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INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Annual Meeting Reinforces Global Importance of Nuclear Materials Management

As I write this message, it is a little more than a week since the conclusion of the 36th Annual Meeting of the Institute of Nuclear Materials Management. From my perspective, it was a most successful meeting by any number of measures: the content and quality of the plenary speech, given by Kenneth Luongo, director of the Office of Arms Control and Nonproliferation at the U.S. Department of Energy (DOE), on behalf of DOE Secretary Hazel O'Leary; number of papers and their technical contents; range of issues covered; international character of the attendees; number of formal and informal side meetings addressing nuclear materials management issues; opportunity to meet new and old friends; and meeting location.

I recognize and thank Vice Chair Obie Amacker for his contributions as general chair of the Annual Meeting, Charles Pietri for once again leading the Technical Program Committee, all of the paper presenters and authors, Gary Carnival for organizing the Registration Committee, Ken Ystesund for handling the exhibits, and headquarters staff members Barb Scott, Greg Schultz, Kathleen Caswell and Colleen Sanderson for their efforts on behalf of the Annual Meeting.

The Annual Meeting provides the Institute the opportunity to honor members of the INMM and the nuclear materials management community for contributions to the field. At the awards banquet, 27 INMM members were elevated to the rank of senior member of the Institute in recognition of their long service to the nuclear materials management profession and the INMM. Included in this number were 12 members from the Japan Chapter. The Institute also added four names to the distinguished group of Fellows: Carlton Bingham, Bob Curl, John Lemming and Darryl Smith. The awards banquet also recognized the sustaining corporate members of the INMM and the new Russian Federation Chapter. We remembered the passing of Willy Higinbotham by reading a Resolution of Respect that was adopted by the INMM membership.

The Institute's highest awards — the Meritorious Service Award (for exceptional service to the INMM) and the Distinguished Service Award (for exceptional service to the nuclear materials profession) — were presented to four outstanding nuclear materials management professionals. Shelly Kops, Takeshi Osabe and Charles Pietri were recognized with Meritorious Service Awards, and Ken Sanders was honored with the Distinguished Service Award. [See page 9 for more on the award winners.]

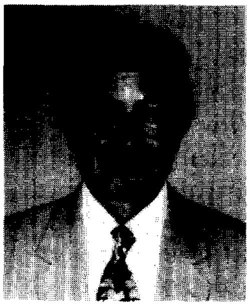
The overall interest in and support for the INMM Annual Meeting serves to reinforce a message that I have tried to convey in this space for the last year — nuclear materials management is important not just to the INMM and its membership. It has become a topic of concern to presidents, prime ministers, governments and the general public around the world. We have gone from being a relatively obscure community to one in the limelight. There is much work to be done and we can make a difference. I am looking forward to a second year as chair of the INMM and to working with Obie Amacker, Secretary Vince DeVito, Treasurer Bob Curl, Past Chair Dennis Mangan and new Executive Committee Members-at-Large Marcia Lucas and Scott Strait, who join Jill Cooley and David Crawford. I also thank outgoing members Phil Ting and especially Gary Carnival for their service to the Institute.

James W. Tape
Los Alamos National Laboratory
Los Alamos, New Mexico, U.S.A.

Correction

In the July 1995 "Chair's Message," an error changed the meaning of a central part of the message regarding the importance of the indefinite extension of the Nuclear Nonproliferation Treaty (NPT). The second sentence of the message, which should have said, "This significant achievement [the indefinite extension of the NPT] represents a major victory for all States and serves to strengthen the nonproliferation regime through continued broad support for the NPT" was changed by adding the modifier "Nuclear-Weapons" to "States." This error completely changed the intended meaning of the sentence, which was to emphasize that indefinite extension is a victory for *all* nations party to the Treaty. On behalf of the INMM and the *Journal*, INMM headquarters apologizes for the error.

Newly Formed Russian Chapter Seeks Back Issues of *JNMM*



As most of you probably know, in September 1994, seven Russian members of INMM submitted a petition to form a Russian Federation Chapter under the terms of the INMM constitution and bylaws. In November, the Executive Committee enthusiastically approved the Russian Federation Chapter. In July, at INMM's Annual Meeting in Palm Desert, Calif., the chapter was presented with its Chapter Charter and banner.

Andrei Zobov is chair of the chapter, which appears to be very active and is growing. Dr. Vladimir Sukhoruchkin, vice chair, accepted the charter and banner on behalf of the chapter.

The Russian Federation Chapter has asked for a set of *JNMM* issues after 1990 for its library. I am trying to assemble such a set for them. INMM headquarters had a few back issues, but I need your help in completing the set. I still need:

- February and May, 1990;
- May, August and November, 1991;
- February, May, July and October, 1992;
- February, July and October, 1993;
- January, April and July, 1994; and
- February, 1995.

If you have any of these issues that you are willing to part with for a worthwhile cause, please let me know.

Speaking of *JNMM*, once again, we have only two technical papers in this issue. I have many promises, and if even half of these papers get written, we will see the *JNMM* grow into the journal it can and should be. It is the only journal that I am aware of, that is devoted to issues of nuclear materials management. It is read by technical folk and policy-makers. I know all of you are extremely busy, but you do need to publish. Please consider *JNMM*.

Both of the technical papers in this issue address the handling of radioactive waste materials. The first, by Shoou-Yuh Chang and Muhammad Muquit at the North Carolina A&T State University, describes the development of a modeling method for generating preliminary designs of low-level radioactive waste management systems that would provide more insight to decision makers than conventional approaches. The second paper is authored by R. J. Munz and G. Q. Chen of the Plasma Technology Research Center at Université de Sherbrooke - McGill University in Quebec. It discusses the vitrification of nuclear waste — a timely topic indeed.

On a personal note, by the time you read this, I will have retired from the Los Alamos National Laboratory (LANL) after 37 years, 28 of which have been involved with safeguards research and development. It has been a very satisfying career, but it is time to begin the next phase of my life. I expect to travel much less and mostly stay home and putter. I will very much miss frequent interactions with my many friends and colleagues in the safeguards community. It's been fun and you are the greatest!

Although I am leaving the LANL, I have agreed to continue as the technical editor of *JNMM* for as long as I am needed or I can remain relevant. I hope to see you at the Annual Meetings, and I will still be pestering you for more papers for *JNMM*.

My telephone number remains (505) 667-6394, where you can leave messages. I will occasionally check for faxes sent to (505) 665-0492. My e-mail address continues to be dbsmith@lanl.gov, which will eventually work at home. Please send your correspondence and submissions to headquarters or to my home address, which is 63 Delicado Dr., Los Alamos, NM 87544 U.S.A.

Call, write or use the Internet — and send those papers.

Annual Meeting Rewards Institute and Its Members

In the position of vice chair, one experiences a great deal of apprehension prior to the INMM Annual Meeting. Although the member volunteers and staff of the Institute's management firm do an excellent job of preparing, there is no guarantee that everything will turn out like it was planned. From all indications, this year's meeting was a very positive experience for the attendees and provided the Institute with some rewarding events.

The 36th Annual Meeting, in Palm Desert, Calif., presented a forum for technical presentations that addressed some of the most pressing nuclear materials management issues facing the world. The international attendees provided a wealth of technical knowledge that may not be matched at another meeting this year. From the plenary presentation of Secretary of Energy Hazel O'Leary's perspectives (delivered by Kenneth Luongo), through the paper presentations, poster demonstrations and exhibits, there was a plethora of information to be shared.

Technical Program Chair Charles Pietri and his committee did an excellent job putting the program together. There are many more volunteers who made the meeting a success, and I thank all those individuals who contributed to any activity associated with the meeting.

In addition to the technical program, the Annual Meeting provided an opportunity for individuals from across the country and world who are working on the same issues to get together in between and after the sessions for technical interchanges of their own. Also, the formal recognition of the new Russian Federation Chapter marked the beginning of a new era in INMM history. There were some detailed discussions during the meeting that may lead to the formation of one or more new chapters in Europe.

The Institute has a vital role to serve with respect to nuclear materials management around the world, and the ideas and experiences shared during the Annual Meeting are an important catalyst. The formal and informal input received and knowledge gained by the Executive Committee, Technical Divisions, Fellows and Standing Committees during the Meeting will help facilitate effective planning for the coming year and development of a long-range plan for the Institute. If you have any specific ideas or concerns that you would like to see addressed, please give me a call at (509) 372-4663 or drop me a note on e-mail at o_amacker@pnl.gov.

Obie Amacker, INMM Vice Chair
Pacific Northwest Laboratory
Richland, Washington, U.S.A.

INMM Member Chosen for Nuclear Waste Technical Review Board

John Arendt is one of three new members of the Nuclear Waste Technical Review Board appointed by President Clinton on June 29. Arendt is a professional engineer and certified nuclear materials manager and is chair of the INMM N15 Standards Committee.

INMM 36th Annual Meeting Sparkled With Papers Controversial and Comforting

The 116-degree temperature in Palm Desert, Calif., may have led some meeting attendees to suspect that this INMM 36th Annual Meeting might be a training ground for additional IAEA Middle East nuclear materials inspection activities. However, in the cooler environs of the meeting sessions indoors, it was apparent that hot topics were not exclusively related to the weather.

Unfortunately, a last-minute call for congressional testimony precluded U.S. Secretary of Energy Hazel O'Leary from making her planned presentation as the plenary speaker at the meeting. Nevertheless, her surrogate, Kenneth Luongo, director of the Office of Arms Control and Nonproliferation at the U.S. Department of Energy, did a marvelous job. Attendees learned about some comprehensive and explicit programs and polices related to the almost overwhelming challenge of international management of nuclear materials, especially in regard to the former Soviet Union's stockpiles. The plenary speech and this year's roundtable discussion, INMM's informal interview with the plenary speaker, will be featured in the January issue of the *JNMM*.

The other sessions sparkled with the most current information, both controversial and comforting — just the way INMM planned it. Credit for the success of this meeting goes to the authors and speakers, who made major professional contributions to the nuclear materials management community, and to the session chairs, who helped manage the meeting program. Look for the eclectic array of papers presented at the meeting in the Annual Meeting Proceedings, which will be distributed in November. (The INMM is making some headway into putting the Proceedings on CD-ROM and making it available on an INMM home page on the Internet. See page 9.)

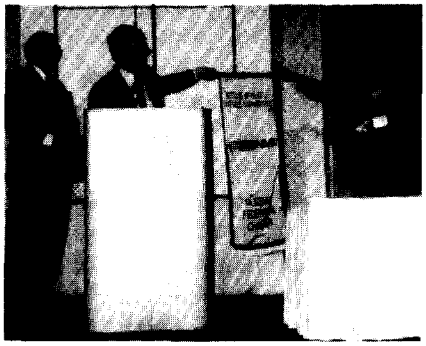
The usual Annual Meeting attendee survey was most interesting: Very few written responses, and most of them were positive. There were lots of super verbal comments regarding the overall quality of the papers and meeting arrangements. From the viewpoint of the Technical Program Committee, this Annual Meeting was one of the best programs INMM has orchestrated, in terms of the planning and operations. My sincere appreciation goes out to the committee, the INMM headquarters staff and all those who made what could have been a logistical nightmare a smoothly operating event.

