were the major authors of the ITTS studies, William J. Quapp, INEL; Blaine Brown, INEL; and Fred Feizollahi, Morrison Knudsen. EM-30 also provided David Camp, LLNL, and Lee Borduin, LANL, who provided valuable insight and input. Thanks are extended to them and the Panel for their efforts and assistance.

I. Panel Comments on the ITTS Study

The ITTS study addressed treatment of an "average" DOE waste. The average was defined by using the site-provided waste profile data (Reference 6, MWIR-1) from the twenty largest DOE stored mixed waste inventories. This waste profile was then combined on a mass-averaged basis to derive the "average" profile (Reference 2). From the average profile, the chemical composition was generated for use in the mass and energy balance calculations. This average profile will not exactly match any specific site but was judged to be representative of the wastes arriving for processing if regional treatment at a few DOE sites is selected as the DOE MLLW treatment strategy. If treatment at all individual DOE sites is the selected option, this "average" profile is only likely to be representative of the largest DOE sites. It was on this basis that the ITTS study was produced and that the Panel was asked to review and comment on the technologies.

It should also be pointed out that time and resource constraints precluded every potential usable combination of thermal treatment technologies from being examined under the ITTS study. EM-50 convened meetings of scientists and engineers from around the DOE complex in the late summer and fall of 1993 to narrow the candidates for inclusion in Phase I of the ITTS. A similar meeting was held in March, 1994. This time DOE headquarters and field personnel from EM-30 and EM-40, representing a newly formed Mixed Waste Focus Group, were convened to perform the same function for Phase II.

One clear need that has been recognized by stakeholders and by members of the Panel is the need for a comparable evaluation for non-thermal treatment technologies. The Panel recommends that such a study can be expeditiously accomplished. This next phase might also include some thermal systems that resource constraints caused to be left out of ITTS Phases I and II.

II. Cost Implications

The ITTS Study focused primarily on material balances and cost estimates for the evaluation of various treatment systems. The ITTS Study developed life cycle cost estimates of the processing systems by developing the following on a common basis:

- Mass balances
- Functional allocation diagrams
- Lists of required equipment
- Facility layouts
- Staffing requirements

Construction costs for all equipment and buildings were combined with very rough estimated research and development, demonstration, testing and evaluation (RDDT&E); operating; and decommissioning costs to arrive at a total life cycle cost (TLCC) estimate. Disposal cost of treatment residuals was developed on the basis of a mass (volume) balance with a unit disposal rate

applied to the materials produced for disposal.

The study shows that the ratio of capital to total life cycle costs varied among the systems. Figure 1 shows the normalized comparison of these costs. The range of total life cycle cost with disposal varied within a range of about 30% with most one-step treatment systems such as plasma, joule melter, and molten metal technologies being on the low end of the cost range (Figure 2). The slagging rotary kiln is the exception where this one-step processor has had extensive use for the treatment of hazardous waste. This system was also at the lower end of the cost range.

For the baseline system (air-fired rotary kiln with vitrified waste form), treatment of lead, mercury, metals, and special wastes represents about 32% of the total waste throughput and 13% of the total life cycle costs. Support subsystems (receiving, sorting, shipping, etc.) represents about 47% of the total cost. Thus, of the total cost for the baseline system, only 31% is directly associated with the primary treatment system (incinerator, air pollution control, vitrification of ash, stabilization of salt, aqueous waste treatment). The remaining 9% is disposal cost.

Although these cost distributions will be different for each of the systems, it is easy to see why the total system costs are not dramatically affected by the choice of the technology.

The Panel believes that the fixed contingency (25%) used in the study was acceptable for the more commercially-ready technologies but suggests *this contingency should be increased for some of the non-commercialized technology systems.* If higher contingencies are applied, cost advantages for the lower cost systems may diminish or disappear. Secondly, the study gave credit to the molten metal system for metal recycle (i.e., no disposal cost applied for the metal portion of the waste). If that metal is not recyclable (due to its potential radionuclide contamination), the disposal cost will further reduce the apparent cost advantage of using molten metal processing.

Based on the ITTS cost estimates, no significant cost advantage is evident for any of the technologies when considered on a total system basis. However, systems that vitrified the waste did cost less than those producing a grout or polymer final waste form due to the attendant reduction in disposal volumes. *For the baseline system, the cost advantage for vitrification over grout occurs when the disposal fee exceeds about* $\$58/ft^3$. This crossover point is believed to be high by 10 to 20% due to the assumptions used.

Operating cost is the largest element of the total costs and is the parameter most dependent on local site operating practices and regulatory requirements. *The dependence of operating mode and, therefore, operating costs on specific technologies has not been explored. This remains a major weakness of the study method.*

Uncertainties in the cost estimates are driven mostly by parameters independent of the treatment technology used. These include:

- Total volume of waste processed and processing capacity for a given set of process equipment;
- Uncertainties of vendor-supplied cost estimates for equipment (estimates versus firm competitive bids);
- Site- and technology-specific manpower staffing estimates;
- DOE reviews for items such as NEPA, Hazards Analysis, Safety Analysis, etc. (no allowance is made for DOE to learn by past efforts in any of these areas); and
- Uncertainties in DOE project financing schedules.

The ITTS study used constant FY 1994 dollars rather than discounted dollars. The use of discounted dollars will reduce the apparent life cycle costs but will not significantly change the differences among technologies evaluated.

The requirement for processing of environmental restoration (EM-40) wastes, consisting largely of solids and soils, was not included for any of the systems evaluated. The Panel is pleased that this will be considered in future studies.

III. FFCA Criteria/Evaluation Strategy

The Panel initially attempted to evaluate technologies based on the FFCA criteria evaluation guidelines developed by WM (EM-30). WM-developed FFCA criteria include treatment effectiveness; implementability; environment, health and safety; regulatory compliance; technology development; stakeholder acceptance; and life cycle cost. However, due to time limitations, specific evaluations were rejected because there would have been at least 418 discussion points -- 22 criteria applied to 19 technologies. Instead, treatment systems were grouped by commonalities, especially waste feed (metals, combustibles, and noncombustibles), final waste form, APC type, etc. Significant advantages, disadvantages, potential "fatal flaws" or "potentially major concerns", and issues for discussion and recommendation were identified for each ITTS system and evaluated with respect to the FFCA criteria and ITTS goals and assumptions.

The current FFCA criteria need to be adapted for recognition of issues associated with total systems. This is also true for the selection of technologies within the system for development and for selection of systems to be implemented by EM-30. For example, factors such as volume reduction, minimum waste pretreatment, ease of emission control, permitability, and ability of final waste form to be shipped were most useful for the Panel's purposes.

The life cycle cost differences were less significant than generally expected ($800-900 million out of approximately $2-3 billion). A selection process should include significant stakeholder acceptance issues such as hazardous emissions, performance during upset conditions, catastrophic failure potential, and final waste forms. *The Panel agrees that stakeholder needs should be addressed by involving them early in the planning process.*

To enhance technology permitability, the EPA Risk Reduction Engineering Laboratory and the DOE Rocky Flats Office have formed an Interagency Agreement (IAG) to exchange information on permitting of thermal treatment systems for mixed waste. This IAG formed the National Technical Workgroup (NTW) on Mixed Waste Thermal Treatment. The NTW is composed of permit writers (state and Federal EPA), DOE (HQ, sites, and contractors), U.S. Nuclear Regulatory Commission (NRC), citizen advisory groups, EPA (R&D and regulators), and other stakeholders. The NTW has reviewed technology selection criteria developed by others and has adapted these to their particular interests. The NTW technology evaluation criteria were developed and are available. *The Panel recommends that, due to the importance of permitability of thermal treatment units, the FFCA criteria be reviewed against the NTW evaluation criteria.*

IV. Versatility

Versatility of the primary thermal treatment subsystems is an important feature of any technology system required to process a major portion of DOE's MLLW. *The most versatile systems evaluated in the ITTS study included those involving a rotary kiln incinerator, plasma hearth furnace, and the joule melter.* None of these systems requires extensive shredding or waste sorting (joule melters require bulk metal removal, but other melters such as AC and DC arcs can accommodate metals). Even with blending of the waste, the physical and chemical composition is expected to be so variable that the treatment systems must be capable of accepting a wide variety of materials.

For example, the properties of glass and slag are dependent on chemical composition. The proper glass viscosity is required for discharge and flow through the vitrification equipment. The process tolerance to variations in chemical compositions must be determined and verified for any system using a melter.

Shredding and blending may be needed to "average" the incoming composition. For a rotary kiln, shredding and blending of all wastes to reduce variations in the combustible fraction and associated oxygen demand should be optimized to reduce challenges to the kiln seals by reducing system pressurization transients. The storage, mechanical handling, and feeding of shredded material may be a consistent operational problem due to bridging or sticking of material. The preferable method is to discharge directly into the thermal treatment unit from the shredder, but this restricts the opportunity to blend and sample the wastes. Thermal systems with good mixing and long residence time can dampen out these variations and reduce the demand for up-front blending.

Primary treatment technologies with lower waste acceptance versatility place a greater demand on up-front waste characterization. The range of pre-treatment (sorting and sizing) required for the various waste streams must be evaluated for each of the candidate primary treatment technologies. For some systems, techniques for sorting of metals and non-combustibles must be used that will be safe and reliable in radioactive service. Size reduction of waste streams for the thermal treatment unit becomes increasingly more difficult as the required waste feed size becomes smaller. Extensive size reduction of solids

is a requirement for some systems (MSO, molten metal, MEO, SCWO and fluidized bed gasification). This is a disadvantage for several of the systems when applied to treatment of solid wastes.

While versatility is a desirable attribute, achieving it may result in dealing with other problems. Issues began to emerge when the Panel discussed the use of some of the "omnivore" thermal treatment technologies for application in the DOE nuclear waste environment. Most of these operations issues originated from taking "off-the-shelf" metal-, or glass-processing technologies and trying to apply them to treatment of radioactive mixed waste containing RCRA (Resource Conservation and Recovery Act) organics. High-temperature arcs, plasmas, and molten metal baths would be needed to melt steel components in the mixed waste inventories. *These temperatures, often in excess of 1,700° C, cause maintenance and reliability concerns, especially during radioactive operations. Another concern is the volatility of radionuclides and hazardous metals.*

At the other end of the spectrum, there could be a multiplicity of narrow-band processes corresponding to a wide variety of waste types. Such narrow-band treatment may be better suited to individual sites with specific treatment needs than the full waste inventory treated in the ITTS study. The assumption of the study is treatment of DOE's full inventory at a centralized location. This precludes evaluation of needs for specialized technologies for site-specific wastes. In any event, there is a more general need for versatile systems.

The Panel considers the rotary kiln system with ash-vitrification (the "baseline system"), the slagging rotary kiln system, the plasma torch reducing (steam) or oxidizing (air) system, and the joule-heated vitrifier (especially the AC and DC arc melter systems) to be the most versatile (i.e., they are capable of accepting a high percentage of the combustible waste as well as non-combustible waste and have the potential of being flexible enough to accept wide variations in waste composition). *The long residence time and the mixing action of the rotary kiln provide the highest potential for accepting variations in chemical compositions.* In general, the Panel favors pretreatment operations that provided better homogenization of the waste before sending it to thermal treatment.

V. Performance

Two chief considerations guided this evaluation by the Panel:

1. *Operational Effectiveness.* The Panel feels that since none of the systems has been completely tested on DOE MLLW, sound engineering practice should lead the Panel to favor those systems that are mechanically and chemically less complex and those that have less potential for upset conditions and control problems.

2. *Final Waste Form.* Given the ever-evolving regulatory climate and the lack of a disposal site with well-defined waste acceptance criteria, the Panel also believes that a thermal product (vitreous

or glass-ceramic form) should be the preferred primary waste form. Cost figures from the ITTS study indicate a penalty does not have to be paid for this choice and, depending on the ultimate disposal cost, it may be lower when total life cycle cost is considered. It should be pointed out that the performance conclusions drawn here are based upon the ITTS study that evaluated essentially only thermal processes. Many of the processes evaluated have no operational experience and, therefore, there are no valid operational effectiveness nor cost data to be had. This must be recognized as a limitation for some of the technologies that appear in this analysis. The ITTS study did not specifically address non-thermal treatment scenarios.

From a performance perspective, ITTS systems such as A-1 (air-fired rotary kiln with dry/wet APC), A-7 (slagging rotary kiln), C-1 (plasma hearth), and J-1 (joule-heated vitrifier or other melter one step systems) are predicted to have the best long-term performance for systems producing a vitrified final waste form. The Panel also thinks that if a vitrified form was unnecessary, then the ITTS case A-5 (air-fired rotary kiln with polymer stabilization) would have a high level of predicted performance.

Based on work on vitrification in the EM-50 programs and some commercial firms, vitreous final waste forms appear to be the most long term or high performance waste forms. However, they do entail more complex processed for which there is only laboratory scale experience. The question might be posed, "Are they better than needed, considering the implementation risks?" Some DOE sites have previously used cement stabilization of the ash from incineration of low level waste (LLW). At INEL, cement stabilization of the Waste Experimental Reduction Facility (WERF) ash was usually successful in passing required leach tests (on occasion, the product failed such tests). Commercial processors of LLW have successfully used both cement and polymer resins. The latter are more expensive on a per pound basis but are justified by the higher effective loading and, thus, reduced disposal cost.

DOE sites, Brookhaven National Laboratory and Rocky Flats Plant, have been testing stabilization using polyethylene. This material appears to work very well for dry wastes and has high tolerance for salts (in contrast, most vitreous processes have very low salt tolerance). The polyethylene appears to be more chemically inert, thus, has broader compatibility with a wide variety of materials. Furthermore, waste loading is at least twice as high as for grouts (but less than 1/2 of a glass-ceramic such as iron enriched basalt). Lifetimes are difficult to assess but are expected to be very good in applications where the final forms are buried.

"A-1 like" systems are defined as the combination of thermal treatment in front of a vitrification system. "Thermal treatment" could be any number of systems ranging from rotary kilns to

thermal desorbers. Vitrification could be plasma, AC or DC arc, or perhaps even a slagging rotary kiln. A "C-1 (plasma hearth) like" system refers to a single-step generic plasma torch based. An "A-5 like" system refers to any thermal treatment followed by stabilization using grout or polymer, but not vitrification. The Panel feels that an important next phase would be an attempt to choose the best, most effective, most versatile, most appropriate thermal treatment and vitrification processes. See Table I for a summary of all nineteen technologies evaluated in the ITTS.

The Panel feels strongly that systems using "CO_2 retention" or "delayed release" (see the definition in the "Major Conclusions" section, Section XVI, of this report) would add complexity for the purpose of obtaining improved emissions control to assuage possible opposition from the public and regulators. Making them work will be a difficult, complex, and costly development project; however, it may be what is needed to become permitted.

Steam reforming technologies also do not appear to have a strong advantage unless a need for the resultant H_2 and CO gases ("syngas") is identified. Use of steam reforming cogeneration does not appear to be justified for DOE MLLW because of the low energy value of the total DOE MLLW waste stream (about 0.5 megawatts for a gas turbine on a steady stream basis). The cost of handling these potentially radioactive gases as fuel will tend to override any benefit. The potential safety concerns associated with syngas caused by the generation of this flammable gas probably overshadow the potential reduction in dioxin emissions.

The Panel feels that the molten metal process appears to require substantial technical development work. Specifically, the Panel is concerned about the generation and carryover of pyrophoric metals to the baghouse, generation of an flammable gas, significant feed grinding, offgas system plugging, and excessive dust. The Panel also feels that MEO, MSO, and SCWO are "niche" technologies that may have potential for isolated use on specific DOE wastes, but they require unneeded complexity if used as a fully-integrated system to process all of the DOE's MLLW.

Finally, *the Panel notes the lack of performance data on the technology systems and strongly suggests more experimental data be developed on performance as a function of feed characteristics, feed rates, particulate entrainment, metals volatilization, and containment for the most promising systems.*

VI. Safety

Although safety is an issue that is usually addressed during the design stage of a facility, *the Panel urges strong consideration of the safety issues of the various technologies during the development stage.* From the information available on the technologies, it is apparent that safety issues have not received the attention they warrant particularly for considering which technologies should be developed by the DOE for waste streams containing radionuclides. Also, permitting from a safety point of view must be more

integrally entered into planning, research, and development of these technologies. Further, *the development data should provide key safety information upon which safety analysis reviews can be prepared.* Examples of such concerns include:

1. For the reducing systems including steam reforming, pyrolysis, and molten metal, the gases produced during treatment (H_2, CO) are potentially explosive if leaked from the system or if air leaks into the system. Explosive limits need to be determined to show the margin of safety available and what steps are necessary to avoid unsafe conditions.