There are still some problems surrounding the meeting. Twenty-eight papers were withdrawn this year after publication of the Preliminary Program, 18 of which occurred after the Final Program went to press. Some of the graphics and tables in the presentations were not readable by the audiences, and some of the presentations were not delivered clearly or audibly.

In addition, a few papers were not up to quality standards, as reported by attendees. The INMM urges authors to have their papers reviewed by peers either within their organizations or elsewhere. The Institute can assist authors in such reviews or direct them to others who can provide insight. Remember, the credentials of the INMM as a professional organization is dependent upon the stature of its members and participants.

The following anecdote will demonstrate the point. One speaker revised his paper extensively, incorporating some of the enlightening comments received at the meeting. Another speaker, somewhat new to the community, included in his paper some "rediscovered" concepts that INMM members long ago discarded as inept. The value of proper peer review cannot be underestimated — it provides a benefit both to the individual and to the Institute.

The number of no-show speakers — those who did not notify INMM of withdrawal of their papers and did not appear at the meeting — diminished this year, but is still a concern. The INMM continues its policy of not



INMM Chair Jim Tape officially recognizes the new INMM Russian Federation Chapter.

The Third Annual INMM Golf Tournament had a great turnout.

INMM sustaining corporate members were recognized at the Awards Banquet.

Also at the awards banquet, the INMM inducted new Senior Members.

accepting future papers from these contributors if adequate reasons for withdrawal are not provided to INMM. For several reasons, a significant number of speakers could not attend the meeting this year (a disappointment for both the speaker and the Institute), but fortunately many of them made sincere efforts to find suitable alternates to present their papers.

Plans for next year include an update to the Speaker's Manual to include poster session guidelines, an expanded section on session chair duties and other informative tidbits. Of course, the INMM is already thinking about another super hotel, great papers and even more fun for 1996.

Look for the 1996 Annual Meeting Call for Papers this fall, and start thinking about the Feb. 1, 1996, deadline for submitting abstracts.

Charles Pietri, Chair
INMM Technical Program Committee
U.S. Department of Energy
Chicago Operations Office
Argonne, Illinois, U.S.A.

INMM attendees perused exhibits between sessions.

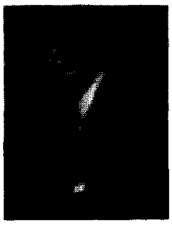
Mark Your Calendar!

INMM's 37th Annual Conference

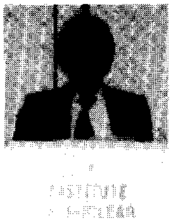
July 28-31, 1996
The Registry Hotel
Naples, Florida

INMM Members Receive Awards for Service to Institute, Nuclear Community

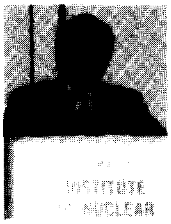
The Institute of Nuclear Materials Management presented three meritorious service awards and one distinguished service award during the awards banquet at the INMM 36th Annual Meeting in Palm Desert, Calif., July 9-12.



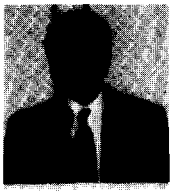
Sheldon Kops



Takeshi Osabe



Charles Pietri



Kenneth Sanders

The first meritorious service award was presented to Sheldon Kops, chair of the INMM Fellows Committee. Kops is one of the 19 founding members of the Institute and served as its first treasurer. He also served on the Executive Committee and was chair of the ANSI Subcommittee.

Kops began his career in 1952 at the Chicago office of the Atomic Energy Commission as senior accountant in the materials safeguards branch. He was an early proponent of the importance of establishing and maintaining high professional accounting standards in nuclear materials safeguards. He was an innovator in many areas of nuclear materials management and safeguards, working with the instrument development staffs of the national laboratories to obtain nondestructive assay capabilities for both the operations office and the contractor. He also served as an instructor for six years in the International Safeguards Training School at Argonne National Laboratory.

Even though he is now retired from the U.S. Department of Energy (DOE), Kops is an instructor for the basic nuclear materials accounting course at the DOE Central Training Academy and remains an active member of the INMM. In 1991, he was selected as a Fellow.

The second recipient of the meritorious service award was Takeshi Osabe, who is in charge of nuclear material accountancy for both domestic and international safeguards at the Japan Nuclear Fuel Co. Through his extensive contributions to Japan's safeguards program, Osabe helped mold a productive program, including ratification and implementation of the Nuclear Nonproliferation Treaty. He is a member of the Japanese government Safeguards Advisory Group of the Science and Technology Agency.

Within the INMM, he helped establish the Japan Chapter in 1976 and served as its secretary. Much of his time and energy has been spent as liaison between INMM headquarters and the Japan Chapter to assure a strong, close, lasting relationship.

The recipient of the third award was Charles Pietri, chair of the Annual Meeting Technical Program Committee, a position he has held for nearly 10 years. Pietri began his career with the Savannah River E.I. du Pont de Nemours Co. as a supervisory chemist. He moved on to assistant director for operations at the New Brunswick Laboratory and is now the administrator for laboratory management at the Chicago Operations Office of the DOE. He is an INMM Fellow and chair of the ANSI 5.1 Subcommittee on Analytical Chemistry Laboratory Measurement Control.

Outside of the INMM, Pietri is the U.S. delegate to the International Organization for Standardization and a consultant on nuclear materials safeguards, nonproliferation and quality assurance to the International Atomic Energy Agency. He also holds membership in the American Chemical Society, American Nuclear Society, American Institute of Chemists and Health Physics Society.

Kenneth Sanders, director of the International Safeguards Division at the DOE, received the Distinguished Service Award. Sanders has 23 years of professional experience in nuclear materials management, international and domestic safeguards and security, and nuclear nonproliferation. He is widely known for his expertise in technical leadership of bilateral negotiations with foreign countries.

Sanders began his career as project engineer with the U.S. Atomic Energy Commission. He went on to the IAEA Department of Safeguards, where he was responsible for negotiating international agreements. He returned to the United States in 1979 to join the Nuclear Regulatory Commission and then the DOE. He personally led IAEA inspection teams to determine the extent of Iraq's nuclear weapons capability. Currently, he chairs a group for President Clinton's initiative on the safe, secure dismantlement of nuclear weapons in the former Soviet Union.

Through his career, Sanders has been recognized for many achievements, including awards from Ambassador R.J. Kennedy for his efforts in staffing the IAEA, the director of Arms Control and Disarmament Agency for his work on focusing high-level U.S. attention on

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1994 INMM Annual Meeting Proceedings Placed On-Line

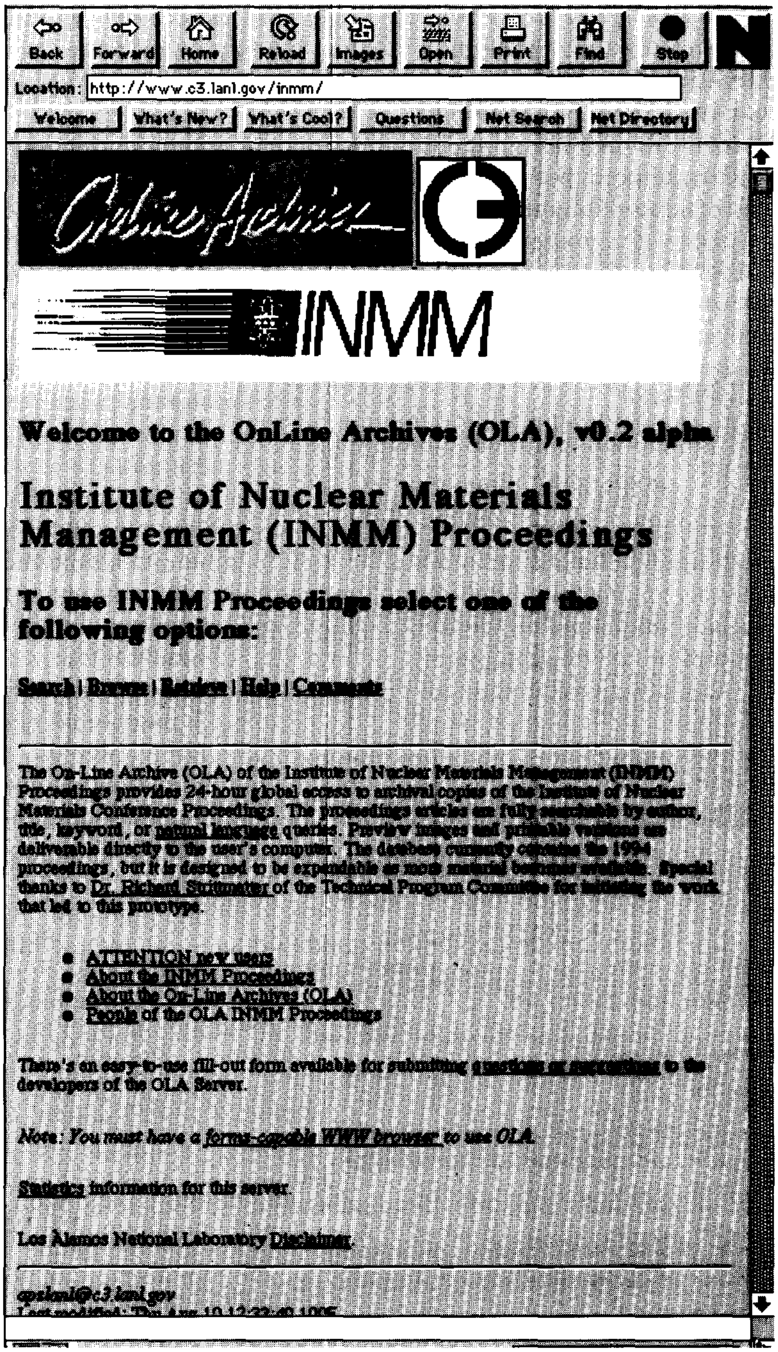
The 1994 INMM Annual Meeting Proceedings are on-line on the World Wide Web (WWW), as an experiment in electronic distribution methods for archival copies of the Proceedings. The address is http://www.c3.lanl.gov/inmm.

Because the traditional paper version of the Proceedings is relatively expensive to distribute (it costs $75 per copy and weighs 6.5 lbs.), the full value of the material in the Proceedings is not always realized. The Proceedings are often not available to researchers, such as scientists, in the nations of the former Soviet Union, and students whose libraries do not maintain the INMM Proceedings set. But recent advances in image processing and optical character recognition, combined with the universal reach of WWW, make possible a low-cost alternative to the existing library archival system. The INMM Executive Committee decided to take advantage of these recent changes and authorized this experiment in on-line access.