2. The volume, mass, and energy to propagate explosions or pressure excursions available in a system need to be carefully analyzed because of the inherent highly negative consequences associated with release of radioactivity during an incident. This could preclude the use of an industrial process that normally operates under conditions that cannot be tolerated in radioactive operations. Generally, the higher the temperature or pressure (stored energy in the system), the greater the safety consequences. This is an important issue for molten metal technology, super critical water oxidation, plasma torch operation under reducing (steam reforming) atmospheres, and all steam reforming processes. The vitrification systems do not have the problems associated with the gasification systems, but they do have an inventory of molten material that must also be considered in the safety assessment. (Note: Systems without molten materials may present other hazards associated with finely divided alpha-contaminated radioactive material dispersal from unsolidified ash -- e.g., the grout systems.)

3. Pyrophoric APC residues occur primarily in high temperature, reducing systems like the molten metal system and some of the vitrification processes. Adequate protection against fire within the system must be established. For example, baghouses downstream of treatment systems can potentially collect ignitable particulates (finely divided pyrophoric carbon and/or metals) that increase the risk of fire even though a water quench of the gases is used before the baghouse. This concern occurs for situations where there is a possibility of failure of the water quench system or if the dry APC dust is exposed to air (e.g., during down-times).

4. Conventional (OSHA-type) industrial accidents are a major safety factor that must not be compromised in trying to address the more exotic safety aspects associated with hazardous and radioactive materials processing.

VII. Development Status

The development status was difficult to determine based on the information provided to the Panel. Even though some of the technologies have been in industrial use for years, their use as a system for MLLW was generally first-of-a-kind. This fact stressed the importance of considering a complete system rather than a single component of the technology. In turn, inserting an otherwise-proven thermal unit into a system with minimal DOE treatment experience caused higher uncertainty about the overall system's development status.

The Panel feels that the development status of the ITTS systems seemed to be as follows:

Technologies likely to be ready for implementation on MLLW within the next five years (Note: technologies are listed in no particular order within each timeframe):

Rotary kiln, air fired, wet/dry APC (A-1)
Rotary kiln, air fired, wet APC (A-3)
Rotary kiln, air fired, polymer stabilization (A-5)
Rotary kiln, air fired, thermal desorption (E-1)
Rotary kiln, oxygen fired (A-2)
Indirectly fired pyrolyzer (B-1)
Joule-heated vitrifier (J-1)
Plasma torch furnace (C-1)
Slagging rotary kiln (A-7)

Technologies likely to be ready for implementation on MLLW more than five years hence:

Plasma gasification (C-3)
Gasification/Steam reforming (H-1)
Mediated Electrochemical Oxidation (K-1)
Rotary kiln, oxygen fired, CO_2 retention (A-4)
Rotary kiln, air fed, maximum recycle (A-6)
Plasma furnace, CO_2 retention (C-2)
Fixed hearth pyrolyzer, CO_2 retention (D-1)
Molten salt oxidation (F-1)
Molten metal destruction (G-1)
Supercritical Water Oxidation (L-1)

See Section XVII for details supporting the foregoing. Systems are comprised of several subsystems, each with their own development status that had to be averaged.

The Panel notes the difficulty of determining the state of development because of the shroud of "proprietary information" on some technologies and lack of

substantial data on others.[1]

VIII. Risk

The Panel notes that there was no risk evaluation data yet available on any of the technology options. While some risk information was developed for the EM PEIS, *it needs to be adapted and extended to determine if the "risk tool" can assist in discriminating in the selection of treatment systems or whether the level of risk is so low as to not be meaningful.*[2] This should particularly be applied to the potential reduction in risk through improved waste forms such as glass, polymers, etc. The Panel notes some doubt about the long-term acceptability of polymer without data on long term tolerance of alpha radiation.

IX. Recommended R&D and Engineering Needs

The Panel endorses the technique used in the ITTS study to compare technology options serving the same functions within the process flowsheets. A detailed Panel discussion of the potential advantages and disadvantages (see Appendix A) of each of the ITTS systems led to a list of RDDT&E needs (see Section XVII). Of the thermal treatment technologies evaluated, those identified as needing the least R&D were those that have been demonstrated in full-scale radioactive or commercial hazardous waste processing service. Other issues not specific to particular types of thermal treatment, APC, or stabilization technologies were raised at the system level and can be addressed by engineering analysis and pilot-scale experimentation.

The following areas were identified as requiring research, development, and ultimately demonstration prior to full-scale implementation in mixed waste service:

A. Waste Feed Pre-treatment, Sorting, and Size Reduction

Thermal treatment technologies with lower waste acceptance versatility (i.e., require more extensive size reduction) place a greater demand on up-front waste pre-treatment. The range of pre-treatments (sorting and size reduction) for the various waste streams must be evaluated for each of the selected thermal treatment technologies. *For the less versatile technologies to be used, techniques for sorting of metals and non-combustibles must be developed that will be safe and reliable in radioactive service.* Size reduction using

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[1] Some Panel members question the validity of this protection of information considering that patents can be protected through appropriate note book recording. The impact of proprietary protection on market position of a company was not clear. However, it is essential that performance information be made available to any Panel evaluating a technology if judgments are to be made about its acceptability for inclusion into a waste treatment system.

[2] With highly efficient APC systems, stack emission risk will be very low for all or most systems. However, risks need to be calculated for the combustible gases, pyrophoric APC residues, etc.

conventional shredders for solid wastes will allow smoother operation of the thermal treatment unit. Size reduction becomes increasingly difficult for technologies that require smaller particle size feed streams. Acceptable size ranges must be established for all the technologies under final consideration. The ITTS study's coverage of waste shredding (Reference 3) is a first step in understanding the cost and impact of size reduction on integrated waste treatment systems. Conventional shredding is widely used in hazardous waste treatment systems. Fine shredding as required for MSO, SCWO, MEO, and molten metal has not been done before on heterogenous waste (plastic, wood, glass, sludge, cement, etc.) in radioactive service.

B. Primary Thermal Treatment

The issues critical to successful implementation of specific primary thermal treatment technologies include: (1) organic destruction performance; (2) versatility with regard to waste acceptance; (3) characteristics of the primary effluent to be treated in second stage destruction; (4) characteristics of the offgas emissions and the demands placed upon the APC system; (5) the type of gaseous atmosphere in the treatment system (i.e. oxidizing v. reducing mode); (6) total distribution of organic reaction products and organic particulate in the second stage combustion chamber; (7) secondary waste generation and volume reduction; (8) safety and risks associated with normal and upset conditions; and (9) operating costs which are a function of waste throughput capacity.

Some of the thermal treatment technologies that offer the potential for greatest versatility, i.e., those that function as single-step waste processors, generally require the greatest amount of development (and may not succeed or be worth the development effort as single-step processes). *The Panel feels that future R&D needs should focus on the above criteria for the potentially most "omnivorous" technologies -- slagging rotary kiln, plasma (AC or DC arc and plasma torch), and direct vitrification processors.*

A continuing evaluation of technology development status and process control, safety, and reliability needs to be maintained. It is not completely apparent that the omnivorous technologies are safe, reliable, and economic. The baseline system -- a rotary kiln combined with vitrification of the ash -- is a versatile system requiring a minimum of development or demonstration. The slagging rotary kiln is a one-step processor that is also expected to require minimal development and demonstration. Likewise, direct vitrification will require minimal development and demonstration except in the area of handling high organics in the feed. Combustion of organics in the head space above the glass melt in the vitrifier needs to be demonstrated.

C. Air Pollution Control (APC) Systems

The composition of products of incomplete combustion (PICs), (dioxins, particulates, metals, radionuclides, soot, acid gases, etc.) and flow rate of the gaseous effluents from the primary thermal treatment unit sets the design requirements for the APC. These requirements may also strongly affect public acceptance of the treatment system. The primary treatment units under

consideration should be assessed in detail with regard to the partitioning of metals, the partitioning of radionuclides, particulate entrainment, and production and subsequent removal of PICs, dioxins, soot, carbon monoxide, acid gases, etc. Full understanding is needed of the improved destruction of each of the foregoing in extended or modified secondary combustion chambers (SCCs).

Due to the likely increase in the Federal regulatory requirements for emission control of incinerators, other thermal treatment devices such as industrial boilers and thermal treatment units in general, substantial increases in the capability of APC systems to control various emissions will be necessary. Improvements in APC performance are expected to be possible with existing commercial technology when components are combined in an appropriate system with emphasis on performance over cost. With respect to incineration of MLLW, this is probably the key element in gaining the public's trust for the thermal treatment of such wastes. Finally, *emission monitors sensitive to the currently regulated low concentrations of pollutants should be aggressively developed.*

D. Final Waste Form

Contaminated soil was added to the final waste feed in most of the ITTS thermal treatment units to provide the "additives" needed to form a suitable glass-ceramic final waste form. Contaminated soil was presumed to be available for the melter. Idaho National Engineering Laboratory (INEL) studies have shown that, for most wastes, a soil addition of 40 to 60% by weight to the combustion residues produces a high integrity final waste form. Using contaminated soil may provide a benefit of treating waste streams arising from remediation activities.

While it seems obvious that the final waste form should be as inert as reasonably practical, there is apparently no DOE policy supporting this position. What is the reduction of public risk by the use of thermal compared to cement stabilization? Does the production of glass or ceramic as a process product add value that is worth the investment? Clearly the answers to these questions need supportive documentation. The regulatory requirements on waste forms are not currently established on the basis of risk. *This requires discussions among NRC, DOE, DoD, and EPA to formulate the disposal criteria for radioactive materials as well as for toxic materials.* The presently-used TCLP (Toxicity Characteristic Leaching Procedure) test provides only a partial answer. *The Panel supports the ITTS approach of providing a secondary waste disposal form for containment of salts that cannot readily be incorporated into glass. The Panel also notes that making non-leachable pellets or bricks from the ash should be explored because of its potential to provide a single waste form rather than glass and polymers.*

The Panel feels that, given the absence of a clear direction with regard to adequacy of final waste form criteria, a glass or glass-ceramic final waste form should be the reference waste form for disposal. The ITTS study

evaluated systems that generated final waste forms that are anticipated to exceed all current RCRA LDR (Land Disposal Restrictions) criteria at costs that are comparable to or less than the facility disposal costs used in the ITTS study. Studies have been conducted to determine the tolerance and consistency of iron-enriched basalt final waste form composition and properties as a function of variations in waste product compositions using simulated wastes. *Further testing on a wider range of waste treatment residues and final waste form materials is recommended.*

E. Materials of Construction

Actual performance data must be obtained on suitable high-temperature refractories and metal alloys for critical components of the ITTS systems, including melter and incinerator refractory linings, feed nozzles, feed injection and slag withdrawal valves, submerged arc and plasma arc torch electrodes, and wetted APC system components. *Use of "corrosion-proof" materials versus the use of sacrificial materials, particularly for refractory liners, must be assessed given the difficulties and safety issues associated with managing radioactive contamination.*

Repair versus replacement of whole process units should also be evaluated.

F. Observations on Subsystems and Recommendations for More Detailed Analyses

Detailed engineering analyses involving collection and analyses of existing data, detailed process modeling, optimization, and trade-off studies should be done to better assess specific subsystem technologies.

Engineering analyses involving process modeling, optimization, and trade-off studies should focus on the following areas:

1. Advanced Second Stage Destruction Design

The issue of dioxin destruction and reformation was discussed by the Panel as the subject of public and regulatory scrutiny. Current thinking accepts the dioxin/furan loadings existing in a secondary combustion chamber and entering an APC system as a given along with the need for backup removal devices downstream, such as activated carbon beds. Removal devices only remove the dioxin, transferring it to another solid medium for subsequent treatment or disposal as a secondary waste stream. They do not eliminate the problem through decomposition.

Much more work can be done in the area of improving SCC performance through better design with the goal of significantly reducing hydrocarbon dioxin precursor compounds exiting in a SCC. The goal of a development program would be to optimize the design of a SCC so that it comes much closer to reaching chemical equilibrium with respect to organic (C-H and C-Cl bond) decomposition than current designs.

Significantly improved destruction performance could be achieved through improved mixing of oxygen with the primary thermal treatment device gaseous

effluent. Current designs exhibit axial dispersion and short circuiting of unreacted pockets of gas that exit in the SCC in less than the average gas residence time. Advanced designs would need to focus on how, when, and where to inject oxygen or air to enhance mixing of reactants. Chemical reactor design modeling could examine configurations that incorporate continuous stirred tank reactor and plug flow reactor concepts. In addition to gas-phase destruction, modeling studies and hardware development would need to address the issue of adsorbed dioxins and furans on entrained fly ash particulate and soot.

Testing of advanced second stage destruction device designs should have as a goal the destruction of particulate and minimization of hydrocarbon dioxin-precursor compounds from thermal treatment device gaseous effluents. The investigations should focus on mixing of reactants, mass transfer, chemical kinetics, and stirred tank v plug flow reactors-in-series models to maximize organic species conversion to carbon dioxide, water, and acid gases. These issues are common to the municipal and medical waste treatment industry, and DOE can apply the research being done in this area.

While advanced second stage destruction design may be critical, a combination of advanced modeling and experimental studies is required to bring it about.

2. Thermal Treatment Equipment

The ITTS study did not cover all of the types of vitrification equipment. Because of the variety of vitrification systems under development, *a detailed study of the advantages and disadvantages of each specific approach to vitrification is needed in support of all of the DOE site programs.* The issues of high-temperature arc melters, plasma torch melters, joule-heated vitrifiers, direct-fired melters, etc. should be put in perspective for application to MLLW. A multi-site combined effort in this regard could be helpful to the RDDT&E programs by establishing functional and operational criteria and specifications to enable the selection of the most workable type of system. A likely outgrowth of this study could be the determination of which type of units should be installed to gain operating experience from demonstration.

3. Reduction v Elimination of Gaseous Emissions

The Panel feels that the proposed delayed release of carbon dioxide would ultimately not provide much improvement in public acceptance of any of the "CO_2 retention" processes. However, the Panel recommends further paper studies on the following: *(1) alternative ways of capturing the carbon-based compounds contained in gaseous effluents and disposing of them without release, e.g., by biological means or as carbon incorporated in a matrix as part of the final waste product (which is still only a hold and delayed release process) and (2) evaluation of whether the reduction of gas flow (by use of "pure" oxygen) will actually be an improvement compared to current systems.*

Several systems evaluated in the ITTS study had greatly reduced gaseous emission flow rates compared to the baseline system. Design choices that provided this included using electrical heating versus fossil fuels and replacement of combustion air with enriched oxygen. While life cycle costs were not strongly affected by this, the following intuitive qualitative Panel statements should be the subject of further study: 1) a lower off-gas flow rate should allow more affordable and higher performance APC; 2) on-line monitoring and response to off-normal readings should be easier and faster; 3) designs leading to reduced emission rates may enhance the concentration of undesirable substances in the lower off-gas volume (but not necessarily the total quantity); and 4) systems using oxygen instead of air have additional developmental and perhaps insurmountable safety hurdles.

4. Liquid Effluent Management

Some of the treatment system options may produce an excess of water requiring further treatment. The Panel endorses the approach of maximum water recycle within the process. Engineering studies should examine the most viable physical form of water discharge from the process, either as a gas via the stack or as a thoroughly-cleaned liquid. These studies are needed to provide the functional and operational requirements for process design.

5. Waste Management Strategy

The DOE-preferred strategy for waste treatment should be clear with the publication of the PEIS and the proposed site treatment plans. Further information is needed on the combination of systems needed at particular sites. For example, many sites need a versatile main-line treatment facility and a special waste treatment operations depending on the site-to-site shipping strategy. Having a clarified overall strategy would provide more focus to the RDDT&E programs. It is not clear whether the systems should be mobile or stationary. Skid-mounted units will be required to have double containment zones if significant levels of alpha contamination are present. The capability to decontaminate and safely transport contaminated equipment is not established. *A detailed operations analysis of transportable unit operations would help identify key issues.*

6. Process Upset Potential and Consequences

The issue of *minimizing the probability and consequences of process upsets should receive more attention.* Paper studies, incident scenarios regarding consequences, and definition of the limits on feed concentrations and rates would provide some perspective on the importance of this issue. Accordingly, they are recommended. Development of simulation models (computer models) may help address many of these questions.