To access the INMM Proceedings, a direct or modem connection to the Internet and a WWW browser, such as Mosaic or Netscape, are required. Many of the commercial on-line services now provide an Internet gateway and a WWW browser. As with most WWW sites, the on-line INMM Proceedings rely heavily on graphics, so users will desire a high-speed modem access of 14.4 kbs.

All 1,358 pages (226 papers) of the 1994 Proceedings were scanned at 300 dots per inch, and ASCII approximations of the text were provided by Stange Associates. The ASCII versions and the full-page images were placed in the Online Archives (OLA) — a complete electronic publication package for scanned images developed at Los Alamos National Laboratory, with the support of the American Physical Society.

Figure 1: INMM home page



The documents published within the archives are fully indexed by title, author and content words. Articles of interest can be easily found by Boolean searches. For those who do

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Proceedings On-Line

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not need a full search, browsers are provided arranged by subject, author and chronological order of presentation at the Annual Meeting. The OLA package is meant to be self-explanatory, but, if problems develop during use, complete help pages are also available.

Figure 1 shows the home page of the INMM Proceedings. From this page, a user can begin the search by using the Navigation Bar (called Navbar in Web jargon) or learn more about the INMM and the OLA system. Figure 2 shows the search page, which lets a user conduct a search, resulting in the page shown in Figure 3, called a hits page. This in turn leads to relevant documents, which are then navigated by the use of a montage of thumbnail images, as shown in Figure 4.

One purpose of this experiment is to get feedback from real users, so most pages have a comments form attached. These comments will be used to improve the system and enhance its usefulness in future iterations. Obviously, to be fully useful, the entire set of INMM Proceedings should be included in the OLA, but, before that step is justified, some evidence of the value of the system must be provided to the INMM publication authorities. If the feedback is positive, then a decision to go ahead with putting the full set of Proceedings on-line will likely follow. At that point, the INMM Proceedings would be available in a readily usable form, 24 hours a day, directly on the desktop of the interested reader. This exciting possibility has the potential to significantly improve the flow of information within our community, reach a much wider audience, increase interest in the activities of the Institute, and, ultimately, accelerate the rate of scientific progress.

Rich Strittmatter, Timothy Thomas, Mojo Nichols and Carlos McEvilly
Los Alamos National Laboratory
Los Alamos, New Mexico, U.S.A.

Albert Glock
Stange Associates
Newport Beach, California, U.S.A

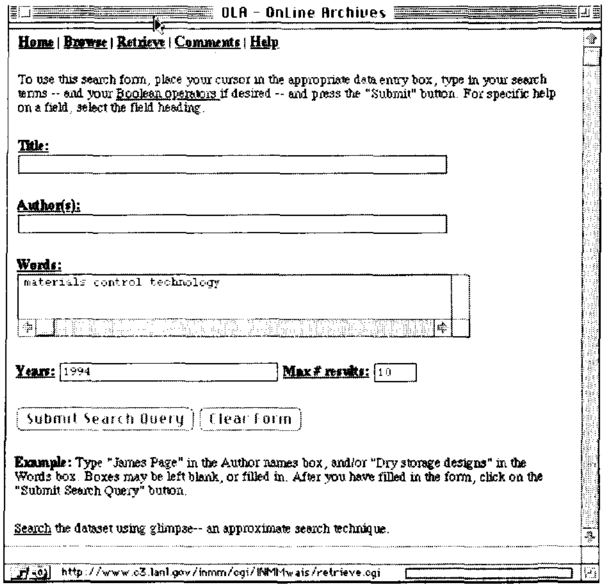

Figure 2: INMM search page

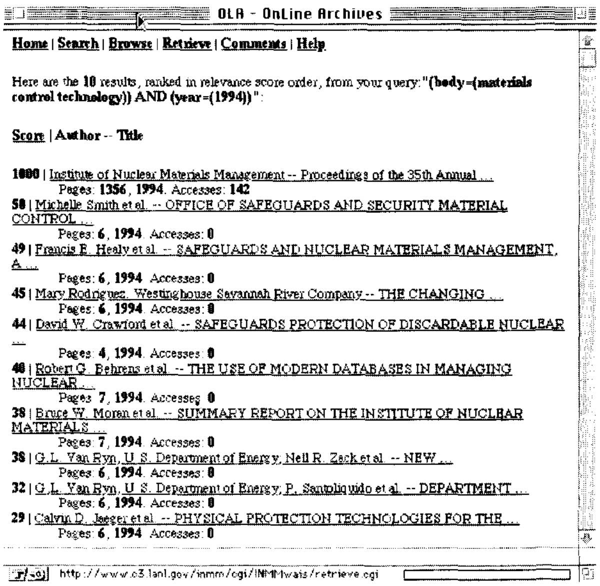

Figure 3: INMM hits page

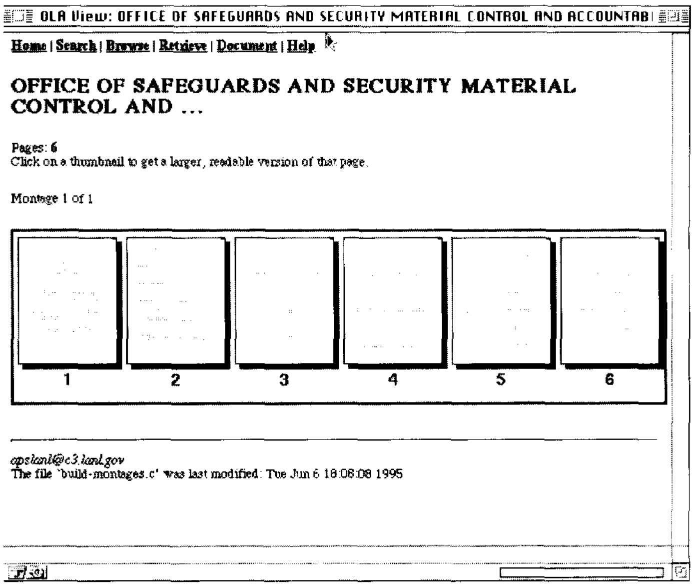

Figure 4: Montage of thumbnail images

INMM Membership Elects Executive Committee

According to INMM bylaws, "The Secretary shall notify each member in good standing of the results of the election before Oct. 1 of each year." This notice in the *Journal of Nuclear Materials Management* is construed as having met that obligation.

Ballots were mailed to each of the 725 Institute members, 195 of whom returned ballots. As a result of the balloting, the officers and members-at-large of the INMM Executive Committee, effective Oct. 1, 1995, are:

- Chair James Tape,
- Vice Chair Obie Amacker,
- Secretary Vincent DeVito,
- Treasurer Robert Curl,
- Immediate Past President Dennis Mangan; and
- Members-at-Large Jill Cooley, David Crawford, Marcia Lucas and Scott Strait.

The Japan and Vienna chapters have not filled their designated positions on the committee.

There were write-in votes for the following people:

- Chair Wendell Belew,
- Vice Chair Richard Greene, and
- Members-at-Large Ken Byers, Terry Lewis, Michele Smith, Ken Thomas and Tom Williams.

Each year, write-in votes are received for the elective positions. The Nominating Committee believes that this is an honest and sincere effort by the members to recognize these members as potential leaders and policy makers of the INMM. The committee does not wish to diminish members' interest in seeing their candidates on the ballot. However, a more effective way to get responsible members elected to the Executive Committee is by making recommendations to the Nominating Committee chair, who is the immediate past chair of the INMM. Additionally, according to the bylaws, "Candidates may also be nominated for any of the elective offices or positions by 15 members who submit to the secretary in writing over their signatures a petition naming the candidates and the office or position to which that candidate is thus nominated. Such petitions shall be submitted to the secretary on or before April 1, preceding the election."

Award Winners

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recruiting and selecting candidates for the IAEA, the DOE for his nonproliferation work in Iraq and the director general of the IAEA for assistance to the inspection team in Iraq.

Committees: Government Liaison

For the past four years, the INMM Government Liaison Committee has organized a special session at the Annual Meeting. The committee tries to identify the hot topics of general interest to the INMM membership. The invited speakers tend to be experts from whom members want to hear but are unlikely to respond to the Annual Meeting call for papers.

The committee does not require these speakers to submit written papers and, thus, they are not included in the Proceedings. However, in response to numerous requests to document these presentations, the committee is, for the first time, summarizing these informal talks in the *Journal of Nuclear Materials Management*.

This year's session included five speakers. Michael Rosenthal of the U.S. Arms Control and Disarmament Agency spoke about the U.S. nonproliferation agenda. Michael Evenson from the U.S. Defense Nuclear Agency gave a presentation on the status and future of the Nunn-Lugar Act, also known as the Cooperative Threat Reduction Program. Joerg Menzel with the On-Site Inspection Agency talked about the defense provided by international arms control treaties. After the session break, Mark Hibbs from the European office of *Nucleonics Week* addressed the issue of nuclear materials smuggling. The session ended with a talk by Kenneth Sheely of the U.S. Department of Energy (DOE) describing the use of remote monitoring systems as a nonproliferation tool.

Several Government Liaison Committee members contributed to this summary article. Robert Behrens, Los Alamos National Laboratory, reports on Menzel; Vince DeVito, INMM secretary, summarizes Hibbs; and William Floyd, DOE, records Sheely. A special effort was made by James Lemley, Brookhaven National Laboratory, who recounts Rosenthal and Evenson and adds comment on Menzel. The committee welcomes feedback on this session summary and ideas for next year's special session.

John Matter, Chair
INMM Government Liaison Committee
Sandia National Laboratories
Albuquerque, New Mexico, U.S.A.

The U.S. Nonproliferation Agenda
Presented by Michael Rosenthal; synopsis prepared by James Lemley

The first speaker was Michael Rosenthal, head of the recently combined International Nuclear Affairs and Nuclear Safeguards and Technology divisions at the U.S. Arms Control and Disarmament Agency (ACDA). At the Nuclear Nonproliferation Treaty (NPT) Review and Extension Conference in spring, Rosenthal was the U.S. representative to Main Committee II (safeguards and nuclear-free zones).

In introducing his remarks, Rosenthal observed that the end of the Cold War created a new environment where nonproliferation and disarmament issues overlap to a significant degree. The last year was productive for achieving the twin objectives of limiting the spread of nuclear weapons and reducing their number. He then outlined and explained the U.S. nuclear nonproliferation agenda.

The NPT is the focal point of the U.S. nonproliferation policy and, in May, the treaty was extended indefinitely without condition. Since July 1994, 15 countries became new state parties to the NPT. These included Algeria, Argentina, Chile and Ukraine, all of which have significant peaceful nuclear activities. Only 10 countries in the world are not bound by the provisions of the NPT or other comparable agreements and, of these 10, only three have not placed all their nuclear facilities under IAEA safeguards. The recent extension process helped to define the nonproliferation agenda in a number of important ways.