7. Process Simplicity

Although many people focus on the primary thermal treatment subsystem(s), the full facility integrated system flowsheet became very complex once the various

technologies were assembled into the nineteen ITTS complete systems. All other things being equal, the more complex the subsystems, the more operational difficulties will occur and will prolong anticipated schedules of operations. The challenge is to find the best trade-off between a complex flowsheet with each function performed by a specific piece of equipment designed for that function and a simple flowsheet with more complicated, flexible, and versatile equipment performing many functions. *Detailed reliability and risk analyses should be conducted to establish the relative merits of each approach.*

8. Special Requirements

The need for auxiliary processing steps for mercury, reactive metals, and lead are essential unless the absence of these metals in waste feed streams can be adequately established.

X. Primary Thermal Treatment

The principal issues for primary thermal treatment include: (1) should the equipment be operated in a reducing or oxidizing mode; (2) what are the relative advantages/disadvantages of different temperatures and the associated kinetics and volatilities of metals and metal compounds; (3) how do the processes vary in versatility as discussed above; (4) what is the overall volume reduction including the generation of secondary waste; and (5) what is the effectiveness of the primary treatment technology? *The Panel thinks that significant cost incentives exist for processes that produce minimum volume and keep the operating costs low as a result of high capacity and shorter total processing time.* All of these suggest the need for the following performance data:

- Demonstration to confirm kinetics and volatilities;
- Demonstration of the shredding and handling capability to feed waste to the primary thermal treatment;
- Demonstration of process versatility and flexibility to accept wide variations in waste composition;
- Demonstration of the level of PICs and dioxins/furans (or their precursors) produced and subsequently removed;
- Demonstration of the levels of entrainment and carryover of particulates and their subsequent removal; and
- Tests on performance of advanced seals for rotary kilns for alpha containment.

The strategy for overall DOE MLLW treatment is not totally clear even with the publication of the PEIS. Information feedback from the FFCA activities is needed to identify facility deployment alternatives that are going to be acceptable to the public. These will dictate the acceptable technologies.

Further information is needed on the combination of systems needed at particular sites. For example, some sites or regional facilities need a versatile main-line treatment facility and a special waste treatment line depending on the site-to-site shipping strategy. The recommended treatment system for sites or small clusters of sites that have predominantly noncombustible wastes would be different than that for sites with predominantly combustibles.

XI. Sensitivity Studies and Systems Analyses

While the ITTS study provided considerable perspective on the relative importance of certain technology features and attributes, it also raised a number of questions that still need to be answered by further studies. The ITTS study shows, at this level of analysis, no significant differences in life cycle costs between most of the processes. This is in part due to the small fraction of total life cycle costs that are attributed directly to equipment and total quantities of net waste generated. This appears to leave the choice of systems to be deployed by DOE to those systems that can be safely and rapidly implemented. *This lack of ability to discriminate in performance of the technologies is the critical limitation of this study.* Follow-on studies are needed in sufficient detail that the basis for cost differences and options for significant improvement can be identified.

Studies need to be conducted to evaluate the potential of alternative technologies or of significantly improved technologies to reduce life cycle costs and/or shorten deployment times and correspondingly reduce times to complete clean up of DOE MLLW inventories. The ITTS study follow-on investigations need to examine in detail the factors and the associated uncertainty that make up the total life cycle cost to identify potentials for significant changes. Components that could have significant impacts on costs could be varied to the maximum extent deemed feasible. Non-technical alternatives include private industry vs DOE Management & Operating (M&O) contractor approaches.

The Panel notes the inclusion of significant quantities of soil in the flowsheets and observes the potential for possible economies by considering further the combination of wastes from EM-40 with stored or newly generated waste. The final selection of a treatment process should consider this potential for cost savings. Studies similar to the ITTS could provide some perspective on the potential cost savings derived from this combination. Flowsheets and waste form formulas are needed that do not rely on large quantities of soil additives.

XII. Capacity and Distribution Among DOE Sites

Based on ITTS cost information, several opportunities for cost savings appear possible if specific studies are initiated. The potential exists to standardize the design, safety analyses, preparation of operating procedures, and permitting of facilities if the same treatment system is used at more than one site. *The capacity tradeoff and processing rate to shorten the time from 20 years to less than 10 years should be studied immediately because of the*

potentially significant savings from reduced operating years.

XIII. Simplicity

The Panel notes the complexity once technologies were assembled into a complete system and recommends finding ways to simplify the system and its equipment. Operating problems will likely abound, and prolonged schedules for operations are anticipated. This requires use of reliable equipment with long operating lives. *A complete detailed reliability analysis for key systems is needed based on the best information available.*

XIV. Public Acceptance

In general, public acceptance issues related to treatment of radioactive and mixed wastes include but may not be limited to:

- Historical public preference for non-incineration and non-thermal technologies
- Risks associated with testing and use of technology systems (especially new and/or high temperature systems)
- Need for risk assessments related to each technology under consideration
- Credibility of DOE science and information dissemination
- Political expediency vs good science
- Waste volume reduction
- Off-gas capture: ways to eliminate hazardous emissions
- Efficiency of offgas systems
- Real-time monitoring of off-gas for pollutant concentrations
- Continuous performance assurance
- Opportunities for public input to the treatment systems selection process
- Opportunities for public input to analysis of treatment options
- Potential for upset or accident within mixed waste treatment systems

- Radioactive content of both the inputs and the outputs from treatment systems
- Clear definition of "trade-offs" system-by-system
- Technology descriptions and information written in language understandable to the public
- Identification of percentage of total and type of waste stream to be handled by each technology
- Proof of applicability of systems to mixed and radioactive wastes
- Sorting minimization so as to decrease chance of human error
- Long-term stability of final waste form
- Experimental data to support all decisions made

In more specific terms, public acceptance issues related to those technologies addressed in the ITTS Phase II review include:

High Temperature Processing: Due to the fact that high temperatures tend to volatilize metals, any temperature above "red hot" (i.e., 700° C) raises public concerns related to the vaporization of contaminants, gaseous releases, worker safety, and the potential for system failure. The plasma arc furnace, plasma gasification, plasma furnace with CO_2 retention, the rotary kiln system (including slagging rotary kiln), molten metal, and joule-heated vitrifier fall into the "high temperature" category, from the standpoint of public perspective. (Vitrification of oxide feed materials may be exempt in terms of this concern, given the fact that some level of public acceptance for vitrified waste as a final waste form has been recently evidenced.) Supercritical Water Oxidation and Mediated Electrochemical Oxidation definitely fall within the "low temperature" category in terms of the thermal systems being addressed but exhibit other shortcomings in terms of public acceptance.

Off-gas Discharge/Off-gas Capture Systems: Several of the ITTS technologies claim offgas discharge volumes significantly lower than the "baseline." Although this characteristic would be of primary interest to the public, the baseline figure itself would have to be clearly and credibly established, defined, and minimized. In addition, significantly more effort would have to be put into mapping out the pros, cons, and risks associated with APC devices attached to specific treatment systems. In its present form, documentation of technologies places the APC device in yet another "black box" showing little technical detail, evidence of data to support confidence in the system, or proof of experimental success. Given current data availability, technologies identified as having low off-gas discharge rates include: indirectly heated pyrolyzer (1/2 of baseline discharge); plasma arc furnace (1/2 of baseline);

plasma furnace with CO_2 retention; rotary kiln incinerator (1/3 of baseline system (and with a potential for decrease in dioxin releases related to supposed "low" average of 900° to 1000° C)); steam reforming gasification; and Mediated Electrochemical Oxidation (which claims off-gases that are generally non-toxic).

Incineration v Non-incineration: Despite the fact that an effort has been made to differentiate "incineration" from other thermal and thermal non-flame processes, it is likely that all but a select few of the technologies addressed in the ITTS study will be viewed by the public as (relatively) standard incineration or clearly equivalent. In addition to the high temperature status, one of the primary factors in establishing this perception (whether it is a correct assumption or not) will be the regulatory permitting status of the technology. The indirectly-heater pyrolyzer, plasma arc furnace, the slagging rotary kiln, molten metal (unless its current "recycler" permitting status is replicated in other states), and joule-heated vitrifier are all likely to be permitted as incinerators. Plasma gasification and Molten Salt Oxidation are still being regarded with "an open mind" in terms of regulatory permitting, but, to date, nothing has been demonstrated to prove they are not incinerators. Supercritical Water Oxidation and Mediated Electrochemical Oxidation will most likely not be permitted as incinerators.

Experience with Radioactive and Mixed Waste: It is likely that one of the higher-order discriminators of public acceptance of technologies for treatment of DOE MLLW will be whether the system identified has had any "experience" in dealing with radioactive and mixed wastes. Only incineration has operating experience with DOE MLLW. HLW has only been processed in a fluid bed calciner although extensive development has been done on HLW vitrification. This is clearly a dilemma of "Catch-22" proportions. Without public acceptance, "hot" testing cannot occur; without "hot" testing, no experimental data can be collected; without experimental data, the public will not be willing approve a technology for future use, and without that approval radioactive waste will not be treated.

It is clear that a public education program on this issue must be designed. The program should include not only education about the pros/cons, safety factors, and risk trade-offs related to thermal technologies but the need for testing of all technologies. This must also include a clear and fair analysis of the potential for utilizing non-thermal technologies to treat radioactive and mixed wastes.

Final Waste Form: Although the public may express a preference for an equally or more stable waste form than grout, the process for producing that final form will be of the utmost concern. A fairly strong level of acceptance for polymer stabilization and, at a higher level, vitrification, of treated radioactive wastes, has been voiced by certain public organizations and sectors. Some of these sectors include those citizens who are also vehemently opposed to the use of incineration technologies for organic destruction to treat waste. Considering the fact that vitrification, in particular, is a high-temperature thermal process that will likely be permitted as or equivalent to an incinerator, it is difficult to gauge what route public

support or opposition to final waste form concepts will take.

Strong public interest has also been expressed regarding the potential for recovering wastes for re-treatment once technology has advanced to the point of being capable of total and final "destruction of radioactive materials". While the foregoing may be true, it is technically infeasible, and the Panel does not support it. In consideration of this particular acceptance factor, it will be important to define the potential for re-structuring of the waste form at some future point in history and to thoroughly address "permanence factors" related to each final form (i.e., permeability, structural integrity, etc.).

Public Acceptance "Fatal Flaws": Because the great majority of technologies reviewed as a part of the ITTS study will be regarded by the pubic as incineration, it is unlikely that any inherently new "fatal flaws" will surface. The general anti-incineration attitude expressed by various organized publics is well known, and this study did not highlight anything that might be new or surprising in relation to that dialogue. However, *what may become a fatal flaw if not dealt with fairly and directly will be the obvious lack or presence of a review of equal technical credibility and fairness, focused on non-thermal approaches to treatment of DOE radioactive and mixed wastes. This should be rectified.*

On a technology-specific basis, advantages and disadvantages related to public acceptance of ITTS-reviewed technologies might include:

Rotary Kiln System Technologies (RKS) (A-1 through A-7) -- Despite elaborate and technically redundant off-gas cleaning and capture systems, technologies related to the RKS will be hard to sell to the public. It is unlikely that new or unusual arguments against traditional incineration will arise, but the RKS has suffered the same public blows that other incinerators have.

Indirectly-Heated Pyrolyzer (IHP)(B-1) -- Advantages from the standpoint of public acceptance accrue to relatively low (650° C) temperatures; claimed low off-gas discharges; a stable final waste form (vitrified); and the fact that the system is currently commercially available. Disadvantages will include the fact that, because the IHP includes a secondary combustion unit, the system will be permitted as an incinerator; there has been some, albeit inconclusive, evidence that starved air incinerators produce dioxins at increased levels.

Plasma Arc Furnace (PAF)(C-1) -- Obvious advantages are claimed due to: low off-gas production; a stable final vitrified waste form; reduced incidence of organic release at high temperatures; and production of a solid residue product. High temperatures will, however, draw negative public attention related to metal vaporization problems, public and worker safety, and potential for industrial accidents. PAF will probably have to be permitted as an incinerator, which will raise a "red flag" in terms of public acceptance.

Plasma Furnace with CO_2 Retention ($PFCO_2$)(C-2) -- Claimed lower off-gas production and the possibility of lower incidence of NOx problems when $PFCO_2$

is used in the main reaction chamber will be credited to the positive side of the public acceptance discussion. Accrued negatives will include the production of a high final waste volume and the $PFCO_2$'s probable regulatory standing as an incinerator.

Plasma Gasification (PG)(C-3) -- PG experience with medical waste in California, as well as the potential for reducing dioxin production (which has been cited as an arguable assumption) and the fact that the system has been permitted as a non-incinerator in California will be of some positive public interest. However, the fact that there is little documented PG experience with metals and PG's high operating temperature (1650° C) will attract attention on the down side.

Molten Salt Oxidation (MSO)(F-1) -- Perceived lower operating temperatures (850° - 950° C) and the attendant potential for reduced dioxins related to "low" temperatures and the portability of the MSO system will garner positive response. Additionally, the fact that claimed offgas credits could result in a reduction to 1/3 of the baseline offgas system size and MSO's high-level suitability for treating liquid wastes will perhaps be viewed as positive by the public. However, because MSO functions in a very selective manner, requiring a high degree of sorting or pretreatment to treat no more than 10-20% of DOE's mixed wastes, it requires a high degree of sorting; and because it has not been clearly proven to be a non-incinerator, some public opposition is likely to occur.

Molten Metal Technology destruction (MMT)(G-1) -- MMT has broad waste stream applicability, produces a non-leachable end product and accepts metals -- all positive features from the public standpoint. On the negative side, corrosion of ceramic liners with related increase in meltdown potential; the extensive feed preparation required; the existence of the possibility of steam explosions; and the production of pyrophoric fly ash as a solid byproduct coupled with a combustible gas byproduct will all serve as a source of public concern. It remains to be seen if the public's likely concern over these issues is assuaged by the technology's obvious benefits as a recycler.

Steam Reforming Gasification (SRG)(H-1) -- The advantages of this indirectly heated fluidized bed reduction system from the public point of view are: comparatively low operating temperature (1300° - 1400° F); limited versatility (handles up to 30% of DOE's combustible waste streams); potentially low dioxin formation as a result of the reducing atmosphere; and relatively low offgas volume. SRG does, however, require extensive waste pre-treatment; may need auxiliary fuel to increase heating value; and will probably be permitted as an incinerator -- all of which will tote up on the "no-confidence" side of the public equation.

Joule-Heated Vitrification (JHV)(J-1) -- Low sorting requirements and evidence of JHV experience with DOE MLLW and HLW along with a somewhat positive public attitude towards vitrification as a means of producing a stable final waste form will be pluses for this technology. Corrosion may be an operating problem similar to other technologies.

Supercritical Water Oxidation (SCWO)(L-1) -- Lower-than-incineration temperatures (400° - 600° C) and a probable non-incineration permitting status will be immediate gains from the public acceptance perspective. However, extremely high pressures, extreme corrosion potential; and the fact that, without a thermal desorber, SCWO is suitable for only 3%-5% of DOE's aqueous organic mixed wastes will serve as negative indicators. Because of the high pressure safety issues, public acceptance for SCWO will likely be difficult to come by.

Mediated Electrochemical Oxidation (MEO)(K-1) -- On the positive side, the public will appreciate the fact that MEO is an extremely low temperature (50° - 80° C) non-incineration treatment system that is claimed to destroy virtually all organics; boasts off-gas that is said to be generally non-toxic; and has a high destruction removal efficiency (DRE). From the negative side of public acceptance, MEO has a very limited potential application (only 3% of DOE's organic and aqueous-organic liquids); treatment of additional DOE MLLW would require very high levels of feed sorting, size reduction, and/or extensive treatment (i.e., washing to put organics in solution); generates H and Cl as by-products; and is a fairly complex, low DRE system.

XV. Air Pollution Control

New emissions standards which are currently being developed by the EPA for hazardous waste combustors on the basis of Maximum Achievable Control Technology (MACT), will significantly increase the stringency of air emissions requirements. These new emission standards will cover: dioxins/furans, carcinogenic and toxic metals, residual organic stack emissions (ROSEs), particulate matter, HCl/Cl_2, CO, and total hydrocarbons. These emission standards will be at least as stringent as that achieved by the top 12% of the best hazardous waste combustion units in operation today. While the actual emissions standards have not yet been proposed, early indications from the Combustion Emissions Technical Resource Document (CETRED) and EPA statements suggest that the emissions standards will be significantly more stringent than currently exist. These emissions standards will likely be significantly more stringent than the proposed levels assumed in the ITTS reports (see Table II, which is a reprint of Table 1-2 of the draft ITTS Phase II report).