Each of the non-Nuclear-Weapon State parties to the NPT made a legally binding commitment not to develop or acquire nuclear weapons. In addition, each of the 179 State parties, including the five Nuclear-Weapons States, agreed to pursue negotiations in good faith on effective measures relating to "cessation of the nuclear arms race at an early date and to nuclear disarmament." This remains the ultimate goal.

The United States continues to dismantle nuclear weapons at a rate of between 1,000 and 2,000 per year. For the first time, the United States placed nuclear weapons material from its stockpile under IAEA safeguards. In December 1994, the United States and Russia, together with Ukraine, Belarus and Kazakhstan, brought the Strategic Arms Reduction Treaty (START I) into force. Nine thousand nuclear weapons from U.S. and former Soviet strategic delivery vehicles will have been removed from deployment when the treaty is fully implemented. Responding to President Clinton's urging, the Senate began START II hearings on Jan. 31, 1995. When START II is implemented, an additional 5,000 nuclear weapons will have been removed from the deployed arsenals of the United States and Russia.

Also in January, the United States extended its moratorium on nuclear weapon testing until a comprehensive test ban treaty (CTBT) enters into

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5.1 Subcommittee

At a meeting on July 13 in Palm Desert, Calif., a revitalized INMM 5.1 Analytical Chemistry Laboratory Measurement Control Subcommittee found answers to some critical concerns.

For the past five years, INMM 5.1, although one of the most active subcommittees, continued to lose members through programmatic changes from nuclear materials management to environmental restoration and waste management, and through retirement. Action taken by Bruce Moran, chair of ANSI N15 Standards Committee, resulted in an expanded charter that now includes environmental monitoring and measurements and related activities as functions of the Subcommittee. The revised Charter allows the subcommittee to retain nuclear materials expertise and attract members in the expanded area.

In addition, three new members joined INMM 5.1: Guy Marlette, from the U.S. Department of Energy, Radiological and Environmental Sciences Laboratory (RESL), with experience in performance evaluation programs; Lynn Preston, DOE headquarters, Weapons Safeguards and Security Operations; and Jim Crabtree, DOE headquarters, Materials Control and Accountability (MC&A).

Another bright highlight of the meeting was David Crawford, DOE-HQ, MC&A, who enthusiastically confirmed his strong support for the efforts of INMM 5.1 in the development of consensus standards to replace DOE directives, wherever applicable. He designated Jim Crabtree to work with the subcommittee as his surrogate. Don Joy and Tom Pham, Nuclear Regulatory Commission, declared their organization's support for the subcommittee's activities. Similar to DOE, NRC's position is to encourage consensus standards to support regulatory requirements for the licensee.

A major issue reconciled by the subcommittee regarded the action to be taken on the N15.51 standard, which expires in 1995. The subcommittee unanimously resolved to renew the current standard without changes. It further proposed to plan a future update of N15.51 to include sample exchange programs, measurement uncertainties and reference materials.

To enhance subcommittee communication, video teleconferences will be held periodically starting this fall. Potential new members and those people interested in working on the N15.51 update topics, especially DOE contractors and NRC licensees, are invited to discuss participation in the subcommittee. Detailed minutes of the INMM 5.1 Subcommittee meeting are available in hard copy or by e-mail (preferred) by contacting Charles Pietri at (708) 252-2449 or by e-mail: charles.pietri@ch.doe.gov.

Charles Pietri, Chair
INMM 5.1 Analytical Chemistry Laboratory Measurement Control Subcommittee
U.S. Department of Energy
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Divisions: International Safeguards

On July 9, the INMM International Safeguards Division (ISD) met at the Marriott Desert Springs Hotel in Palm Desert, Calif., the site of the INMM 36th Annual Meeting. Forty-two members of the international safeguards community, from the IAEA, EU/JRC-Ispra, Australia, Canada, France, Germany, Finland, Japan, Sweden, United Kingdom and United States participated in the meeting.

The chair opened the meeting with an expression of regret from ISD Vice Chair Paul Ek for his not being able to attend the meeting. In addition, it was announced that the secretary, Roger Case, will not be able to continue in that position. Steve Dupree, of Sandia National Laboratories, was proposed as the new secretary, and there were no objections.

The principal topic discussed in the meeting was the IAEA 93+2 Program and its purpose, progress and future activities. In addition, the group discussed the current environment surrounding international safeguards and the changes that are likely to occur in the coming years. There are a wide variety of new measures under consideration and related field trials, including expanded SSAC interactions, extended declarations, extended access, and environmental and remote monitoring. As in past meetings of the ISD, it was recognized that many factors, from both technical and policy perspectives, must be considered before introducing the changes under consideration. This also applies to the vast array of new technology that may support these changes.

Cecil Sonnier, Chair
INMM International Safeguards Division
Sandia National Laboratories
Albuquerque, New Mexico, U.S.A.

Nonproliferation and Arms Control

The INMM 36th Annual Meeting was a great one. The Nonproliferation and Arms Control Division sponsored six technical sessions and shared sponsorship on another two. Participation by managers, scientists and other technical staff from international organizations and former Soviet republics contributed significantly to the technical program and the sharing of experience and expertise.

The division held a meeting on Sunday afternoon, July 9. Fourteen attendees participated in broad-ranging discussions on: follow-up to the Nuclear Nonproliferation Treaty Review and Extension Conference; the U.S. excess fissile material offer; the special nuclear material production cut-off; applicability of standards to international nonproliferation efforts; and the possibility of holding one or more workshops in the spring of 1996.

Plans were made to start canvassing Washington policy makers and technical support staff in the executive and legislative branches about nonproliferation-related subjects of interest or concern that would serve as good topics for a workshop in the spring of 1996.

C. Ruth Kempf, Chair
INMM Nonproliferation and Arms Control Division
Brookhaven National Laboratory
Upton, New York, U.S.A.

MC&A

The INMM Materials Control and Accountability (MC&A) Division sponsored or co-sponsored 12 sessions at and contributed more than 100 papers to the 36th Annual Meeting, making this year's meeting the division's most successful. In addition to the regularly scheduled technical sessions, division members coordinated and participated in an array of special interest meetings held in conjunction with the Annual Meeting. These special meetings were open to the INMM membership.

For the coming year, the division is planning to co-sponsor two workshops. The first, a workshop on IAEA safeguards of U.S. excess defense materials, is in the planning stage for March 1996. This is a topic of great interest to many INMM members, as evidenced by the heavy attendance for sessions on this topic at the Annual Meeting. Those interested in helping with the workshop should call Neil Zack, (505) 667-7777.

The second workshop will be led by the Nonproliferation and Arms Control Division on a yet undecided policy-oriented subject. Interested members should call C. Ruth Kempf, (516) 282-7226, for more details.

Chairs are in place for two of the five division standing committees: Norbert Ennslin for the Measurement Technology Committee and Ken Lewis for the Training and Professional Development Committee.

Ennslin reports that a successful Neutron Users Group on measurement uncertainty was held at the Annual Meeting and is planning a second meeting for early 1996.

Chair positions for the three remaining standing committees identified in the division charter — material processing, material storage and systems technology — are vacant, and interested members should call MC&A Division Chair Rich Strittmatter at (505) 667-7777.

Members of the MC&A Division and INMM Executive Committee were instrumental in an experiment to place the INMM Annual Meeting Proceedings on the Internet. An article describing the features of this service and information on how to access it is on page 9. The cooperation of Stange Associates and Los Alamos National Laboratory, both of which made this effort possible, is appreciated.

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force, on the assumption that a CTBT will be signed by the end of September 1996. In March, Clinton announced that the United States would permanently withdraw 200 metric tons of nuclear weapons material from its stockpile. The United States also agreed to purchase 500 metric tons of highly enriched uranium from dismantled Russian nuclear weapons. This material will be converted to low-enriched uranium for use in power reactors.

Also in March, the Conference on Disarmament agreed to establish an ad hoc committee to negotiate a multilateral ban on the production of fissile materials for nuclear weapons or other nuclear explosive devices. The United States and Russia agreed to cease production of plutonium for use in nuclear explosives. In April, the United Kingdom announced that it no longer produces fissile material for nuclear weapons.

At the NPT Review and Extension Conference, the parties to the NPT agreed on an ambitious agenda including, inter alia, the adoption of the following measures and undertakings:

- Universal adherence to the NPT as an urgent priority;
- A universal, international, effectively verifiable CTBT no later than 1996, with the Nuclear-Weapons States exercising the "utmost restraint" pending entry into force of the CTBT;
- A convention banning the production of fissile material for nuclear weapons or other nuclear devices;
- The determined pursuit of systematic and progressive efforts to reduce nuclear weapons globally;
- The development of nuclear-weapon-free zones, as well as the establishment of zones free of all weapons of mass destruction, as a matter of priority;
- Full-scope safeguards as a condition of supplying nuclear equipment and material; and
- Increasing the capability of the IAEA to detect undeclared nuclear activities.

Part of the agenda agreed on at the NPT Review and Extension Conference was implemented. Adherence to the NPT is universal except in the Middle East and South Asia, and there is a special focus on these regions where the only three nonparties with nuclear programs are located. To deal with these issues, the United States supports a number of measures, including agreement on a global cutoff treaty; the Middle East peace process; the adoption of regional nonproliferation measures in the Middle East; restraint by suppliers so that the transfer of nuclear and sensitive technologies does not exacerbate tension; and steps in South Asia to cap, reduce and eliminate unsafeguarded nuclear programs.

Some countries, including India, Pakistan and Israel, do not believe that signing the NPT is in their national interests. In these cases, the United States and the international community encourages them, for now, to consider steps outside the NPT that can contribute to their security and help promote the goal everyone shares: the ultimate elimination of nuclear weapons.

The United States welcomes opportunities to work closely with these governments to pursue a CTBT and a fissile material cutoff treaty. These countries are being encouraged to take other steps designed to contribute to regional and international security, including adopting nuclear and missile-related export control regimes, placing selected nuclear facilities under IAEA safeguards, and continuing dialogues that will contribute to regional stability.

Until all countries can agree that their security interests are best served by universal adherence to the NPT, the United States and the international

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community are working to promote the adoption by all states of measures designed to reduce the motivations for maintenance or pursuit of nuclear weapon programs. In this connection, the ACDA and DOE are cooperating to bring small groups from South Asia and the Middle East to the Cooperative Monitoring Center at Sandia National Laboratories to discuss the techniques and technologies of arms control and confidence-building measures (CBMs). In the formal Middle East peace negotiations, the United States has also been supportive of consultations on subjects such as nuclear-weapon-free zones, regional efforts to support the CTBT, and interaction between the IAEA and regional nuclear verification authorities.

In South Asia, the United States supports the ongoing bilateral dialogue between India and China on outstanding border disputes and encouraged India and Pakistan to resume meeting at the foreign-secretary level to expand on CBMs they negotiated in the past.

The dramatic progress flowing from the NPT and the end of the Cold War requires that the nonproliferation agenda address many new issues related to stockpile reduction. These include disposition of plutonium and highly enriched uranium; new requirements for sound material protection, control and accounting worldwide; cooperative measures to reduce the threat of illicit trafficking in nuclear material; and issues addressed in the Cooperative Threat Reduction Program (the Nunn-Lugar Act).

Yet another part of the agenda depends on maintaining the institutions and structures developed to support the NPT. These include a stronger IAEA through its 93+2 Program, the Zangger Committee, the Nuclear Suppliers Group and the application of sound export controls on nuclear and dual-use commodities by all suppliers.

All parts of the agenda previously mentioned are included in the agreed-upon language of the documents produced by the NPT Review and Extension Conference. In conclusion, Rosenthal noted that another part of the agenda is reflected in the issues which were not agreed to at the conference, i.e., in the bracketed text. The important nonproliferation concerns in the Democratic People's Republic of Korea, Iran and Iraq must continue to be addressed.

An audience member inquired whether the immediate goal of reducing the number of weapons to the level of several thousand in the United States and Russia was sufficient to justify indefinite extension of the NPT. Rosenthal commented that, while it clearly was not enough for total disarmament, the world community expressed incredibly strong endorsement of the NPT. Even the weakest resolutions offered at the conference called for "implied" indefinite extension through renewal for a series of 25-year periods or automatic renewal with review at five-year intervals, showing understanding that systematic reduction takes time.

Implementing the Nunn-Lugar Act

Presented by Michael Evenson; synopsis prepared by James Lemley

The second speaker of the morning was Michael Evenson, assistant director, Arms Control and Test Limitations, at the U.S. Defense Nuclear Agency (DNA). This office coordinates research, development, testing and evaluation in support of arms control agreements. When this directorship became a civilian position less than a year ago, Evenson retired at the rank of colonel and subsequently continued to direct the program as a civilian in the Special Executive Service.

Evenson reviewed the status and future planning for implementation of the Soviet Nuclear Threat Reduction Act of 1991 (PL 1102-228), commonly known as the Nunn-Lugar Act (NL). DNA is the executing agency for this act.

NL advances national security interests of the United States by facilitating on a priority basis the transportation, storage, safeguarding and destruction of nuclear and other weapons in Russia and the successor states of the former Soviet Union (FSU) and by assisting in the prevention of weapons proliferation. Originally viewed as a one-shot program with $400 million of reprogrammed U.S. Department of Defense (DOD) funds, NL was funded as a line-item at $400 million per year from 1993 to 1995. The budget request for fiscal 1996 is for $371 million.

Negotiations during 1992-93 established the framework and developed necessary arrangements with Russian and other FSU states. Management structure and acquisition strategy for implementation of cooperative programs were developed in 1994-95. A multiyear, objective-oriented, requirements-driven Comprehensive Threat Reduction (CTR) Program is being planned through the year 2000.

Authorized CTR programs include eliminating nuclear, chemical and other weapons and their delivery vehicles; safely and securely transporting and storing weapons and fissile materials; preventing proliferation of weapons of mass destruction and related production technology and expertise; expanding defense and military-to-military contacts; converting defense industries with military technology and capabilities to civilian activities; and housing FSU military personnel to expedite dismantlement of strategic nuclear weapons.

Emphasizing the CTR is a finite program with a beginning, middle and end; long-term planning is focused on the following objectives:

- Assist Ukraine, Belarus and Kazakhstan in becoming non-nuclear states;
- Assist Russia in accelerating strategic arms reduction to START II levels;
- Enhance security, safety and control of nuclear weapons and fissile materials in Russia by assisting with development of centralized storage for fissile materials at a limited number of locations; strengthening security, safety and control of materials during movement and while in interim storage; and helping to initiate and accelerate the destruction program for Russian chemical weapons; and
- Encourage demilitarization of FSU states by supporting conversion of FSU defense enterprises to civilian purposes and by expanding confidence-building defense and military contacts.

Specific objectives include the elimination of strategic warheads by 1997 and elimination of 40,000 metric tons of chemical weapons by 2001. Businessmen should continue to take over demilitarization support from the defense establishments on both sides. In this regard, Evenson cited the relatively faster progress being made through civilian teams in the laboratory-to-laboratory and export-control programs.

In response to a question about conditions placed on the NL program by Congress subsequent to its initiation, Evenson noted the Dornan Amendment, which prohibits aid unless the president certifies that the recipient state has no offensive chemical or biological weapon programs, and spending limitations added because of the apparent lack of cooperation by Russia. Discussion noted that NL is not an aid program, but rather a program to accomplish specific threat-reduction objectives in benefit of U.S. national security.

In spite of limitations due to available resources and the degree of intrusiveness that sovereign states will allow, one measure of the effectiveness of the NL program is the progress toward meeting the time schedules for the arms-reduction goals set forth in various agreements, such as the START treaties and the CWC. Evenson noted that the United States and Russia are ahead of schedule regarding START I goals and that effectiveness in verifying elimination of weapon systems is very good, citing observation of wings being cut off bombers at Air Force bases.

Evenson offered several observations in response to questions concerning apparently slow progress under NL. Sometimes there is misunderstanding in the United States about what is really needed for effective materials protection, control and accounting (MPC&A), and the time required to develop mutual understanding. The Russians are very good at engineering practical things that last, although their systems are sometimes labor-intensive and time-consuming. High technology does not always serve FSU needs effectively; meat scales and fingerprint identity were mentioned as examples of simple systems being used effectively in the MPC&A. The Russians did not immediately identify portal monitors as a high-priority need because their systems incorporate different means to accomplish objectives addressed by portal monitoring. For the Russian storage facility being developed with NL assistance, the primary technical issues are safety and heat dissipation in containers and storage tubes. Evenson thought that the heat issue might not be adequately addressed.

There was consensus that an integrated MPC&A system is not implemented primarily by establishing rules and equipment needs at the national level. Years are required to codify safeguards needs in effective regulations. The laboratory-to-laboratory program has been more successful to date because it has been able to identify equipment needed at specific facilities and proceed with procurement and implementation for each facility. However, a potential shortcoming of the low-level laboratory-to-laboratory approach is that it does not necessarily promote a national commitment to the MPC&A in support of nonproliferation. In Evenson's opinion, there remains a serious problem regarding national "will."

Although the NL program developed from a one-shot to a multiyear program, Evenson expressed concern about "Balkanization" of NL among the supporting U.S. government agencies, i.e., that the MPC&A is becoming a U.S. Department of Energy interest and responsibility and export control lies with the State Department, while containers and storage facilities are still the responsibility of the DOD. Interagency coordination avoids mistakes but does not manage the program. It was pointed out that the governments do groundwork to establish goodwill so

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that progress can be made at the laboratory-to-laboratory level. For example, the safeguards community developed the right approach for the Russian storage facility.

With regard to continuing support from the INMM community, INMM Government Liaison Committee Chair John Matter recalled the exercises begun during the 1960s and 1970s between the U.S. national laboratories and the U.S. nuclear production facilities and that more than 10 years were needed to develop and implement integrated MPC&A at U.S. facilities. The continuing support of the entire INMM community will be needed to maintain continuity and promote progress in development and implementation of effective safeguards and nonproliferation programs through times of institutional change.

Defense By Other Means

Presented by Joerg Menzel; synopsis prepared by Robert Behrens

Joerg Menzel is principal deputy director of the On-Site Inspection Agency (OSIA), headquartered at Dulles International Airport in Washington, D.C. There are two points of entry for inspections in the United States, Dulles in the East and Travis Air Force Base, Fairfield, Calif., in the West. In 1994, OSIA had a staff of 770 people, two-thirds of whom were military and one-third civilian. Many spoke fluent Russian. OSIA has people at many embassies and in 19 time zones.

Menzel's presentation centered on the theme that successful negotiation, implementation and enforcement of various arms control treaties can be viewed as providing defense against military threats, as they lead directly to the destruction of military armaments. He focused on the results of three particular treaties as supporting the theme of his talk: the Intermediate-Range Nuclear Forces (INF) Treaty, CFE Treaty and Strategic Arms Reduction Treaty (START).

The INF Treaty, which was in force from 1982 to 1987, had as its objective the elimination of Soviet intermediate-range nuclear missiles that threatened the heart of western Europe: the SS-20 and SS-12 intermediate-range missiles. The INF Treaty eliminated 846 U.S. warheads and 1,846 Soviet warheads from deployment in Europe. The greater number of Soviet warheads is attributable to the SS-20, which is a mobile-launched missile with three warheads; about 600 were deployed. Through the successful implementation of five types of inspection (baseline, elimination, close-out, short notice and portal monitoring) the INF Treaty successfully eliminated the threat posed by an entire class of nuclear-armed missiles.

The CFE Armament Reduction Treaty (1990) was the second example Menzel discussed to illustrate his theme of "defense by other means." The purpose of this treaty was to establish a secure and stable balance of conventional armed forces in Europe at low levels, and to eliminate those military capabilities that threatened stability and security through surprise attack. This treaty led to the destruction of massive numbers of conventional Soviet offensive military hardware.

Finally, Menzel discussed the status of START. As an example, he cited that this treaty demonstrated itself as a successful alternate means of defense by successfully eliminating all strategic nuclear weapons in Belarus, Kazakhstan and the Ukraine. The threat addressed by START I includes 10-warhead intercontinental ballistic missiles (ICBMs) (SS-18), mobile ICBMs (SS-25), rail mobile systems (SS-24) and multiple-warhead Slams. ICBMs could reach the United States in about 30 minutes and the Slams in less time. When implemented, START I will eliminate about 50 percent of the heavy ICBMs in the former Soviet Union (FSU) and 30 percent to 40 percent of the total strategic nuclear forces. Both sides are ahead of schedule.

As for the future, additional arms control treaties, such as START II, the U.S.-Russian chemical warfare destruction agreement and the Chemical Weapons Convention all lead to support Menzel's thesis that arms control is "defense by other means."

Discussion noted that destruction of silos and launch vehicles were verified with high confidence, and that the next steps were to destroy warheads removed from stockpiles and ensure that the nuclear material could not be reused in nuclear weapons. Since difficulties related to the identification of weapon components, or pits, were mentioned in several papers at the Annual Meeting, an audience member inquired about how the public could have confidence that nuclear weapons were actually destroyed.