As indicated in the discussion on public perception, the greatest concern to the public is air emissions and continual assurance of performance. These issues apply to all types of thermal treatment systems since there have only recently been certified continuous emission monitoring systems (CEMs) that allow direct, real-time measurement of the trace species of regulatory and public concern. OTD is working on developing other CEMs for mercury, other trace metals, and organic molecules, as well. The EPA has recently surveyed available and emerging CEM techniques and determined that it is unlikely that such CEMs will be available for monitoring ROSEs, dioxin, or the majority of trace metals to acceptable levels in the near future. Therefore, it becomes particularly important to establish a systems approach that incorporates the most current CEM technologies in conjunction with sampling and analysis certifications and protocols with APC devices to demonstrate, on a continual basis, that they are achieving control of trace species for all possible

emissions from the thermal treatment units operated under both normal and upset conditions. It is imperative that high performance, flexible, reliable APC system configurations be developed and demonstrated that can control emissions under all expected flue gas conditions from the primary thermal treatment system. The effectiveness of the APC system configuration is probably more important to the public than the selection of thermal treatment units that were examined in the ITTS study.

The APC system configuration used in the ITTS studies consisted of two basic configurations:

1) dry/wet system: quench, fabric filter, activated carbon, HEPA, hydrosonic scrubber, packed tower scrubber, mist eliminator, reheat, selective catalytic reduction (SCR), and

2) wet system: same as dry/wet, except dry fabric filter (baghouse) is eliminated, using all wet filtration and cleaning techniques.

Both of these systems include state-of-the-art components and are likely to achieve stack emissions control levels better than the most (if not all) of the currently operating hazardous waste combustion units. However the Panel has some reservations about the arrangements of these components, particularly with respect to how the arrangement impacted radioactive and chloride solid waste residue.

It is not clear that the baseline APC system configuration is providing optimal emission control in its current embodiment. In particular, the dry/wet system may be prone to form dioxin in the baghouse due to its moderate temperature. However, the activated carbon beds designed for mercury control could be modified to effectively control dioxin before it could escape to the stack. The specific concern is the use of any fabric filter at moderately hot temperatures (ca. 350° F) which will likely promote formation of dioxin at least in the baghouse fly ash (at this temperature, the vapor pressure of many of the congeners will be high enough so that they will potentially be carried away with the flue gases).

For dioxin control, the optimum control strategy is the use of a rapid quench and fine particulate matter removal at as low a temperature as possible (near the dew point). In the current design this cannot be accomplished due to the fact that acid gases are not removed prior to particulate removal and, hence, the fabric filter cannot be run at low enough temperatures to avoid the re-formation of dioxins. An alternative design to the baseline is the use of a polishing carbon bed filter configured after the wet scrubber. This carbon bed filter must be carefully designed to effectively control dioxin emissions along with mercury. In this operation, the carbon bed filter will generate a new dioxin-bearing waste stream. Some of the thermal treatment technologies are intrinsically better at preventing dioxin formation. Molten salt oxidation, gasification/steam reforming, and mediated electrochemical oxidation all minimize the combination of chlorine, organics, and time-at-temperature that might produce dioxins.

In addition, there is some concern about the ability to maintain the baghouse in an alpha radiation environment. A health safety review would have to be undertaken to examine the worker safety issues associated with exposure to dust from baghouse maintenance (which is, typically, a particularly dusty environment). Significant routine maintenance is required to assure proper baghouse performance particularly when attempting to continuously meet the emerging and more stringent particulate matter standards. Worker exposure to uranium and plutonium dust, if present, must be avoided and the Safety Analysis Review (SAR) may prevent the use of baghouses for TRU alpha-bearing wastes due to these routine maintenance requirements. Finally, there is significant concern when using a baghouse for fuel-rich flue gases due to the potential for finely divided carbon or metals being collected in the filter to ignite when air is accidentally introduced to the baghouse.

These reservations concerning the baseline APC system are a trade off against the ability of this configuration to keep the radionuclide and metal-containing ash separate from the acid salts. Therefore, the baseline APC system may not be optimal, and some consideration should be given to evaluating the impacts of changes to the baseline design.

The wet APC system option can be used to effectively minimize the re-formation of dioxin by avoiding particulate holdup in the re-formation regime. Unfortunately, this system mixes the halogen salts with the radioactive particulate catch in the scrubber blowdown resulting in a requirement for handling liquid waste contaminated with radioactive components. In addition, high performance mist elimination is required prior to the HEPA filters to avoid blinding the filters. Scrubber sludge, high in salt, is not suitable for vitrification. It increases solid residue volumes, and more of the residues would not be in optimal vitrified form. High-salt sludges can be stabilized in polymer. Nonetheless, this tradeoff could minimize dioxin re-formation while maintaining control of other pollutants of interest.

Thus, more consideration needs to be given to the optimal design of the APC system and the tradeoffs with other measures of performance. *The key recommendation is to conduct a design study in the next phase of the ITTS study focussed on the ability of the offgas control system to meet the emerging standards.* In addition, this study should focus not only on the thermal treatment unit operated under normal conditions but over a range of upset conditions. A study on the impacts of different thermal treatment units on APC system performance would also be useful.

Finally, *the Panel recommends that the thermal treatment units be investigated in how they challenge the performance of the APC systems.* Direct measurements and currently available engineering analysis models (e.g., see those developed by the EPA) could be used to estimate the flue gas constituents from the different thermal treatment units under normal and upset conditions. The important indicators are flue gas flow rate, particulate loading, size distribution of particulate matter, size distribution of metals, acid gas concentration, carbon content of particulate matter, radioactive particulate size distribution, and residual organics. The EPA has recently developed a comprehensive emissions data base on all (300) hazardous waste combustion

devices in the United States that could be used to explore the performance of different APC system configurations for these different thermal treatment unit output characteristics. In this way, *alternative APC system configurations could be defined which achieve optimal emissions control for the special configurations dictated by mixed waste thermal treatment.*

XVI. Major Conclusions

The Panel offers the following conclusions based on the ITTS Phase I and II systems review. The conclusions are based on the whole system which consists of waste characterization, pretreatment, feeding, thermal treatment, stabilization, APC, and effluent water treatment:

- The technology system deployable today on MLLW is thermal destruction with polymer stabilization, grout stabilization, or vitrification of the ash. Compared to vitrification, however, grout or polymer processing results in higher waste disposal costs due to substantially higher waste volumes.

- From a cost effectiveness and systems viewpoint, other systems that are close to implementation include incineration (rotary kiln or fixed hearth) with separate vitrification of the ash and with a "super safe" APC system.

- Differences in total lifecycle costs were within about 30%. Most of the lowest cost systems were the evolving technologies (plasma, joule-heated vitrification, and molten metal). The slagging rotary kiln was also at the low end of the cost range and is a well-developed treatment process. Vitrification of the treatment residues produces a significant reduction in disposal costs as well as a high performance final waste form. Other major factors in treatment costs relate to implementation assumptions such as facility capacity and operating time. These are not a function of facility size and are fairly constant. Total pre-operational costs are directly proportional to the number of facilities operated. Quantification of these effects was outside of the scope of the ITTS study. (Note: the DOE Waste Management PEIS has been addressing these issues.)

- All thermal treatment systems, with the probable exceptions of MEO and SCWO, will likely be permitted as incinerators, no matter what proponents call them. Any high temperature thermal treatment system with a secondary combustor or thermal oxidizer will likely be regulated as an incinerator under Subpart O or Subpart X of RCRA.

- Effluent gas volumes can be reduced by using enriched oxygen, recycling gases, and chemically removing carbon dioxide from the flue gas by reacting it with lime (the so-called "CO_2 retention" or "delayed released" process). While some reduction in cost and in the public's opposition to "incineration" appears achievable with systems producing lower offgas, such a strategy lacks a commanding incentive because they do not assure a reduction in the emission of hazardous

pollutants. The Panel sees no significant technical or cost driving force for developing offgas capture and delayed release options. New and significant issues may be raised by changes in the combustion gas to oxygen or to CO_2 as well as recycling.

- The low-to-medium temperature aqueous options, MEO and SCWO, seem to provide publicly acceptable treatment approaches. However, these technologies lack versatility, i.e., the capability to process any significant fraction of the waste as received, resulting in greatly increased waste separation and pretreatment requirements, such as thermal desorption or washing. Both technologies also have serious development issues remaining. SCWO was especially noted to have critical corrosion and safety issues.

- A new integrated non-thermal system study (INTS) should be conducted for non-thermal options to balance the predominant emphasis in the ITTS on thermal technologies and vitrification.

- The high cost and uncertain approaches to finely shredding wastes to feed systems for processes such as the molten metal process, the MSO process, the SWCO process, and the MEO process are major barriers to implementation of these technologies on DOE MLLW. These relatively undeveloped systems also pose technical and operating problems not yet addressed in DOE or commercial waste destruction programs.

- There are alternative thermal treatment systems that should be evaluated in the next phase of systems studies, such as infrared and microwave melters.

- Future studies include: comparison of the preferable incineration systems or non-thermal processes that DOE should utilize at its MLLW sites; selection of the preferable final waste form; the type of waste pre-treatment needed across the complex; the type of "super safe" APC system needed; and the development of effective emission monitoring techniques for real-time process performance assurance.

- The cost contingency for less-developed technologies, permitting, and operating strategies should be increased. Doing so will reduce the <u>apparent</u> cost advantage of some of the more evolving technologies.

- The Panel recommends that DOE study treatment technologies that can minimize the need for extensive characterization of the waste. Because of the containerization and diverse mixture of DOE solid wastes, the practicality of such characterization is questionable. The embedded regulatory requirements encourage characterization before treatment even though R&D could eventually show that post-treatment verification of waste destruction is a better, more reliable method to protect DOE workers and the public adjacent to DOE sites. Research programs should be implemented to demonstrate that with extremely versatile thermal treatment and "bullet proof" air pollution control systems (over-designed compared to commercial

practices), the need for extensive waste characterization can be minimized while protecting the environment from hazardous emissions. A state-of-the-art APC system is necessary to assure environmentally safe operation regardless of waste input to the system and to help attain minimization of waste characterization.

XVII. Recommended RDDT&E Needs

The Panel evaluates the ITTS treatment technologies relative to the level of development that would probably be required to implement each treatment technology on MLLW. Each process was placed either in a low, medium, or high level of development category.

The "low" level of development category was used for a process that, in the Panel's opinion, could be developed and successfully implemented in about 2 to 3 years. The "medium" level of development was for a process that could be developed and successfully implemented in approximately 3 to 7 years. The "high" level of development category was used for a process that would require more than 7 years to be put in place.

The Panel makes the following observations and identified the following development needs for each of the ITTS systems technologies:

(System A-1) Rotary Kiln, Air Fed, Vitrifier, and Polymer Stabilization (overall development needs are Low; for the vitrifier Low-Medium with noncumbustible feed) Development needs are less for this system than most others

- Most development needs for this system are shared by other incineration systems
- Front-end feed sorting to remove large metal items
- Needs specific to the rotary kiln:
  - Demonstrate partitioning of radionuclides into bottom ash
  - Demonstrate containment of alpha radionuclides in rotary kilns (air tight rotary kiln seals for alpha controls)
  - Define refractory life for kiln or develop a kiln with a replaceable barrel

- APC needs:
  - Investigate temperature limitations of baghouses or demonstrate effectiveness of ceramic filters
  - Mercury capture and control effectiveness
  - Production units for back-flushable HEPA filters
  - Measurement equipment for stack discharges
  - Dioxin control

(System A-2) Rotary Kiln, Oxygen Fed (overall development needs are Medium) Development needs are similar to system A-1 in addition to:

- Needs specific to the rotary kiln used with oxygen:
  - Oxygen burner design and flame propagation and control
  - Prevention of ash slagging
  - CO_2 safety issues
  - Temperature control, especially cooling
- APC needs:
  - Effectiveness of the APC system with the smaller volume of offgas
  - Effect of temperature on offgas after charcoal filtration

(System A-3) Rotary Kiln, Air, Wet APC (overall development needs Low) Same as A-1 with the addition of:

- Needs specific to the wet APC system:
  - Mercury capture and control effectiveness in wet scrubber system
  - Removal of mercury from aqueous blowdown stream
  - Drying of off-gas prior to HEPA's (gas stream conditioning)

(System A-4) Rotary Kiln, Oxygen, CO_2 *Retention (overall development needs High because of* CO_2 *retention system*) Same as A-1 and A-2 with the addition of:

- Needs specific to the CO_2 retention system:
  - Absorption of metals, and particularly PICs or ROSEs, in fluidized bed and subsequent release from calciner
  - Evaluation of other adsorbents besides lime
  - Cost/benefit analysis of CO_2 retention approach
  - Process control development

(System A-5) Rotary Kiln, Air, Polymer Stabilization (overall development needs Low) Same as A-1 without vitrification development issues

- Needs specific to the polymer stabilization system:
  - Techniques using sulfur cement, polyethylene, or other trade name polymers need to be characterized as to the non-leachability of their solid product stream
  - Effect of carbon in ash on the final waste form
  - Longevity of the final waste form
  - Alpha radiation sensitivity
  - Stabilization of salts needs to be fully understood

(System A-6) Rotary Kiln, Air, Maximum Recycling (overall development needs High) Same as A-1

- Needs specific to the recycling approach:
  - Mercury capture from spent carbon needs development

- Salt cracking concept and implementation must be developed
- Engineering development needed for metal recovery devices

(System A-7) Slagging Rotary Kiln (overall development needs Medium to Low)
Same as A-1, including:

- Slag management and viscosity control
- Effect of variations in temperature, feed rate, and feed type on waste slag needs to be determined
- Design of dry slag removal system appropriate for MLLW
- Metals volatilization

(System B-1) Indirectly Heated Fixed Hearth Pyrolyzer (overall development, needs Medium to High)

- Pyrolyzer development needs:
  - Control of oxygen concentration to maintain adequate reactivity under pyrolysis conditions
  - Design must allow evenly mixed and well distributed under waste air flow to minimize carbon in the ash (which is difficult under reduced oxygen conditions)
  - Verification of process control with plastics, etc. in waste (sticking of materials)
- APC development needs:
  - Develop process control of a single APC unit for two processes (pyrolyzer and vitrifier)
  - Analyze cost effectiveness of providing 2 separate, dedicated APCs
- Vitrifier development needs (same as A-1 plus):
  - Limitations on amount of carbon in ash without affecting stability of final waste form
  - Ability to oxidize the organic material left in the feed

(System C-1) Plasma Furnace (overall development needs Medium)

- Plasma furnace development needs:
  - Torch selection (DC plasma/DC arc/AC arc) and electrode lifetime improvement and/or replacement techniques
  - Particulate carryover definition and control
  - Feed preparation requirements and limitations
  - Demonstration of partitioning and control of radioactive particles, especially actinides
  - Management of slag and metal discharge
  - APC system material disposition

(System C-2) Plasma Furnace, CO_2 Retention (overall development need High)

- Same as C-1 with CO_2 issues and CO_2 capture issues
- CO_2 retention scheme requires significant process development

(System C-3) Plasma Gasification (overall development needs Medium to High)

- Same as C-1 with respect to Plasma plus Syngas issues
- Determine fate of RCRA metals and radionuclides
- Evaluation of DRE

(System D-1) Fixed Hearth Controlled Air Pyrolyzer (controlled-air incinerator) (overall development needs High, but if CO_2 and O_2 were removed it would be Low except for specialized ash handling for high ash waste)

- CO_2 retention system same as A-4
- Development needs:
  - Control of oxygen concentration to maintain pyrolysis conditions
- Vitrifier development needs same as B-1

(System E-1) Rotary Kiln, Air, Thermal Desorption (overall development needs Medium to Low)

- Development needs include those for A-1 and thermal desorption
- Needs specific to thermal desorber:
  - Define criteria for desorption operation
  - Develop operating strategy for processing compounds with a range of boiling points: plastics, mercury and PCBs
  - Demonstrate fate of mercury and PCBs in desorber
  - Evaluate final waste form for acceptability

(System F-1) Molten Salt Oxidation (overall development needs High)

- Molten salt in-process handling issues
- Salt recycle
- Discard salt final waste form
- Corrosion issues in vessel and downstream and salt recycle piping
- Plugging of APC piping with salts downstream of MSO unit
- Waste feed preparation (sorting and sizing)
- Melt composition control
- Same issues with vitrifier as B-1
- CO emission without secondary combustor on MSO
- Safety issues with salt overflow and alpha control

(System G-1) Molten Metal Technology destruction (overall development needs High)