Menzel indicated that identification of weapons components was not a technical problem speculating that the United States and Russia possess the necessary technology. The difficulty is in determining the balance between the risk of sharing or revealing weapons design information as a result of the inspection process, thereby possibly increasing proliferation risk due to wider dissemination of nuclear weapons design information. The benefit is in increasing confidence from the verification process through more reliable identification. Negotiating this balance is a continuing challenge.

Responding to a question about extending the INF Treaty to China, Menzel indicated that a goal is to make INF global, i.e., the elimination of short and intermediate range missiles. Currently, the INF Treaty involves only the United States and FSU states.

Nuclear Smuggling: Where Are the Buyers?

Presented by Mark Hibbs; synopsis prepared by Vincent DeVito

Is nuclear material smuggling rampant, and are there buyers around every corner, as many in the European press would have us believe? These are the questions that Mark Hibbs, investigative journalist and European editor of *Nucleonics/Nuclear Fuel*, addressed in his talk.

Citing four incidents that occurred in the past 18 months, primarily resulting from sting operations, Hibbs noted that, with the exception of 500 grams of mixed oxide, the quantities were small and believed to be either standard sources or samples. Of the sources/samples, two were plutonium with a high concentration of Up-239 and the other was highly enriched uranium.

Hibbs also cited information obtained from classified German sources that, in 1994, two Spanish informants who were recruited by the German police reported that kilogram quantities of processed plutonium from Siberia was available on the black market. The informants also told German authorities that a bank credit of $250 million was established in a German bank by potential buyers from the Middle East or Far East. However, these reports were viewed skeptically by the German authorities, noting that Libya, Iran and Iraq seek international recognition, and black market activities by those countries would certainly negate that ambition.

Additionally, IAEA officials stated that they had no information that Middle East countries were involved. It was also noted that India, Pakistan and Korea have, or can provide, their own plutonium inventory and would have no need to further provoke the international community by indulging in the black market.

As a result of the cited incidents and persistent press allegations, the German Chancellery issued the following statement on June 1, 1995:

"The BND (Bundesnachrichtendienst) thus far knows of no case where the path of illegally traded nuclear material from the production site to an end-user, involving sellers and intermediaries, has been traced. For that reason, there is, therefore, no information about end-users or the intended final destination of materials.

"There is no proof for the allegation, above all made by the press, that certain countries in the Third World seek to buy nuclear material on the black market.

"BND knows of no reliable information indicating that terrorist groups have considered using radioactive material for their purposes or have already taken initial steps in this direction. The first vague tips in this direction are judged with skepticism by BND."

While this appears to address the larger problem of "Nuclear Smuggling: Where are the Buyers," there is some evidence that the nuclear materials in the cases previously mentioned did find their way out of Russia/FSU.

Meeting attendee Joerg Menzel asked how the material got out of Russia.

Hibbs responded, "That is a problem that needs to be addressed by the Russians."

Helen Hunt, another meeting attendee, asked what role intelligence agents may have played in the incidents. In response to this question, Hibbs stated that it is believed by many that the materials found in Germany were the result of provocation by an individual or individuals to embarrass Russia.

DOE Views on Remote Monitoring as a Future Nonproliferation Tool

Presented by Kenneth Sheely; synopsis prepared by William Floyd

According to Kenneth Sheely, U.S. Department of Energy (DOE), remote monitoring is now a reality in a world setting that is experiencing numerous post-Cold War political changes. Some of these political changes are especially significant between the United States and the former Soviet Union states. In this changing global environment, there is a refocus on nuclear weapons proliferation, especially in the areas of smuggling nuclear materials for sale on the world black market and preventing clandestine nuclear programs.

The potential applications of remote monitoring can now be realized. This type of system could be employed by the IAEA for safeguards verification purposes. The system could be used on a regional basis to increase confidence among neighboring states. Most importantly, remote monitoring could help promote bilateral transparency.

A bilateral program between the Kurchatov Institute and Argonne West using a remote monitoring system on storage vaults demonstrated that transparency can be

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achieved. A monitored site (in this case, a storage facility at Kurchatov and one at Argonne West) is equipped with alarm sensors that, when activated by an event, trigger a video capture system. The alarm data (date, time and the number of sensors that went off) and a video image of the incident is recorded and stored in a 486 computer system. Each monitored site is equipped with a monitoring center to review that data and to transmit the data to an independent monitoring center (in this case, Sandia National Laboratories) where the transmitted data is analyzed.

A live demonstration of the system was made to DOE Secretary Hazel O'Leary on March 27. After the demonstration, O'Leary stated, "Remote monitoring represents the future of nonproliferation monitoring."

Perhaps this statement best summarizes the DOE position on the subject. The secretary's comment is extremely relevant because remote monitoring, more than any other system, satisfies the needs of nonproliferation. Simply stated, these nonproliferation needs are to:

- Increase transparency,
- Increase effectiveness and reliability,
- Limit impact on facility operations, and
- Limit cost.

Equally important are the benefits that can be achieved by using a remote monitoring system. Such a system will reduce worker or inspector radiation exposure. The system is also less intrusive on all phases of facility operations. The components of remote monitoring are commercially available, which will obviously reduce costs for all concerned parties. However, perhaps the most important benefit is the fact that remote monitoring can effectively promote global transparency.

The next steps associated with remote monitoring may be monitoring of the excess material at the Y-12 Storage Vault at Oak Ridge and some field trials with the IAEA. There also may be some new applications for remote monitoring in the area of weapons dismantlement and perhaps in process monitoring.

INMM Thanks Sustaining Corporate Members

Following is a list of the INMM sustaining corporate members. INMM thanks them for their support.

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Generating Alternatives for Low-Level Radioactive Waste Management Systems

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Abstract

The safe disposal of radioactive wastes is a complicated public sector problem. More stringent regulations and increasing public concerns exacerbate the seriousness of the radioactive waste management problem. Traditional methods of treatment and disposal often fall short of being cost-effective and simplistic in design. An increased awareness of environmental issues and energy conservation necessitates a safe, cost-effective alternative to conventional methods. The chosen alternative must consider important factors such as environmental impact, ease of operation, resource recovery, energy efficiency and site-specific factors that relegate the final design.

The objective of this study was the development of a useful modeling-to-generate-alternative (MGA) method for the generation of preliminary designs of low-level radioactive waste (LLW) management systems that would provide more insight to decision makers than conventional approaches. The MGA method utilizes an optimization model and a search technique to produce a set of cost-effective LLW treatment and disposal alternatives. Data and information gathered on LLW processing, treatment and disposal were compiled and used to illustrate how the method can be employed. The resulting flowcharts indicate that various cost-effective alternatives utilizing different treatment and disposal methods can be generated efficiently.

Introduction

Low-level radioactive wastes (LLW) include everything from slightly radioactive trash (e.g., contaminated clothes, gloves, mops, papers, etc.) or research wastes (e.g., phosphorus-32) to radioactive metals, such as those from the inside of nuclear reactors contaminated with radionuclides. The LLW management problem demands much attention and interest because in the United States alone, LLW accounts for more than 80% (by volume) of all radioactive wastes.[1] In 1987, approximately 18% (by volume) of the LLW originated from power plants, and nearly 14% came from the use of radioisotopes in institutional applications and various industrial processes. The Department of Energy (DOE)/Defense program produced nearly 66% and the remaining 2% came from non-DOE government facilities. In 1988, a total of 5.6 million cubic meters (19.3 million Curies) of LLW had been generated in the United States, an increase of 31% since 1980. The total is expected to increase by an additional 44% over the 1988 level to 8.12 million cubic meters (25.4 million Curies) by the year 2000.[2]

LLW management is a complex multistage problem. From generation to disposal, the waste goes through various processes, including treatment, conditioning and volume reduction. Mathematical modeling is a helpful tool that can be used in cases such as this to simplify the system so that solutions can be obtained and examined.

However, a model often fails to completely represent the problem being evaluated. Because of this, the least-cost solution from the optimization model of the system may not provide the best solution for the real problem. Realizing the imperfections of the model, it is desirable to use the model as a basis from which to generate attractive alternatives for examination and evaluation. The objective of this study is to develop a mathematical model that will generate various cost-effective alternatives for an LLW management system. The model developed as a result of this research will be useful to LLW generation facilities for (1) the preparation of preliminary cost estimates for LLW waste treatment and disposal, and (2) the generation of alternative LLW systems with various treatment and disposal technologies.

Literature review

From reviewing the available literature, it is evident that very little research has been done in the area of modeling which can be used to generate alternatives for an LLW management system. Several studies have been done on specific technologies for disposal techniques to evaluate the performance of these particular options, but no system approach was considered to evaluate the whole waste management system.

Gilbert and Luner[3] developed and applied a comparative method for evaluating technical alternatives for greater-confinement disposal (GCD) of LLW. The method ranks nine GCD alternatives based on a ranking parameter (RP) that equals C (cost in dollars) plus H (health risk converted to dollars). The report, which was prepared by Teknekorn Inc.[4] for the Nuclear Regulatory Commission, presents a comprehensive database of volume reduction techniques for LLWs that are generated in fuel cycle and non-fuel cycle facilities. Discussions of the volume reduction techniques are provided to include system disciplines, performance, limitations, volume reduction capabilities and process parameters. An economic analysis is presented for shredding and compaction, incineration, calcination, evaporation and bituminization.

There are several computer codes that are available to facilitate the design and analysis of the operation of the radioactive waste management system. The codes can be categorized into several subject areas: air dispersion, biosphere transport, rock mechanics and transportation.

INTERTRAN is a code that provides a simple and rapid method of assessing the risk involved in the transportation of radioactive materials.[5] RADTRAN III code calculates the expected radiological risk of transporting radioactive materials. Meteorological, demographic, health physics, transportation mode and route, packaging and material factors data are included in the input data and accounted for in the models embodied in the code.[6] WASTE-II (Waste System Transportation and Economic Simulation-Version II) is a spent fuel logistic model for cost and logistics analysis. The model simulates a user-defined system of spent nuclear fuel (SNF) generation, transportation, storage and final disposal.[7]

The code SYVAC contains a set of submodels that represents the major components of the disposal system: the vault, geosphere and biosphere. Uncertainty and variability in the data needed to drive the models were taken into account by using probability distributions to define the input parameters. The code selects a simulation by randomly sampling a value for each parameter from its prespecified distribution, which is used deterministically within the submodels to estimate the radiological consequences.[8] PABLM is a computer code that is used to calculate accumulated radiation doses from radionuclides transported to aquatic and terrestrial pathways in the biosphere. It considers exposures from ingestion of food and water contaminated with radionuclides from external radiation doses. The program also calculates accumulated radiation doses from chronic ingestion of food products that contain radionuclides and from chronic external exposure to radionuclides in the environment.[9] Kastenberg and Newman[10] developed a framework to compare waste management alternatives, such as partitioning and transmutation (P-T), to the currently open light water reactor fuel cycle in the United States.

Amiro and Davis[11] described the pathways through which radionuclides might move to the atmosphere from contaminated terrestrial and aquatic surfaces. A model was developed that considers natural phenomena, such as wind erosion of soil, forest fires, gaseous emissions from soil and bubble bursting at lake surfaces. The model gives reasonable, but conservative, estimates of air concentrations of contaminants that could migrate from an underground nuclear fuel waste vault. Matsuzuru and Suzuki[12] developed a computer code, ENBAR-1, for the simulation of radionuclide release from an engineered disposal facility for shallow-land burial of LLW. Results of calculations with the model showed that the model gave a lower source term than did an equilibrium model.

Darnell and Larsen[13] proposed an approach based on existing technology to develop a waste treatment and disposal complex by colocating the waste treatment and waste disposal facilities. It was estimated that an overall volume reduction factor of 17-to-1 could be achieved through sorting, incineration, metal sizing, intense compaction and grouting. The treated waste packed with contaminated grout in steel boxes would be stacked tightly in above-grade, earth-mounded, concrete disposal vaults. After filling a vault, a concrete roof would be poured directly on top of the waste stack, and engineered earthen covers placed over the vaults at final closure to protect the waste from water. The total cost was estimated to be $13 (1988 dollars) per cubic foot LLW, which is considerably less than the current LLW disposal cost in the range of $20 to $113/ft^3. Jacobs et al.[14] presented an economic evaluation of different volume reduction techniques. Their approach allowed different systems to be ranked on the basis of disposal cost savings, in terms of either present value, levelized, or equivalent capital investment dollars.

Methodology

In order to simplify the complexity of handling an LLW system, LLW wastes are grouped into either liquid or solid LLW. The multioption flow diagram for the liquid system is shown in Figure 1 (page 23), and the solid LLW system is shown in Figure 2 (page 23). The process of setting up a flowchart for either solid or liquid waste is outlined in the following steps. The solid LLW is classified as either combustible or noncombustible, and compactible or noncompactible. After initial classification, the waste goes through a sorting process. After sorting, the waste is segregated and passed to the appropriate processes before disposal. The applicability of each technology to the particular type of waste to be treated was carefully examined. First, different stages of treatment were identified

Figure 1

Multioption Flow Diagram for Liquid LLW Management Systems

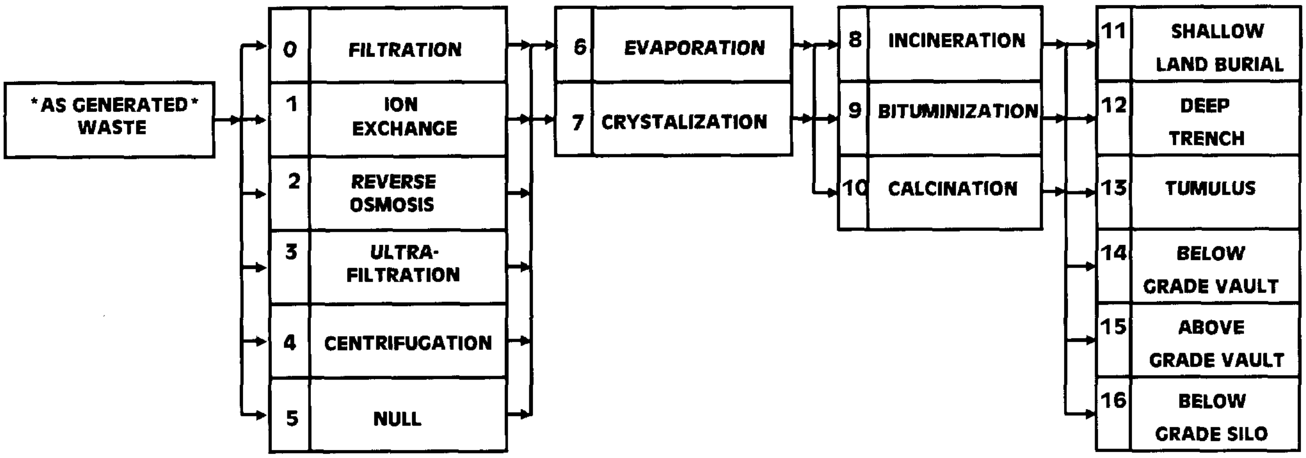
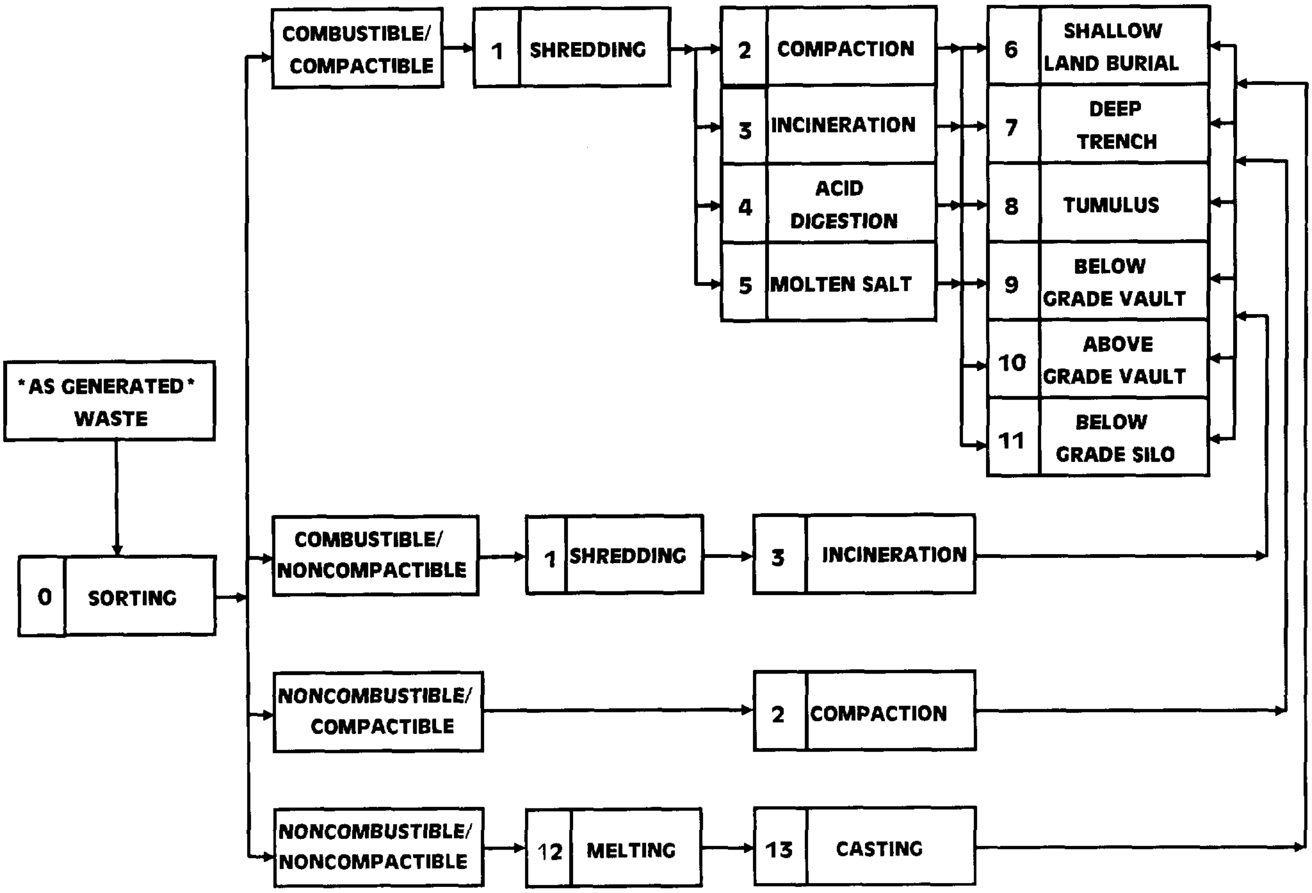


Figure 2

Multioption Flow Diagram for Solid LLW Management Systems



for safe disposal of the LLW. At each stage, the possible options to be considered were identified as shown in Figures 1 and 2. Once the flow diagram was set up, the next step was to calculate cost values for each process option.

One of the objectives of this research was the calculation of cost for each process option for liquid and solid LLW. There are 17 process options for the liquid LLW and 17 process options for the solid LLW. The process of developing a general method to calculate cost for such a complex system was very difficult, but a common framework was developed to accomplish this. Costs were calculated using appropriate user input data. Consequently, values of cost will only be accurate if the user input data is correct. Therefore, efforts were given to develop the methodology for determining cost values for all unit processes. Cost values were calculated based on each process option; capital and operation and maintenance cost.

Major direct capital costs include process equipment, installation and piping, instrumentation and controls, and electrical service. Operation and maintenance cost are labor intensive and depend primarily on the volume of the waste to be processed. In this study, it was assumed that one man-hour is needed to handle 7 ft^3 of waste.[4] Operation and maintenance cost generally include operating labor, maintenance, consumables and utilities. The design period of the incinerator is considered to be 30 years with an interest rate of 7%.

The cost was calculated from the appropriate user input data. Detailed cost calculation for each process option for liquid and solid LLW is shown elsewhere.[15] Cost data were compiled from research literature, as well as from information collected through telephone contacts. Costs associated with the treatment options are presented on an annual cost basis.

The basic cost calculation procedure is similar for each of the process options. The only variables that differed were the amount of kilowatt-hours (kwh) and British thermal units (Btu) consumed by the different processes. Solidification is performed at some point before the disposal stage but was not shown as a separate stage in Figures 1 and 2. For liquid low-level radioactive waste, cement was used as a solidification agent after both incineration and calcination, but asphalt was used after bituminization.

For solid LLW, cement was used as a solidification agent after compaction, incineration, acid digestion and molten salt. No solidification was done for noncombustible/noncompactible waste, because the waste is already in stable form after casting. For each disposal method, heavy equipment cost and labor cost were calculated. For tumulus, below-grade vault, above-grade vault and above-grade silo, structure cost was assumed and added with equipment and labor cost.