- Pyrolysis issues apply
- Demonstrate process on wide range of wastes with high solids
- Develop bulk solids feeding process for DOE solid wastes
  - Sizing for tuyere injection
  - Top loading: submerged lances, baffles, other methods to blend waste into metal melt
  - Control of residence time for larger particles
- Demonstrate acceptable slag and metal discharge method
- Demonstrate applicability for DOE waste varieties
  - Particulate, radionuclide, toxic metals, acid gas control
- Demonstrate acceptable refractory and critical component lifetimes
- Develop acceptable safety bases (pyrophoric fines in baghouse, pressurized operation, explosive gases)
- Demonstrate neutralization of HCl in melter and retention of $CaCl_2$ in slag

(System H-1) Gasification/Steam Reforming (overall development needs Medium to High)

- Same vitrification, pyrolysis, and size reduction issues

(System J-1) Joule-heated Vitrification (overall development needs Medium)

- Same issues as C-1 without torch-related issues
- Electrode materials and corrosion control
- Operation with solid combustible feed stock
- Uncombusted waste carry over

(System K-1) Mediated Electrochemical Oxidation with grouting (overall development needs Medium to High)

- Thermal desorber issues apply
- Appropriate feed characteristics, preparation, and operational control need to be determined and studied
- Determine fate of RCRA metals and radionuclides in MEO waste streams
- Demonstrate adequate throughput rate
- Gas management and regeneration of working electrolytes
- RCRA organic destruction (DRE) performance
- RCRA compliance with new standards for the grouted waste streams

(System L-1) Supercritical Water Oxidation (overall development needs are High)

- Thermal desorber issues apply
- To add solids treatment to SCWO, demonstrate pretreatment and sizing of DOE wastes to 100 microns
- Corrosion control:
  - Removing acid precursors from feed stream
  - pH adjustment/control in reactor and downstream
  - Equipment designs to prevent corrosion (plate-out in reactor)
- Pressure vessel integrity in corrosive environment with radioactive wastes
- Deposition control of salts in high pressure reactor region
- Demonstrate applicability for DOE wastes
  - Oxidation; maintenance; particulate, radionuclide, toxic metals, acid gas control; scaling
- Demonstrate adequate throughput rate

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APPENDIX A

Advantages and Disadvantages of 19 Thermal Treatment Systems

(System A-1) Rotary Kiln, Air Fed, Vitrification and Polymer Stabilization (Baseline)

Advantages

- Versatile
- DOE MLLW full-scale experience
- Predictable schedule
- Predictable costs
- Highly efficient removal of pollutants in APC
- High availability and implementability
- Sorting and separation of combustibles not required

Disadvantages

- Mechanically complex kiln
- Seal demonstration and operation control required to minimize overpressure events and use with alpha-contaminated wastes
- Stakeholders prefer non-incineration alternatives
- High entrainment problem particulate management required

(A-2) Rotary Kiln, Oxygen Fed, Vitrification and Polymer Stabilization

Advantages

- Same as A-1
- Reduces offgas volume to 1/3 of baseline system; smaller APC system therefore required. Stakeholders would appreciate lower offgas volume
- Reduced entrainment of material to APC system

Disadvantages

- Same as A-1
- Insufficient advantages to justify use of oxygen
- Hotter flame(s) and hot spots with related melter burn through and safety problems
- Concentration of pollutants in offgas may increase (although total quantity due to entrainment should decrease)
- Limited experience with oxygen combustion for waste processing

- Potential for ash slagging due to high temperature of the oxygen flame

(A-3) Rotary Kiln, Air Fed, Wet APC, Vitrification and Polymer Stabilization

Advantages

- Same as A-1
- Less complex APC system
- Effective removal of pollutants early in APC -- alpha control may be easier

Disadvantages

- Same as A-1
- Higher volume of waste for disposal due to ash addition to salt or chemical separation steps would add to process complexity
- Higher TLCC costs
- Higher volume of salts requiring polymer treatment due to extra fly ash in scrubber
- Mercury capture in aqueous liquid will require treatment

(A-4) Rotary Kiln, Oxygen Fed, CO_2 Retention, Vitrification and Polymer

Advantages

- Same as A-1
- Reduces offgas volume to 1/8 of baseline system
- Provides for delayed release of offgas to atmosphere
- Provides for testing of offgas contaminants prior to release
- Delay of offgas may be attractive to stakeholders

Disadvantages

- Same as A-1
- Concentration of pollutants in offgas may increase (although the total quantity due to entrainment should decrease)
- Precise control of air leakage through kiln seal required
- Process & mechanical complexity increased significantly

	• CO2 retention part of system has not been demonstrated with a waste treatment operation
	• Limited experience with oxygen or O_2/CO_2 combustion for waste processing
	• Final waste volume is increased due to processing of lime and calcium carbonate, and calcium utilization is expected to be extremely poor adding to waste management volumes
	• Workability of this particular retention system highly unlikely (others may be better choices)
	• Expensive CO_2 gas retention provides little benefit for acceptance of system

(A-5) Rotary Kiln, Air Fed, Polymer Stabilization

Advantages	*Disadvantages*
• Same as A-1	• Same as A-1
• Less complex process --	• Higher waste volume, less stable final form than vitrified waste
• Facility size and technical uncertainty reduced	• Higher overall waste disposal costs due to increased waste volume
	• Future acceptability of waste form uncertain; vitrified waste form perceived to be better

(A-6) Rotary Kiln, Air Fed, Maximum Recycling, Vitrification and Polymer

Advantages	*Disadvantages*
• Final waste volume is less than baseline	• Increased operational complexity
	• Concept for salt recovery system is not developed
	• Mercury capture from spent carbon requires further development
	• Recycled metal may be a liability

(A-7) Slagging Rotary Kiln

Advantages	*Disadvantages*
• Same as A-1	• Same as A-1
• High operating temperature to achieve more complete combustion	
• Can accept some metallic waste with blend	• High operating temperature and flux addition can reduce refractory life
• One step processing	• Larger output offgas (20%) compared to ashing rotary kiln
• Commercial units probably adaptable for MLLW use	• Uniformity of slag product and its leachability needs to be better understood
• Eliminates separate vitrification facility	• Operability and control needed to maintain slagging mode; will require composition control similar to vitrifier
	• Consistent feed is required to protect refractory
	• Slag may require remelting

(B-1) Indirectly Heated Pyrolyzer, Vitrification and Polymer

Advantages

- Offgas volume less than 1/2 A-1
- Lower operating temperatures for pyrolyzer means less entrainment and less metal volatility
- No brick liner replacement

Disadvantages

- Complex APC process control
- Dependant on one APC failures shut down processing of most waste
- Control of oxygen concentration and under fire air flow to pyrolysis operation is critical

(C-1) Plasma Furnace

Advantages

- Off-gas volume less than 10% of A-1
- Stable final waste form possible with correct feed mix
- Separate vitrification unit eliminated
- Reduced complexity in feedstock storing operation; some sorting is required to ensure correct blend for making glass/ceramic
- Can process higher temperature melting materials and improve flowability
- No metal waste separation

Disadvantages

- Plasma has limited experience
- Short electrode life affects system's operating time
- Partitioning of radionuclides into slag must be verified
- Volatilization of metals needs to be controlled
- Corrosion of components
- Furnace design requires development for DOE wastes
- Air operated torch has high Nox
- Attentive operational control required
- Uniformity of slag and its leachability needs to be better understood

- Slag may require remelting forquality control

(C-2) Plasma Furnace Waste Destruction and CO_2 Retention System

Advantages

- Same as C-1 and A-4
- Low off-gas flow offers less volatized APC demand
- No metal waste separation

Disadvantages

- Same as C-1 and A-4
- Metals may be more than in C-1

(C-3) Plasma Gasification Destruction System

Advantages

- Same as C-1
- Lower NO_x
- No metal waste separation

Disadvantages

- Immature technology, lack of data
- Experience with metals in this type of plasma reactor needs further study
- Pyrophoric carbon poses hazard
- Fire explosion control needed throughout entire system
- Uniformity of slag and its leachability need to be better understood
- Slag may require remelting for Q.C.

(D-1) Controlled Air Fixed Hearth Incinerator

Advantages

- Refer to A-4 for CO_2 retention

Disadvantages

- Refer to A-4 for CO_2 retention

- Off-gas volume 10% of baseline
- Minimum particulate entrainment
- Some feed will require size reduction
- Minimal air leakage allows recycling of oxygen to furnace

(E-1) Rotary Kiln, Air Fed, Thermal Desorption

Advantages

- Kiln and desorber are both commercially available
- Eliminates the vitrifier operation
- Predictable construction costs

Disadvantages

- Mechanically complex system with kiln and desorber
- Final waste form less and much larger volume
- Noncombustibles must be and schedule separated from combustibles
- Desorber operation with combustibles is problematic
- Mercury and PCBs may remain in the desorbed solids

(F-1) Molten Salt Oxidation

Advantages

- Can accommodate some difficult-to-treat wastes (e.g., SiC, Carbon, Na)
- In-bed neutralization of acids
- May have higher metal and radionuclide retention

Disadvantages

- Salt recycle necessary to keep disposed waste volume low and fractional separation of sodium carbonate from NaCl may be difficult
- Noncombustibles must be separated from combustibles
- Size reduction of combustibles to 1/8 to 1/4" diameter
- Salt carryover and build-up from bed to offgas system

- Hot salt handling safety
- Corrosion

(G-1) Molten Metal Waste Destruction

Advantages

- Stable final waste form
- Same as C-1, except has higher operating temperature
- No metal waste separation required
- Apparent low cost if metal is baghouse
- Permittable as a recycle technology

Disadvantages

- Requirement for extensive size reduction to 2 mm
- Emerging technology, no operating commercial units
- Slag and metal removal/ handling requires further development
- Pyrophoric potential in recycled off-gas from solids that collect in -- fire, explosions need control throughout system
- Volatilization of metal needs to be established
- Corrosion a critical concern
- Separate heat source required to keep slag fluid Above molten metal
- Waste composition and additive control complex
- Potential pyrophoric particulates/ gases in baghouse
- High levels of dust carryover to APC

(H-1) Fluidized Bed Gasification System

Advantages

- Commercially used for biomass wastes
- Organic waste destruction at lower temperature compared with system A-1
- Reduction process reduces the possibility of dioxin/furan reformation
- Low offgas volume
- Potentially more acceptable to public

Disadvantages

- Fine shredding within a narrow size range is needed
- Fire explosion hazards need control
- Requires removal of metals and noncombustibles

(J-1) Joule-heated Vitrification

Advantages

- Experience with DOE HLW
- May accommodate combustible and noncombustible waste in single melter
- Stable final waste form
- One step process
- Cold top reduces volatilization

Disadvantages

- Electrode corrosion needs development for some waste formulations
- Burning may produce higher load to APC
- Most commercial melters are fossil fueled, but high organic debris concentration not yet demonstrated
- Must remove metals from feed

(K-1) Mediated Electrochemical Oxidation

Advantages

- Same as desorber part of A-4
- Can destroy organic liquids

Disadvantages

- Same as desorber part of E-1
- Requires separation of at low

operating temperatures

- Compact and easy to add capacity
- Low temperature operation

non combustibles and separation of regulated volatile organics from solids

- Very limited experience
- Limited versatility; MEO subsystem requires separations and pretreatment
- Slow reaction kinetics for large reactor
- Chlorine gas and hydrogen from primary unit must be managed
- High complexity

(L-1) Supercritical Water Oxidation

Advantages

- Has commercial application in non-nuclear industries with low chlorine concentration
- Moderate temperature operation

Disadvantages

- Corrosion and deposition problems must be solved; stringent control of halogens required
- Low versatility; SCWO subsystem requires separations and pretreatment
- Major safety issues due to high pressure
- No outstanding advantages given risk
- Same as desorber part of E-1
- Requires separation of non-combustibles and separation of regulated organics from solids

- Accepts minimal solids
- Cannot accept high organic concentrations in feed

APPENDIX B

Summary of ITTS Technical Review Panel Technical Findings

Potential Major Concerns

- DOE stopping studies with Phase II
  - -- Phase II did not address many of the non-thermal treatment options. DOE will be viewed as biased towards thermal treatment. DOE should have a full evaluation of most or non-thermal options in order to defend its choices and gain public acceptance of any course of action. This also applies to the upcoming NAS study.
- Lack of high quality data that regulators can use to reach decision in spite of public opposition
  - -- R&D programs need to acquire such convincing data
- Future LDR criteria and waste acceptance criteria (WAC)
  - -- Higher integrity waste forms and resistance to leachability other than the TCLP test may be required in the future. Waste disposal must consider that possibility
  - -- Often, there is no WAC
- Future air emission limits
  - -- Need CEM technology for all important toxic pollutants of concern
- Low versatility
  - -- Capability of the organic treatment unit to accept a wide variety of waste, liquids, and solids is needed because of the cost to more extensively characterize and sort solid waste
  - -- Applies especially to MSO, MEO, and SCWO, and in progressively lesser degrees to MSO, steam gasification, molten metal, and fixed hearth furnace
- Materials corrosion and lifetimes
  - -- Applies to all options with incinerators being the least susceptible

- -- Supercritical water oxidation is the most challenging system for corrosion control

- Processes requiring shredding finer than KOMAR shredder capability

  - -- Applies to MSO, molten metal, SCWO, and MEO

- High pressure

  - -- High pressure can create a safety hazard for workers; it is generally not acceptable practice in DOE nuclear operations

  - -- Applies to SCWO

- Systems with combustible gases (CO, H_2)

  - -- Potentials for fires or explosions have serious consequences and the potential must be adequately mitigated or eliminated

  - -- Applies to any steam reforming, pyrolysis, and molten metal

- Potential pyrophoric solids

  - -- Fine combustible particulate, e.g., carbon or metal, can create a fire potential

  - -- Applies to molten metal, pyrolysis, and steam reforming

- Perceptions of stack gas emissions (risks)

  - -- Education that controls can be trusted based on reliable "consumer-approved" data on process normal performance and upset conditions (trial burns)

  - -- Applies to all options except MEO and perhaps SCWO

APPENDIX C

Technical Review Panel Observations on the ITTS Phase I and II Studies

- The study is useful in comparing thermal treatment technologies as a system relative to the same basis. A good building block for additional studies, such as on non-thermal technologies, to complete the perspective
- Study seems to be balanced for all selected systems
- DOE needs balance by including more non-thermal options in future studies
- DOE needs to link with the PEIS and its non-flame option
- Needs to address the other waste problem -- D&D and remediation
- Needs to be more widely communicated to "decision makers" in the field
- Sensitivity studies are needed to provide discrimination among treatment units
- Some sensitivity studies, including FFCA-driven treatment options, are needed to establish effects of variations in waste composition, capacities, operating period, etc.
- Needs to more clearly focus on key decisions needed in the field, which incinerator, which melter, which APC, etc., so criteria and specifications can be appropriately written
- Before being issued, study needs to address that Phase III will be done on solely non-thermal systems so DOE is not biased towards thermal treatment
- Future studies need to focus not only on costs but also more thoroughly on quality of technical performance and risks/safety
- Maturity of the technology should be reflected on system cost by use of variable contingency factors
- Results need to be presented in a parametric way that allows not only comparison between the 19 ITTS complete systems but comparison between different subsystems that accomplish the same "black box" function
- Could have taken more advantage of or integrated with previous DOE flowsheet, system F&OR's, design and cost studies, and ASPEN studies, especially the MWTP, MWIP, and HAZWRAP work

APPENDIX D

Acronyms and Abbreviations

APC	Ar pollution control
BDAT	Best demonstrated available technology
CAA	Clean Air Act
CEM	Continuous emission monitoring
CEP	Molten Metal Technology's Catalytic Extraction Process
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
DRE	Destruction removal efficiency
EM	DOE's Office of Environmental Management
EPA	U.S. Environmental Protection Agency
ER	DOE's Office of Environmental Restoration (EM-40)
ES&H	Environmental, safety, and health
FFCA	Federal Facilities Compliance Act
HAZWRAP	Hazardous Waste Remedial Actions Program of Martin (now Lockheed Martin) Energy Systems, Inc., Oak Ridge, TN
HEPA	High-efficiency particulate air (filter)
HQ	headquarters
IAG	Interagency agreement
INEL	Idaho National Engineering Laboratory
ITTS	Integrated Thermal Treatment System
LDR	Land Disposal Restrictions (RCRA)
LLNL	Lawrence Livermore National Laboratory
LLW	Low level waste
MACT	Maximum Achievable Control Technology
MLLW	Mixed low-level (radioactive) waste
MWIP	OTD's Mixed Waste Integrated Program
MWIR	Mixed Waste Inventory Report
MWTP	EM-30's proposed Mixed Waste Treatment Project at LLNL
NRC	U.S. Nuclear Regulatory Commission
NEPA	National Environmental Policy Ac
OSHA	Occupational Safety and Health Administration
OTD	DOE's Office of Technology Development (EM-50)
PCB	Polychlorinated biphenyls
PIC	Product of incomplete combustion
POHC	Principal organic hazardous constituent
ppmv	Parts per million (by) volume
ppmw	Parts per million by weight
RCRA	Resource Conservation and Recovery Act
RDDT&E	Research, development, demonstration, testing & evaluation
SCC	Secondary combustion chamber
TCLP	Toxicity characteristic leaching procedure
TLCC	Total life cycle cost
TOC	Total organic carbon
TRU	Transuranic

TSCA	Toxic Substances Control Act
VOCs	Volatile organic compounds
WIPP	Waste Isolation Pilot Plant
WM	DOE's Office of Waste Management (EM-30)

APPENDIX E

Carl R. Cooley
Office of Technology Development
Office of Environmental Management
U.S. Department of Energy

EDUCATION

- M.S. Chemical Engineering, University of Idaho, 1958
- B.S. Chemical Engineering, Kansas State, 1950

CERTIFICATIONS

- Licensed Professional Engineer, Washington, 1960

CURRENT PROFESSIONAL HIGHLIGHTS

Currently, Mr. Cooley is the Senior Technical Advisor to the Assistant Deputy Secretary for Environmental and Waste Management, Department of Energy. He has 43 years of professional experience in the waste management and chemical industry; 14 years with General Electric at Hanford Plant, Richland, Washington; five years with Battelle Memorial Institute at Hanford; five years with Westinghouse Hanford Co. at Hanford; and eighteen years Federal service with the Department of Energy and its predecessors in Washington, D.C. He is a member of the American Institute of Chemical Engineers and has served as the local program chairman and national session chairman. Mr. Cooley serves as a consultant at waste management meetings and speaks regularly at national and local meetings. He has received numerous outstanding performance awards from the Department of Energy.

EXPERIENCE

Professional Employment: 43 years

- Senior Technical Advisor to Assistant Deputy Secretary for Environmental and Waste Management, Department of Energy. Performed systems analysis and engineering studies on environmental remediation and waste treatment technologies and associated air pollution control, and waste disposal. Conducted cost savings analysis for selection and use of technologies. Organization and coordination of peer review groups. Coordination with EPA and DoD programs on implementing the Federal Strategic Environmental Research and Development Program. Implementation and direction of DOE technical programs and projects for waste management, disposal, spent fuel storage, environmental and waste management technology and depleted uranium reuse. Provided

recommendations of technical plans and options for remediation, waste treatment/incineration low-level and high-level radioactive waste treatment, storage and disposal using cold and radioactive pilot plant demonstrations. Dry spent fuel storage. High-level waste geologic disposal technology and subseabed and space disposal options. Radioactive pilot plant design, construction and operation for spent fuel reprocessing, uranium recovery, plutonium and isotope recovery. Coordination of international activities and projects with other countries, the International Atomic Energy Agency, etc. Design, construction, operation and decontamination of radioactive pilot plants for isotope recovery and spent fuel reprocessing. Conception and development of chemical processes for uranium recovery, plutonium recovery, isotope recovery, waste stabilization and disposal.

ADVISORY ACTIVITIES

1980 - present

- Technical consultant to the International Atomic Energy Agency for waste management in Thailand and Indonesia, 1994.
- DOE Technical Review of waste treatment technology options, 1994.
- DOE Technical Review of molten metal as technology for recycle and waste treatment, 1994.
- Technical Review of Molten Salt Oxidation integrated waste incineration systems and Rocky Flats Fluidized Bed Incinerator Program, 1993.
- IAEA International Waste Advisory Committee, 1992.
- DOE Technical Review of technological needs for the Fernald environmental restoration program, 1992.
- IAEA Technical Consultant to Ireland on radioactive waste management, 1991.
- IAEA advisor for International Waste Advisory Committee to review IAEA waste management program plans, 1991.
- OECD/Nuclear Energy Agency (Paris) Ad hoc committee on planning for environmental restoration and waste minimization, 1991.
- Invitational participation in the Commission of European Communities Five Year Plan Meeting, 1990.
- Office of Technology Development delegate to Radioactive Waste Management Committee of OECD/Nuclear Energy Agency, 1990
- U.S. participant in Radioactive Waste Management Committee of OECD/Nuclear Energy Agency, 1989.
- IAEA technical advisor for Waste Management Advisory Program mission to mainland China and Korea, 1988.
- IAEA annual meetings of the Technical Review Committee for document publication and program plans and participant in OECD/Nuclear Energy Agency Radioactive Waste Management, 1980 - 1988.

Pre - 1980

- U.S. delegation for the International Fuel Cycle Evaluation of Waste Management
- Design for uranium hexafluoride conversion
- Effluent Control Technology
- Designs for vitrification of waste, isotope recovery and low-level waste treatment

PATENTS, PUBLICATIONS, AWARDS

- Mr. Cooley has received many outstanding performance awards from the Department of Energy

Blaine W. Brown
Senior Engineering Specialist
Idaho National Engineering Laboratory
Idaho Falls, ID

EDUCATION

- Ph.D. Chemical Engineering, Brigham Young University, 1985
- BS Chemical Engineering, University of Utah, 1981
- BS Fuels Engineering, University of Utah, 1981

CERTIFICATIONS

- Licensed Professional Engineer, Idaho

CURRENT PROFESSIONAL HIGHLIGHTS

Dr. Brown has been a practitioner of the engineering arts at the INEL for ten years, serving in three capacities of ever-increasing responsibility and breadth of complexity. He supports numerous programs at the INEL, from fossil-related programs to environmental clean up. He is extremely proficient on developing statistical back up, mass balance configurations, and cost-related calculations on the ASPEN and other computer models and was the prime cost-generator for the nineteen thermal treatment technologies developed under the systems studies carried out by the Department of Energy's Office of Technology Development.

EXPERIENCE

Professional Employment: 13 years

- Senior Engineering Specialist, Chemical and Process Engineering, LITCO, Idaho Falls, ID and with its predecessor, EG&G Idaho. Repackaging calculations for WERF incinerator. Modeled release of VOCs from drum venting operations. Assessed treatment alternative of aqueous NPR fuel process waste. Assessed treatment alternatives of aqueous NPR fuel process waste. Wrote management plan for alpha-contaminated mixed low-level waste. Investigated treatment alternatives for mixed waste streams, 1992-present.

- Senior Project engineer, Industrial Conservation Programs, EG&G Idaho, Inc., Idaho Falls, ID. Provided project management direction and technical expertise to DOE Office of Industrial Technologies for industrial energy conservation. Waste characterization and non-thermal treatment plan for Rocky Flats Plant. Technical review of

program proposals. Identified new research program areas. conducted site inspections of various facilities. Responsible for technical monitoring and program guidance of subcontractor performance, 1987-1988.

- Engineering Specialist. Chemical and Process Engineering, EG&G Idaho, Inc., Idaho Falls, ID. Waste remediation support activities for hazardous and radioactive wastes at the Idaho National Engineering Laboratory. Design and pilot plant testing of mixed waste treatment facility. Flowsheet modeling using ASPEN. Process design and engineering of waste treatment facilities. Numerical simulation of diffusion processes. Thermodynamic modeling of chemical reactions occurring in waste retrieval and in-situ processing. Assessment of substitution of nonhazardous for hazardous materials, 1985-1987.

- Graduate Research Assistant, Combustion Laboratory, Brigham Young University, Provo, Utah. Responsible for test program and facility upgrading of coal gasifier. Measured and analyzed experimental data. Determined effect of coal type on entrained gasification, 1981-1985.

- Summer Engineer, Kennecott Research Center, Salt Lake City, Utah. Responsible for statistical analysis in materials technology, 1981.

- Summer Technician, Hercules Aerospace Division, Salt Lake City, Utah. Product engineering and advanced studies. Nozzle erosion, shaped charge studies, 1979-1980.

AFFILIATIONS, AWARDS

- Affiliate Faculty Member, University of Idaho, Department of Chemical Engineering
- Member, American Institute of Chemical Engineers
- Member, Combustion Institute, Western States Section
- Outstanding Achievement Award, EG&G

PATENTS, PUBLICATIONS

- Dr. Brown has written numerous technical papers, journal articles, and reports.

James J. Cudahy, P.E.
President and Senior Consultant
Focus Environment Inc.

EDUCATION

- M.B.A. Michigan State University, 1967
- M.S. Chemical Engineering, University of Delaware, 1966
- B.S. Chemical Engineering, Newark College of Engineering, 1963

CERTIFICATIONS

- Licensed Professional Engineer in Louisiana, Michigan, and Delaware

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Cudahy is a chemical engineer with 25 years of experience in the chemical industry and as an environmental engineering consultant. His chemical industry experience includes research, marketing, and production work, with over 5 years spent in technical and supervisory chemical production positions. As an Environmental Engineering Consultant, he has specialized for 20 years in incineration and various other aspects of solid and hazardous waste management, permitting, and soil clean-up technologies. He has authored over 80 publications and presentations in these areas, has served as an expert witness, and has chaired sessions on incineration, permitting and soil clean-up at international conferences. He has served on national and local committees involved with the environmental aspects of industrial and hazardous wastes, incinerator metals emissions, the development of EPA incineration guidance documents, energy recovery from waste incineration, and environmental quality. He publishes an annual survey on mobile thermal treatment contractor experience.

EXPERIENCE

Professional Employment: 25 years

- President and Senior Consultant Focus Environmental Inc., Knoxville, TN. Responsible for high level environmental consulting in the areas of process engineering design, operations, and permitting with an emphasis on market analysis, technology evaluation, public education, and legal support. 1989 - present.

- Director, Business Development, Thermal Treatment Systems IT Corporation, Knoxville, TN. Defined market needs and potential winning strategies in the areas of fixed and transportable hazardous waste incineration systems. Required staying current on latest developments in thermal treatment and appropriate regulations. 1985 - 1988.

Terry Escarda
Waste Management Engineer
California Department of Toxic Substances Control

EDUCATION

- B.S. Environmental Resources Engineering, University of California (Humboldt), 1988

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Escarda is a Waste Management Engineer with the California Department of Toxic Substances Control. He was a hazardous waste treatment, storage, and disposal permit writer for nearly three years with the Department's Region 1 Office where he was responsible for maintaining land disposal permits for the Chemical Waste Management Kettleman Hills Facility and the Pacific Gas & Electric Company Morro Bay Facility. For the last two years he has worked in the department's Hazardous Waste Reduction Grant Program where he was responsible for developing Requests for Proposals, evaluating proposals, and managing research grant contracts. Terry is currently involved in writing research, development, and demonstration (RD&D) permits for such projects as mixed waste (hazardous/radioactive) management, lead-acid battery recycling, and alternative battery development. He is the RD&D permit writer for the Lawrence Livermore National Lab Mixed Waste Management Facility, where technologies such as molten salt oxidation (MSO) will be demonstrated and evaluated for effectiveness in treating mixed waste. He also serves on the Western Governors' Association Develop On-Site Innovative Technologies Committee mixed waste group, and will be the regulatory liaison for a proposed joint project with Southern California Edison and Rockwell to evaluate MSO's effectiveness in treating a variety of waste streams.

EXPERIENCE

Professional Employment: 6 years

- Waste Management Engineer, California Department of Toxic Waste Substances Control, Sacramento, CA. 1988 - present.
- Environmental Engineer, Oscar Larson and Associates, Eureka, CA. 1987 - 1988.

Fred Feizollahi
Project Manager
MK Environmental Services
San Francisco, California

EDUCATION

- B.S. Mechanical Engineering, University of Maryland, 1970
- Chemical Engineering Graduate Studies, University of Maryland, 1970 - 1972

CERTIFICATIONS

- Registered Professional Engineer, California

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Feizollahi has 23 years of remedial action/environmental restoration and hazardous/radioactive waste management experience. His expertise include designs, construction and operation of nuclear and chemical waste management facilities including liquid, gaseous and solid waste processing/storage, transportation, and disposal. Mr. Feizollahi has held Project Manager, Project Engineer, Technical Leader, and Process Group Supervising Engineering positions for Morrison Knudsen Environmental Services on several waste management, remedial action/environmental restoration projects. Currently, he is a Project Manager on a DOE radioactive waste treatment design and cost estimating project involving integration with several DOE field and headquarter offices and DOE site management contractors. He manages development of design concepts and planning life cycle costs (PLCC) for treatment, storage, and disposal of seven different DOE waste streams: Low-level waste (LLW), mixed low-level waste (MLLW), alpha-technologies considered by this project include incineration, solidification, vitrification, metal-melting, supercompaction, sizing/decontamination and wet-air oxidation. Mr. Feizollahi is also a Project Manager on FMC-San Jose sites final remedial action projection. His responsibilities include remedial design, remedial action, and final closure of three facilities. Remediation technologies employed include bio-remediation, vapor extraction and stabilization of VOCs, TPH, PCBs and lead contaminated soil. He has overall responsibility for planning, control and execution of remedial activities performed by both the home and field offices personnel. Mr. Feizollahi is also a Technical Specialist on DOE integrated thermal treatment study covering various options for treatment of mixed waste. He supervised the preparation of facility design and cost estimates for various treatment options including incineration, vitrification, solidification, mercury separation, lead recovery and metal decontamination. In 1987, 1989 and 1991, Mr. Feizollahi served as the Technical Program Chairman for the ASME Joint International Waste Management Conference.

EXPERIENCE

- Professional Employment: 23 years
- Project Manager, MK Environmental Services, San Francisco, CA. 1991 - present.
- Bechtel, San Francisco, CA. 1982 - 1991.
- Halliburton/NUS, Gaithersburg, MD and San Francisco, CA. 1977 - 1982.
- Hittman (currently Westinghouse/SEG), Columbia, MD. 1973 - 1977.
- Whitman, Requardt & Associates, Baltimore, MD. 1970 - 1973.

PATENTS, PUBLICATIONS, AWARDS

- Mr. Feizollahi has written numerous technical papers, journal articles and reports on hazardous, radioactive, and mixed waste management.

Rod F. Gimpel
FERMCO

EDUCATION

- B.S. Chemical Engineering, University of Idaho, Moscow, Idaho, 1975

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Gimpel has over 20 years of experience in environmental programs and project management, process development, and environmental analysis. He presently works for the Fernald Environmental Restoration Management Corporation (FERMCO) at DOE's Fernald Environmental Management Project (FEMP). He has worked 2 years at Hanford, Richland, Washington in plutonium processing and storage development; 10 years at the Idaho National Engineering Laboratory in Feasibility and Project Management; and 8 years at Fernald as a project manager, CERCLA Operable Unit 1 (OU-1) manager, OU-1 treatability manager, and as the Minimum Additive Waste Stabilization (MAWS) founder and manager. He is presently working in the design and operation of a 1 to 3 metric ton/day pilot vitrification facility for the treatment of OU-4 wastes contained in silos. The OU-4 wastes are thorium, uranium, and radium contaminated residues that produce high concentrations of radon gas. Glass concentrations in the wastes. Vitrification is one of his hobbies and he has become very knowledgeable in glass chemistry and melter design. He has written and presented over 10 papers on vitrification, process development and economics, and process scale-up.

EXPERIENCE

Professional Employment: 20 years

- MAWS Project/Program Manager and vitrification engineer/specialist, FEMP, FERMCO, Cincinnati, OH. Overall FERMCO program management, technical direction and coordination with other stakeholders, program value is $20 million. Responsible for vitrification technical direction and coordination which includes the OU-4 vitrification pilot plant demonstration. December, 1992 - present.

- Operable Unit Coordinator and Program Engineer, Westinghouse (WEMCO), Cincinnati, OH. Program responsibility and management for Site's OU-1 Remedial Action, $1.2 billion. Organized and started development programs including the MAWS program. June, 1989 - November, 1992.

- Group Leader and Project Manager for General Plant Projects, Westinghouse (WEMCO), Cincinnati, OH. Overall responsibility and management for approximately 5 projects per year, up to $2.5 million each. Most EPA mandated environmental projects. October, 1986 - May, 1989.

- Project Manager, Westinghouse (WINCO), Idaho Falls, ID. Overall responsibility and management for approximately 10 projects per year, up to $1.2 million each. March, 1984 - October, 1986.

- Project Engineer, Exxon (ENICO), Idaho Falls, ID. Overall responsibility and management for approximately 7 projects per year, up to $750,000 each. July, 1978 - March, 1984.

- Development Engineer, Rockwell International, Richland, WA. Plutonium processing and storage development. Environmental and safety analysis. Safer storage and facilities. August, 1976 - September, 1977.

- Process Engineer, Atlantic Richfield Co. (ARHCO), Richland, WA. Responsible for plutonium dissolution and processing plutonium metal and oxide--weapons and commercial grades. June, 1975 - July, 1976.

George L. Huffman
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Cincinnati, Ohio

EDUCATION

- B.E. Chemical Engineering, Vanderbilt University, 1962

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Huffman is currently the Chief of the Thermal Processes Section of the Cincinnati-based Risk Reduction Engineering Laboratory (RREL) of the U.S. Environmental Protection Agency (EPA). In this capacity, he directs the Laboratory's incineration research that directly supports EPA's regulation development and permit writing activities. Most recently, he has provided the technical oversight on the Congressionally-mandated EPA research on the use of two innovative technologies, Solar and Plasma "Zapping," for the detoxification of Superfund soils. His major areas of expertise are waste destruction/conversion-to-energy systems (boiler co-firing systems, incinerators, pyrolyzers, solar destructors, etc.) and environmental pollution control; process design for petrochemical plants. Mr. Huffman has authored or co-authored approximately 145 Technical Papers in his career. His major areas of expertise are waste destruction/conversion-to-energy systems (boiler co-firing systems, incinerators, pyrolyzers, solar destructors, etc.) and environmental pollution control; process design for petrochemical plants). He has served the EPA and predecessor Agencies for about 27 years. In this period, he directed numerous EPA bench-scale and pilot-scale research programs related to the incineration of hazardous, medical and mixed wastes, municipal waste "waste-to-energy" technologies, alternative energy sources (such as oil shale, geothermal, in-situ coal gasification, and solar) and the recovery of SO_2 from power plant stack gases. Before joining the Government in environmental research, he was a Process Design Engineer with the Esso Research and Engineering Company (now Exxon). His 5-year career there was highlighted by two long-term assignments in Spain and Germany.

EXPERIENCE

Professional Employment: 27 years

- Chief, Thermal Processes Section, RREL, USEPA. Directing extramural R&D in the hazardous waste thermal destruction (HWTD) area. Of the more than 80 Technical Papers generated in this period, authored key documents describing: (1) pilot-scale research done at EPA's /RREL's Incineration Research Facility in Jefferson, Arkansas; (2) Incinerability Rankings for hazardous waste constituents; and (3) Innovative thermal destruction technologies. Directed Congressionally-mandated EPA research on

the use of two innovative technologies, Solar and Plasma "Zapping", for the detoxification of Superfund soils. Extended EPA's HWTD research into the areas of medical waste and radioactive waste disposal. 1988 - present.

- Chief, Thermal Processes Research Staff, HWERL, USEPA. Directed in-house R&D in the hazardous waste thermal destruction area. Research was on bench- and pilot-scales and was aimed at determining the "modes of failure" and the products of incomplete combustion (PICs) for hazardous waste thermal destructors. In 1986, he was appointed the Agency's Co-Program Manager for the Engineering Research needed to determine how best to control the trace amounts of dioxins and furans being emitted from the over 100 full-scale Municipal Waste Incinerators then operating in the U.S. In 1987, was also designated as the lead author of a Federal Court-required Action Plan for the EPA destruction of cancelled stores of the pesticides "2,4,5-T" and "Silvex." 1982 - 1988.

- Research Chemical Engineer, Engineering Support Staff, IERL-Ci, USEPA (on "detail"). Program Manager for the Hazardous Waste Co-firing in Industrial Boilers Program. 1981 - 1982.

- Chief, Alternate Energy Sources Branch, IERL-Ci. Directed R&D programs in some 10 "energy" areas (e.g., Geothermal, Energy Conservation for Industrial Processes, Indoor Air Pollution, Gasohol, Carbon Fibers, Solar, etc). 1980 - 1981.

- Chief, Fuels Technology Branch, IERL-Ci. Directed a staff of engineering scientists and research programs in (1) "Waste-as-Fuel" [a $20 million (MM) program]; (2) Oil Shale/In-Situ Coal Gasification [a $7.0 MM program]; and (3) biomass-to-Energy [a $0.6 MM program]. 1975 - 1980.

- Energy Coordinator, NERC-Ci/SHWRL, USEPA. Principle author of "Strategy Document for Research in Wastes-as-Fuel"; coordinated/implemented the first-year, $4.5 MM program in that area. 1974 - 1975.

- Research Chemical Engineer, NERC-Ci/SHWRL. Program Manager in the $CaSO_4$ (FGD Sludge) Disposal area. 1974 - 1975.

- Energy Task Force Member, EPA/ORD (on "detail"). Helped plan a 5-year, $75 MM R&D program in the Energy Conservation area. 1974 - 1974.

- Program Coordinator and CPU - 400 Project Manager, NERC-Ci. Technical liaison for the NERC Director with his Solid and Hazardous Waste Research Laboratory (SHWRL). Project Manager for

the CPU-400 Project (a $9 MM Congressionally-mandated waste combustion/conversion-to-electricity project). 1973 - 1974.

- Program Coordinator and "Center Staff Officer," NERC-Ci. Technical liaison for the NERC Director in the R&D areas of oil and hazardous spill technology and industrial water pollution control. 1972 - 1973.

- Chief, Hazardous Waste Technology Section, OWSMP, EPA-Ci. Responsible for the $2 MM Congressionally-mandated study of the worth of setting up National Disposal Sites for hazardous waste. 1971-1972.

- Chief, Industrial and Agricultural Data Section, OSWMP. Produced over 60 consultative analyses on various industrial/hazardous waste disposal problems. 1970 - 1971.

- Research Chemical Engineer, DHEW/NAPCA, Cincinnati (what became EPA's IERL - RTP). Technical Manager for a $2 MM R&D program for SO_2 recovery from power plant flue gases. Initiated the two largest demonstration projects every undertaken by NAPCA (totalling over $12 MM) --- for Mag-Ox and Cat-Ox. 1967 - 1970.

- Process Design Chemical Engineer, Esso Research & Engineering Company (now Exxon), Florham Park, New Jersey. Process design engineer in the areas of crude light ends fractionation, hydrocracking, gas absorption, heat exchange and steam reforming. In Spain, helped an Esso affiliate prepare for an NH_3 plant test-run for process guarantees. In Germany, monitored contractor design/engineering on a $100 MM ethylene/acetylene petrochemical project. 1962 - 1967

PATENTS, PUBLICATIONS, AWARDS

- Mr. Huffman has authored or co-authored approximately 145 Technical Papers for various national and international conferences devoted to his areas of expertise. Another 30 key presentations have been made at major Technical Program Reviews and for various groups of scientific international visitors to the EPA Environmental Research Center in Cincinnati, Ohio.

Gary D. Knight
Senior Policy Advisor
Waste Policy Institute

EDUCATION

- Completed 1/2 the course work for MBA in Business-Government Relations, American University, Washington, D.C., 1974 - 75
- Masters in Public Administration, American University, Major -- Governmental Management; Minor
  -- Organizational Theory and Behavior, 1974
- B.S., U.S. Naval Academy, Annapolis, MD, Major -- Engineering; Minor -- Management & Leadership

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Knight is a skilled practitioner in the national public policy arena and a successful manager at the highest levels of the Federal government. He has spent a career interpreting technology to politicians and policy makers and in interpreting the political process to technologists.

EXPERIENCE

Professional Employment: 24 years

- Senior Policy Advisor, Waste Policy Institute, Gaithersburg, MD. In addition to duties enunciated below, serves the Institute by coordinating with and providing lines of communication to senior policy makers in the Department of Energy and other companies. In addition to policy, provides input into possible fruitful lines of new business and executive recruitment. June - present.

- Program Manager, Waste Policy Institute, Germantown, MD. Provided management, policy, strategic planning and technical advice and support to the Office of Technology Development of the Department of Energy's Office of Environmental Restoration and Waste Management (which is charged with cleaning up the nation's nuclear weapons sites). March, 1993 - June, 1994

- Senior Administrative Specialist/Senior Engineer (Consultant), NJG, Inc., Germantown, MD. Provided management, policy, strategic to the Environmental Restoration and Waste Management Office of the U.S. Department of Energy, the Army Corps of Engineers and NASA. Provided lines of communication to key decision makers on Capitol Hill and the Office of Management and Budget OMB). October, 1991 - February, 1993.

- Deputy Assistant Secretary for House Liaison, U.S. Department of

Energy, Washington, D.C. Headed a staff (with a $1.5 million budget) of fourteen, including twelve Hill liaisons representing a $20 billion Cabinet Department before the U.S. House of Representatives. October 1989 - October, 1991.

- Lobbying Consultant, Multinational Business Services, Inc., Washington, D.C. Provided a legislative capability to this regulatory/trade-oriented consulting firm headed by a former Deputy Director for Regulatory Affairs at OMB for Fortune 500 clients including General Motors, AT&T and IBM. October, 1988 - October, 1989.

- Director, Federal Affairs, Edison Electric Institute, Washington, D.C. Served as the principal liaison between the Institute, representing the investor-owned electric companies of the nation, and the Federal government with a staff of four (including consultants). May, 1986 - October, 1988.

- Expert Consultant (Special Assistant) to the Deputy Assistant Secretary for Security Affairs, Defense Programs, U.S. Department of Energy, Washington, D.C. Served on the staff of the Deputy Assistant Secretary who has responsibility for the security of not only all DOE headquarters and field facilities, but also of the Department's nuclear weapons complex, including management responsibility for a 5000-man guard force. Served on a six-man Secretarial Task Force (the Special Project Team) to examine the strengths and weaknesses of the security of the Department's nuclear weapons complex. July, 1985 - March, 1986.

- Director, House Relations, U.S. Synthetic Fuels Corporation, Washington, D.C. Responsible for all communications with and activities involving the U.S. House of Representatives for this $20 billion quasi-public corporation, established by Congress to help develop a domestic synthetic fuels capability. Oversaw a staff of five. Directed indirect lobbying efforts and set legislative strategy on numerous attempts to divert SFC funds to other purposes and in 1984 helped to hold an imminent $10 billion rescission attempt to $5 billion, as well as an almost-successful effort to reinstate tax credits for synthetic fuels projects. August, 1981 - July, 1985.

- Assistant to the President, American Mining Congress, Washington, D.C. Reported directly to the Chief Executive Officer of this major national trade association on policy-making, legislative, political, organizational and managerial matters affecting the domestic mining industry. Played a major policy-making and implementing (lobbying) role on energy, environment and natural resources issues including synthetic fuels, energy "fast track"

(Energy Mobilization Board), public lands, wilderness, strategic minerals, "Superfund", clean air, utility oil "Backout" and regulatory reform legislation. May, 1979 - July, 1981.

- Director, Environment and Land Policy, Chamber Commerce of the United States, Washington, D.C. Became one of the senior industry policy-makers and lobbying strategists in Washington on issues relating to natural resources and the environment (including impacts on energy development), with a staff of eight. Staff Executive of the Chamber's Committee on the Environment, comprised of thirty-five vice presidents for environmental affairs from major corporations and trade associations, which develops national policy positions for the U.S. business community on environment and natural resources issues. Widely published, quoted in the national media and sought as a speaker on environmental issues as a national business spokesman at many major national forums, including the 1978 series of national debates on the 1977 Clean Air Act Amendments sponsored by the Air Pollution Control Association. Author of a 30-minute slide presentation on the Clean Air Act and of many articles on environmental issues. April, 1974 - May, 1979.

- Assistant for Legislative Affairs, U.S. Department of Housing and Urban Development. Congressional relations and liaison between the Department and Congress. September, 1973 - April, 1974.

- Legislative Assistant to Hon. Norman F. Lent (R-NY). Legislation, legislative policy, research and speech writing, special projects for Freshman Member who later ascended to be ranking Member of House Energy and Commerce Committee. February, 1972 - January, 1973.

- U.S. Naval Officer. Aviator and Personnel Officer with Top Secret Clearance. Medically retired as LTJG due to disabling auto accident. June, 1970 - November, 1971.

Elected to three four year terms on the Falls Church City Council, including one two-year term as Vice Mayor by his colleagues. Among his other accomplishments, he chaired the Personnel Policy, controlling 2/3 of the City's $20 million budget; he directed a ten-year effort to revitalize and beautify the City's downtown; he was appointed by three successive Governors to the Governor's Advisory Commission on the Potomac River Basin; chaired for 3 years the Water Resources Planning Board of the Wash. Metro. Area Council of Governments; chaired other committees on cable TV, sign ordinance, noise ordinance, capital improvements, legislative policy, and All-America City competition.

John Henry Kolts
Principle Scientist
U.S. Department of Energy - Idaho

EDUCATION

- Ph.D. in Physical/Analytical Chemistry, Kansas State University, Manhattan, Kansas, 1978
- BS (Cum Laude) in Chemistry with minor in Zoology, Weber State College, Ogden, Utah, 1974

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Kolts is a holder of 56 United States Patents, over 200 foreign patents and author of numerous technical publications.

EXPERIENCE

Professional Employment: 16 years

- Principle Scientist Advisor, DOE-IDER, Waste Management and site wide Research & Development Programs.

- Morrison Knudsen Corporation. Senior Scientist and Technical Director for the Government Facilities and Environmental Services Division. Responsibilities included selecting, coordinating and implementing technology for the remediation efforts at Oak Ridge, Rocky Flats, Fernald, and the Idaho National Engineering Laboratory.

- EG & G, Idaho. Principle Scientist, EG&G Idaho, Technology Director for the Environmental Restoration and Waste Management Department. Responsibilities included coordinating, approving and directing the implementation of environmental and waste management programs at the Idaho National Engineering Laboratory. Additional responsibilities included providing direction on RI/FS studies, Records of Decision, RD/RA actions, as well as supporting DOE with State of Idaho and EPA technical issues, and directing the Strategic Planning Unit for the INEL in Environmental Engineering and Waste Management and being a representative to the University of Idaho and Idaho State. Also responsible for the technical oversight of all Pit 9 remediation activities.

- Phillips Petroleum. Phillips Petroleum Company, Research Associate responsible for the direction of a diversified research group. Specific technical and management responsibilities were

light and heavy hydrocarbon process research and development, direct methane conversion, new waste treatment techniques, and waste minimization research and development. 1978 - 1990.

PATENTS, PUBLICATIONS, AWARDS

- In addition to holding numerous U.S. and foreign patents, Mr. Kolts received the National R&D 100 Award for developing one of the top 100 new commercial products for the year 1989.

Burdon C. Musgrave
Owner and Principal
BCM Inc.

EDUCATION

- A.B. Chemistry, University of Kansas, 1957
- Ph.D. Chemistry, University of Kansas, 1961

CURRENT PROFESSIONAL HIGHLIGHTS

Currently, Dr. Musgrave is retried from the University of California's Lawrence Livermore National Laboratory; however, he is an active consultant to the U.S. Department of Energy for preparation of the Office of Waste Management's Programmatic Environmental Impact Statement and in support of the Mixed Waste Focus Area and Federal Facility Compliance Act program.

EXPERIENCE

Professional employment: 34 years

- Lawrence Livermore National Laboratory, where he managed NRC standards development program. This effort was providing technical basis for NRC standards for the high level waste repository. Supervised the newly-formed analytical chemistry division; developed the plan for manpower, facilities, and equipment for the long range program improvement and support for LLNL research programs. At the request of the lab's Assoc. Dir. for Operations, conducted a lab-wide survey of status of programs and facilities and defined the program required to bring LLNL in compliance with all applicable environmental requirements. From this was established LLNL's environmental protection program. Supervised waste management, waste minimization, environmental restoration, environmental monitoring, and laboratory-wide environmental guidance programs. Developed flowsheets, waste management alternatives, and process models for the special isotope separation program. 1979-1993.

Also at LLNL, supported the DOE EM-40 program, and the request of EM-30 management, evaluated and defined the waste treatment facilities technologies and capacities, required for DOE compliance with EPA-RCRA Land Disposal Restrictions for mixed wastes. This last effort led to establishment of EM-30's Mixed Waste Treatment Project, which analyzed for DOE the requirements and options for managing mixed wastes at all DOE facilities and designed/proposed a prototype mixed waste treatment facility. This approach has been continued to develop the flowsheets and alternatives for DOE mixed wastes that are analyzed for the EM waste management PEIS.

- Idaho Nuclear Corporation and Allied Chemical Corporation. Managed technical development programs at the Idaho Chemical Processing Plant at INEL including programs in processing of test reactor, research reactor, and naval propulsion reactor fuels. These included graphite, metal, and oxide-based reactor fuels. In support of these reprocessing programs, also conducted waste management efforts in high level waste solidification, performance of calcined high level waste in long term storage, recovery of wastes from the INEL disposal facility, and effluent monitoring and control from nuclear facilities. 1968-1979.

- Associate Professor of Physical and Analytical Chemistry, University of Arkansas. Conducted research programs in atmosphere chemistry, studying methane lifetimes and krypton-85 distributions, chemical kinetics of photochemically-activated systems, and isotope geochemistry of hot springs, geyser, and thermal vent systems in Yellowstone and Lassen Volcano National Parks. 1961-1968.

Richard D. Peters
Staff Engineer, Engineering Technology Center
Battelle Pacific Northwest Laboratory

EDUCATION

- M.S. Chemical Engineering, University of California, Berkeley
- B.S. Chemistry, University of the Pacific, Stockton, California

CURRENT PROFESSIONAL EXPERIENCE

Mr. Peters joined Battelle Pacific Northwest Laboratory in 1978 as an entry level Grade 1 Engineer and by 1993 he progressed to Grade IV Staff Engineer. Duties include management of programs at PNL for mixed waste vitrification, waste form criteria, glass database development, chemical weapons destruction, coordination research with universities, R&D market development, proposal preparation, and interacting numerous industrial clients. Mr. Peters testified as an expert witness on the durability of glass product manufactured by MSP in the trial of *US EPA versus Marine Shale Processors.* He has invented a method for increasing melt rate using reactive additives, Invention disclosure and a method for protection of joule-heating electrodes, Invention disclosure.

EXPERIENCE

- Professional Employment: 16 years

- Staff Engineer, Engineering Technology Center, Battelle Pacific Northwest Laboratory. As a Staff Engineer, accomplished in the areas of process technology, chemical/materials research, and systems engineering. His process technology experience involves managing a multi-year project to develop vitrification technology for mixed waste sludges and solids at DOE; preparing initial proposal project plans, milestone reports; earning value system status reports and; presenting technical results to DOE HQ staff. Assisted in design of modular system to vitrify low-level waste from commercial nuclear power plants. Provided technical review and provided recommendations for mixed waste treatment contract at Hanford. Prepared conceptual design for 5 ton/day vitrification system to treat hazardous waste. Includes feed system, melter, off-gas system, controls, and power system. Performed chemical/materials projects, such as: managed PNL program on national effort to establish performance criteria and testing standards for DOE mixed waste forms; developed a comprehensive database of waste glass properties and composition utilizing data sources from the open literature and from files of Department of Energy projects and; developed techniques to measure the dose rate

and isotopic homogeneity of a radioactive glass canisters. Further, Mr. Peters has achieved many accomplishments in the area of systems engineering, as follows: evaluated feasibility and economics for removal of carbon dioxide from power plant flue gases using potassium carbonate absorption; determined waste management costs for the Department of Energy's new production reactor concepts and; directed tasks on the evaluation of two high-level waste forms: borosilicate glass and spent fuel, where the studies involved analysis of various radionuclide release scenarios, prediction of long term waste form behavior, and evaluation of compliance with regulatory criteria.

PATENTS, PUBLICATIONS, AWARDS

- Co-inventor of Vit-Pac, a batch vitrification system for low-level waste treatment commercialized by Battelle, patent pending. Mr. Peters has authored or co-authored 37 publications. Mr. Peters serves referee for technical articles published in New Technology.

William J. Quapp
Engineering, Technical Staff Consultant
EG&G Idaho, Inc.

EDUCATION

- M.S. Mechanical Engineering, San Jose State University, 1970
- B.S. General Science, San Diego State University, 1966

CERTIFICATIONS

- Registered Professional Nuclear Engineer, California

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Quapp has 26 years of experience in engineering, management and business development in waste management, system engineering, nuclear system design, and safety and risk analysis. He has organized projects and development project costs and schedules. His expertise includes system engineering and life cycle cost analysis, solving complex engineering problems, assembling and managing technical staff and proposals, and managing large projects. He managed the conduct of system engineering studies for buried and stored mixed wastes. He organized and managed a $15M waste technology demonstration program. He also developed technical approach and managed multi-disciplinary teams of 35 engineers and scientists to plan, conduct, and analyze reactor safety research programs. He has been instrumental in identifying requirements for, and barriers to, privatization of DOE waste treatment facilities. Mr. Quapp has developed system designs and life cycle cost estimates for buried waste, mixed waste and transuranic contaminated waste streams.

EXPERIENCE

Professional Employment: 26 years

- Engineering, Technical Staff Consultant, EG&G Idaho, Inc. September 1992 - present.
- Manager, Waste Technology Engineering, EG&G Idaho, Inc. May 1990 - August 1990.
- Manager, Environmental Assessment, Westinghouse Idaho Nuclear Co. 1989 - 1990.
- Manager, Analysis & PRA, Director, Graphite Life Extension Force, Director Strategic Planning, Director, Fuels Programs, Westinghouse Hanford Co. 1985 - 1989.

- Manager, Business Development, EG&G Idaho, Inc. 1984.
- Manager, Strategic Planning, EG&G Idaho, Inc. 1981 - 1983.
- Manager, Thermohydraulic Testing, Idaho, Inc. 1979 - 1980.
- Manager, Nuclear Fuels Research, EG&G Idaho, Inc. 1976 - 1978.
- Senior Research Engineer, EG&G Idaho, Inc., 1973 - 1975.

AFFILIATIONS, AWARDS

- Member and Speaker, Washington Site Study Group.

William Randall Seeker
Senior Vice President
Energy and Environmental Research Corporation

EDUCATION

- Ph.D. Engineering, Kansas State University, 1978
- M.S. Nuclear Engineering, Kansas State University, 1976
- B.S. Physics/Mathematics, New Mexico State University, 1974

CURRENT PROFESSIONAL HIGHLIGHTS

Dr. Seeker is the Senior Vice President and a member of the Board of Directors of Energy and Environmental Research Corporation (EER). He directs over 60 technical personnel located in three offices and his Division conducts over six million dollars annually in widely diverse areas such as a Performance Evaluation, Regulations and Permitting, Engineering Analysis, and Environmental System Research and Development. Dr. Seeker received his Ph.D. in Engineering (nuclear and chemical) from Kansas State University where he received the outstanding graduate student award and a National Science Foundation travel award to present his thesis research in England. He has authored over 100 technical papers on various aspects of environmental systems and was invited to present the plenary lecture on combustion in practical systems at the Twenty Third International Symposium on Combustion held in Orleans, France in the summer of 1990. He currently serves on the EPA's Science Advisory Board and is a member of the Environmental Engineering committee and the Research Strategy Advisory Committee. He has been with all aspects of contract research, process development and engineering, and full scale technology demonstration. Dr. Seeker has been principal investigator and program manager of numerous multifaceted programs involved with a wide diversity of subjects. He has been largely responsible for sales and for much of the contract administration on contract research and development for his Division. He is a member of the American Institute of Chemical Engineers, the American Nuclear Society, the American Physics Society, and the American Society of Mechanical Engineers. Dr. Seeker has provided Congressional testimony, participated on various distinguished panels, and given numerous lectures.

EXPERIENCE

Professional Employment: 15 years

- Senior Vice President, Energy and Environmental Research Corporation. Present.
- Technical Chair of the ASME/EPA workshop on Toxic Metals Emissions, Cincinnati, OH. November 1991.

- Co-Organizer of ASME/EPA workshop on Toxic Metals Emissions, Cincinnati, OH. November 1991.
- Program Advisory Committee and Session Chairman of 1992 Incineration Conference, Alburguerque, NM. 1992.
- Technical Advisory Committee to University of California Davis, NIEHS Superfund Research Center. 1991.
- NSF Panel on Research Needs in the Formation and Control of Fine Particulate, Washington, D.C. 1990.
- EPA Review Workshop on Core Combustion Program Development, Durham, NC. 1989.
- NSF Panel on Research Needs on the Monitoring of Waste combustion Systems, UC San Diego. 1988.
- Technical Organizing Committee chairman of Second International Congress on Toxic Combustion Byproducts, Salt Lake City, UT. March 26-29, 1991.
- Editor of "Toxic Combustion Byproducts: Formation and Control" (published by Combustion Science and Technology, 1990.
- Technical Organizing Chairman for the First International Congress on Toxic Combustion Byproducts: Formation and Control. August 2-4, 1989.
- Chairman of Technical Advisory Panel on Waste Treatment Thrust of the UCLA National Science Foundation Engineering Research Center. 1988 - 1991.
- NATO Advanced Research Workshop on Fundamentals of Physical-Chemistry of Pulverized Coal Combustion (Invited chairman of Pollution Formation, 1986, Les Arcs, France).
- National Science Foundation Panel member on Research Needs in Hazardous Waste Thermal Destruction, Drexel University. 1986.
- Technical Advisory Panel of California Air Resource Board on Hazardous Waste Incineration. 1985.
- Fuels Research Executive Committee of ASME
- Scientific Advisory Committee of LSU Hazardous Waste Research Center. Chairman, 1985-1986.

- Executive Committee of the Western States Section of the Combustion Institute. 1985 - 1988.

PATENTS, PUBLICATIONS, AWARDS

- 5,116,584 May 26, 1992. "Methods for Enlarging the Useful Temperature Windows for NO_x Control in Combustion Systems"

- 5,139,755 August 18, 1992. "Advanced Reburning for Reduction of NO_x Emissions in Combustion Systems" W.R. Seeker, S.L. Chen, and J.C. Kramlich.

- Dr. Seeker has written over 200 technical papers, journal articles and reports on a variety of environmental studies.

Virginia Swartz
Communications and Public Involvement Specialist
Swartz & Associates, Inc.
Golden, Colorado

EDUCATION

- M.A Language and Communication, Regia University, Denver
  Thesis: Bridging the Scientific and Public Communications Paradigms: An Epistemological Approach
  State and Local Government Senior Executive Program, Harvard University, John F. Kennedy School of Government
- B.A. English/Communication, Fort Lewis College

CURRENT PROFESSIONAL HIGHLIGHTS

Ms. Swartz' education, including both her BA and MA degees, is in the field of communication and communication theory. She was the receipient of a 1993 Gates Foundation Fellowship to Harvard University's John F. Kennedy School of Government. She has additional training in facilitation, conflict resolution, and organizational management from the University of Colorado at Boulder, the Kentucky Department of Education and the Colorado Department of Education. She is a member of the Colorado Hazardous Waste Management Society, the National Association of Professiional Environmental Communicators, and a number of citizen and technical advisory boards. In 1991, Ms. Swartz was appointed by Colorado Governor Roy Romer and Congressman David Skaggs as Executive Director of the Rocky Flats Environmental Monitoring Council. Her work history includes creation and management of a country-wide adult education center, coordination of local economic development projects, and ten years experience in the field of NEPA, RCRA, and CERCLA public processes. Ms. Swartz possesses extensive experinece in the areas of public and non-profit management and organizational development. Her skills range from management of major multiple task projects to design and management of citizen participation processes including facilitating and directing work teams and focus groups.

EXPERIENCE

Professional Employment: 23 years

- President, Swartz & Associates, Inc.
- Process Administrator, Federal Committee to Develop Onsite Innovative Technologies, Western Governor's Association
- Interim Project Administrator, Rocky Flats Citizens Advisory Board
- Executive Director, Colorado Council on Rocky Flats, Office of Governor Roy Romer, Denver, Colorado
- Executive Director, Archuleta County Education Center, Pagosa Springs, Colorado
- Executive Director, Southwest Land Alliance, Archuleta County, Colorado
- Project Coordinator, Pagosa Springs Economic Renewal Project Rocky Mt. Institute, Aspen, Colorado
- Project Liaison, East Fork Joint Venture, Pagosa Springs, Colorado
- Project Coordinator, Alamosa Creek Restoration, La Jara, Colorado
- Project Coordinator, East Fork River Restoration Project, Pagosa Springs, Colorado
- Project Liaison, East Fork Joint Venture, Pagosa Springs, Colorado

PATENTS, PUBLICATIONS

- Ms. Swartz has written numerous technical papers, journal articles, and reports in the area of citizen participation and citizen advisory boards.

Michael M. Torbert
Headquarters Program Manager
Waste Management
Oak Ridge Operations Division
Office of Eastern Waste Management Operations
U.S. Department of Energy

EDUCATION

- B.S. Mechanical Engineering, Pennsylvania State University, 1968
- B.A. Liberal Arts, Pennsylvania State University, 1968

CERTIFICATIONS

- School of Environmental Excellence, 1991
- Bettis Reactor Engineering School, 1969

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Torbert is responsible for providing the Waste Management Program guidance and technical management for the waste operations at the Y-12 Plant in Oak Ridge, Tennessee. Responsibilities include planning, direction, and defending the planned and on-going waste management program; the treatment, storage, and disposal of radioactive, hazardous, mixed, and sanitary waste. He managed both the headquarters approval of the justification for mission need of a regional Mixed Waste Treatment Facility in Oak Ridge, Tennessee and the headquarters operational readiness review, start-up, and initial operations of the Toxic Substances Control Act (TSCA) Incinerator in Oak Ridge, Tennessee. He is responsible for mixed waste issues related to the Oak Ridge Reservation sites. Mr. Torbert co-authored the paper, 'Radioactive Mixed Waste Treatment Facilities at Department Energy Sites', presented at the Seventh Annual DOE Model Conference in Oak Ridge, Tennessee.

EXPERIENCE

Professional Employment: 27 years

- Headquarters Program Manager, Waste Management, Oak Ridge Operations Division, Office of Eastern Waste Management Operations. Responsible for the planning, direction, and execution of the treatment, storage, and disposal of radioactive, hazardous, mixed, and sanitary waste. He is a member of the Core Management Group for the new approach to technology development for the Environmental Management (EM) Program. 1990 - present.

- Technical Director and Program Manager for several contracting firms providing diverse technical services to the Department of Defense and the State Department. Services included maintaining secure communications for the State Department, designing mine neutralization systems, reverse engineering for the Navy Foreign Material Program, and design and licensing support activities for the South Texas Project nuclear power plant. 1973 - 1990.

- Member of the Headquarters Technical Staff, Nuclear Power Program, U.S. Navy. Responsible for the operation of two submarine prototype reactor facilities and assisted with the first-time refueling of an advanced large surface ship reactor. 1968 - 1973.

John S. Vavruska
Equinox, Ltd.
Santa Fe, NM 87501

EDUCATION

- M.S. Chemical Engineering, University of Tennessee, Knoxville, TN., 1978
- B.S. Chemical Engineering, North Carolina State University, Raleigh, NC, 1973

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. John S. Vavruska's areas of expertise are in chemical and process engineering primarily related to thermal waste treatment, recycle and recovery processes, and air pollution control technologies. Application of chemical engineering principals of mass and heat transfer, reaction kinetics, reactor design, and fluid mechanics to the solution of materials processing and environmental problems. Mr. Vavruska has numerous accomplishments, is the recipient of numerous awards, and has been actively involved on many projects and many times as a project leader. He is a member of the American Institute of Chemical Engineers. He is currently serving on the Department of Energy's Mixed Waste Integrated Program (MWIP) Technical Support Group for second stage destruction and offgas treatment. Accomplishments include the co-development of a series of design guides for selections of air pollution control technologies for mixed waste thermal treatment, as well as evaluations of thermal technologies for mixed waste treatment.

EXPERIENCE

Professional Employment: 20 years

- Equinox, Ltd., Santa Fe, New Mexico. President and Principal. Consulting in process engineering and design related to thermal waste treatment and air pollution control technology. Project manager and principal investigator on a variety of contracts for government laboratories, universities, and private industry. 1991 - present.

- Plasma Technology, Inc., Santa Fe, New Mexico. Chief process engineer and project manager. Responsible for all activities associated with commercialization of an emerging induction plasma waste treatment technology while on leave of absence from Los Alamos National Laboratory. 1990 - 1991

- Los Alamos National Laboratory, Los Alamos, New Mexico. Project

leader and principal process engineer in the Waste Management Group, University of California. Responsible for waste treatment R&D and a $2.5 million capital equipment upgrade of the Los Alamos Controlled Air Incinerator for transuranic waste treatment. 1980 - 1990.

- Oak Ridge National Laboratory, Oak Ridge, Tennessee. Development Associate in the Chemical T Technology Division, Union Carbide Corporation. Responsible for development of gel-sphere processes for nuclear fuel fabrication and high level radioactive waste immobilization. 1978 - 1980.

- Idaho National Engineering Laboratory, Idaho Falls, Idaho. Research engineer in the Process Support and Technology Branch at the Idaho Chemical Processing Plant, Allied Chemical Corporation. Responsible for pilot plant development of processes for nuclear fuel recovery and high level liquid waste solidification. 1974 - 1976.