The mathematical model developed to generate alternatives for LLW systems is a zero-one integer model that can be solved with implicit enumeration. The decision variables in this model are the process options at each stage. The constraints include the total annual cost constraint and the radiation constraint. The objective function is to minimize the total annual cost of the LLW system. The simplified model is shown as follows:

Minimize:

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} C_{ij}X_{ij} \tag{1}$$

s.t.:

$$\sum_{j=1}^{M_i} X_{ij} = 1 \tag{2}$$

$$X_{ij} = 0 \text{ or } 1 \qquad i = 1, 2, \ldots, N;\ j = 1, 2, \ldots, M_i \tag{3}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M_i} C_{ij}X_{ij} \le C \tag{4}$$

$$\sum_{j=1}^{M_i} X_{Nj}R_j \le R \tag{5}$$

Where:

N = total number of stages;

M_i = number of options at stage i;

C_{ij} = unit cost for option j at stage i;

X_{ij} = decision variable with a value of 1 or 0, 1 for option j chosen at stage i and 0 for null;

C = upper limit of the total cost;

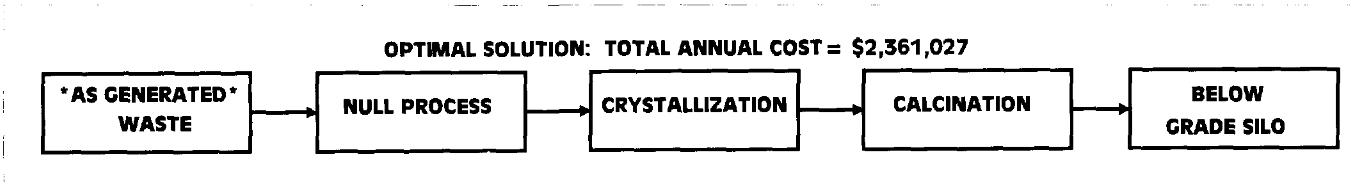
R_j = radiation dose factor (RDF) at option j at the last stage; and

R = radiation limit (RDF).

In this mathematical model, Equation (1) is the objective function representing the annual cost of an LLW system. Equations (2) and (3) are used as constraints to ensure that only one option is chosen at each stage. Equation (4) is the cost constraint to ensure that the total annual cost is below the cost limit. Equation (5) serves as an environmental constraint to ensure that the RDF after the final stage is below the threshold limit.

The enumeration approach is a search technique for obtaining the optimal solution of any multistage, multioption problem. In a total enumeration (TE) approach, all the possible combinations have to be evaluated to obtain the least-cost solution. The implicit enumeration (IE) approach evaluates a small set of options, using an upper bound to eliminate nonpotential options, which is more efficient than using TE. However, if the number of combinations is very large, the number of nodes of the solution to be checked may still be extremely large, thus prohibiting the use of implicit enumeration. Bounded implicit enumeration (BIE)[16, 17] uses a lower bound with the upper bound to obtain the optimal solution that requires less computer time. BIE has an extra step to calculate

Figure 3



lower bound in comparison to the IE approach. The lower bound of each stage is the summation of the minimum objective function values of each of the later stages. Because of the lower bound, few search trees need to be checked to obtain the optimal solution, which makes the BIE algorithm more efficient than the IE algorithm. Because of its wide use in the engineering community, FORTRAN was chosen as the programming language to write the main program for the model to generate alternatives for the LLW management system.

The following assumptions are made in order to simplify model development for the LLW management systèm.

(1) Cement would be used as the solidification agent in all cases except bituminization, where asphalt would be used.

(2) 55-gallon 17H drums would be used for waste shipment for disposal. A maximum of 70 drums could be shipped at one time.

(3) For waste composition, 60% of the waste volume will have an average radioactive concentration, 20% of the waste volume will have a radioactive concentration equal to 10% of the average concentrations, and 20% of the waste volume will have a radioactive concentration equal to 10 times the average concentrations.

(4) For cement solidification, 4 ft^3 of waste and 400 pounds of cement per drum would be used.

(5) For asphalt solidification, 6.5 ft^3 of waste and 266 pounds of asphalt per drum would be used.

(6) All waste filled drums would be shipped to off-site burial locations. There would not be any on-site storage.

(7) No decontamination or decommissioning cost would be considered.

(8) For liquid LLW, $[Ci/ft^3]/[R/hr]$ ratio is 0.11.

(9) For solid LLW, $[Ci/ft^3]/[R/hr]$ ratio is 0.043.

(10) Shipment cost is $5/mile.

Based on the assumption (3) above, the radioactivity distribution is calculated by:[4]

$\alpha = A/(2.62V)$,

where V = Volume of waste in ft^3;

A = Curie loading of the waste in Ci; and

α = Average radioactivity in Ci/ft^3.

Radiation dose factor (RDF) was then calculated according to the assumptions (8) and (9). For liquid LLW, RDF (R/hr) = $\alpha/0.11$ and for solid LLW, RDF = $\alpha/0.043$.

Results and discussions

Liquid LLW management systems

Both the liquid LLW and solid LLW systems have been used to illustrate the MGA approach.[15] Figure 1 shows the multistage, multioption flow diagram for a liquid LLW management system. The system consists of four stages and the total number of possible process options is 17. The possible number of alternatives is (6)(2)(3)(6) = 216, i.e., in this specific multistage scheme, there are 216 possible ways by which the liquid LLW can be managed from generation to disposal.

After generation, liquid LLW needs to be concentrated, and the concentrated volume of waste is passed to the next stages for further processing. In the present case, liquid LLW can be concentrated using different concentration technology, e.g., filtration, ion exchange, reverse osmosis, ultrafiltration, or centrifugation. The waste is passed to evaporation or crystallization for further volume reduction and drying. The dried and compacted waste proceeds to the next stage, in this case, incineration, bituminization, or calcination. After the completion of any of these three unit operations, the waste is solidified and packed for disposal. Six disposal techniques, shallow land burial, deep trench, tumulus, below-grade vault, above-grade vault, and below-grade silo have been selected for evaluation in the present study.

The sodium metaborate waste with a unit weight of 156 was considered in this study. The initial volume of the waste is 20,000 ft^3 with a loading of 200 Ci. The least-cost solution was obtained first. Note that the sum of the minimum cost at each stage may not be the optimal solution if the solution violates the radiation constraint of 2 R/hr. The BIE algorithm was used to implicitly search all of the possible 216 combinations to obtain the least-cost solution. The flow diagram of the least-cost solution is shown in Figure 3 (above). As discussed before, the least-cost alternative may not be the best alternative for the system because the cost data may not be accurate. There also may be other factors or issues that are not included in the model.

Alternatives can be generated by setting any arbitrary cost and environmental constraint. In the present study, alternatives were generated by setting the target on the total annual cost 10% higher than that of the least-cost solution ($2,361,027). Twenty-eight alternatives were obtained. Five of the most unique alternatives were then selected from these 28 alternatives. The flow diagrams of the five alternatives are shown in Figure 4 (page 26). Alternatives 1 and 2 have the largest difference because they have only one treatment process in common: crystallization. The smallest difference is between alternatives 4 and 5, because both alternatives use crystallization, bituminization and below-grade silo.

All five alternatives and the least-cost alternative have one common unit process: crystallization. Because of the low equipment cost ($40,000) assumed for the crystallizer, the total annual cost for that option is low when compared to the others. The pretreatment processes are different in each of the five alternatives. The null process does not have any cost associated with it because all the waste was passed to the next stage. The total system cost came down because of the absence of huge equipment and operation and maintenance cost in this process. Annual cost for filtration, ion exchange, ultra filtration and centrifugation are $139,905, $150,742, $161,349 and $141,456, respectively. Annual costs for bituminization and calcination are within 2% of each other. Disposal cost is the major expense in a radioactive waste management system. The annual cost for below-grade silo was $1,602,049, and annual cost for above-grade vault was $1,660,543.

The annual cost and radioactivity for the five alternatives are shown in Table 1 (below). The radiation dose factor of the waste at time of disposal for all five alternatives is below 2 R/h, mainly because of the constraint. However, it is clear that there is a tradeoff between the annual cost and the RDF. Alternative 2 has the lowest annual cost among the five alternatives, but its RDF is the highest. The existence of a high RDF value for this alternative makes it inferior to other alternatives if the RDF is considered to be the most important issue in comparing these alternatives. In this case, alternative 1 may be the most attractive alternative even though the annual cost is a little higher. This type of tradeoff when comparing alternatives may not be possible in the conventional optimization model.

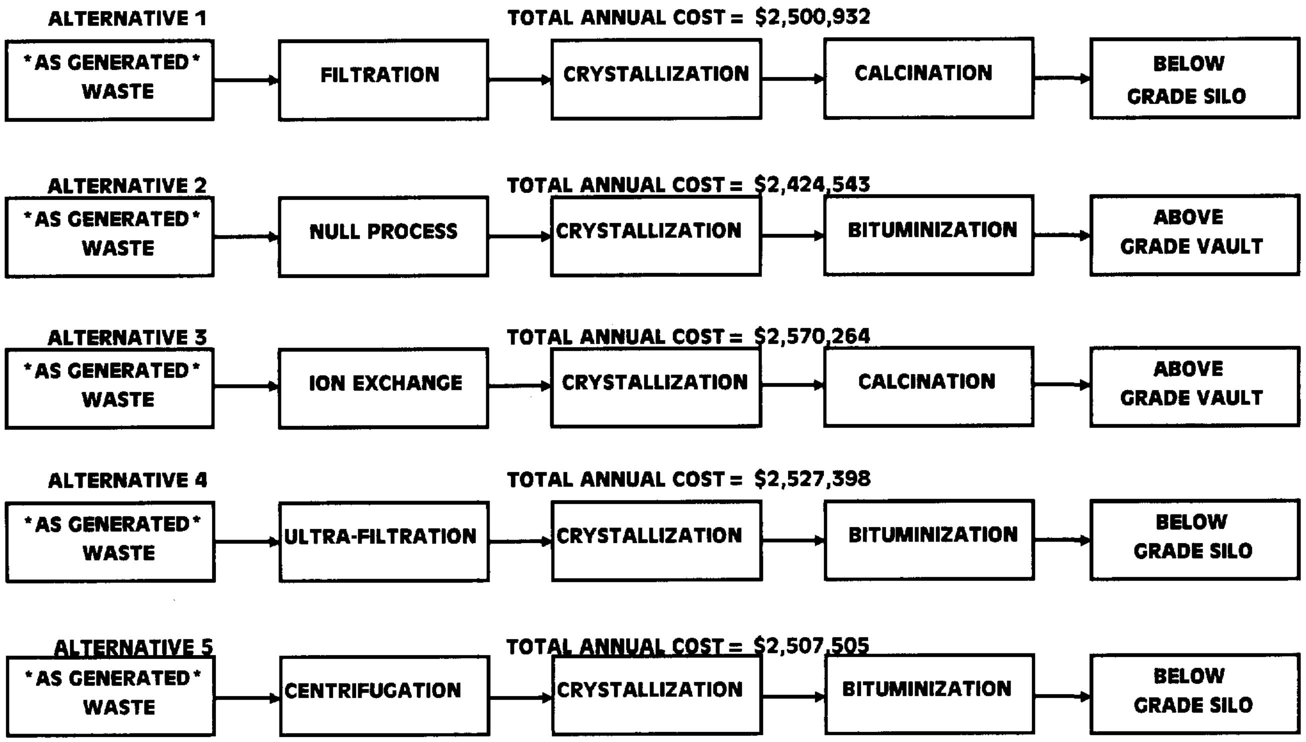
Radioactivity increases according to the volume reduction factor of the unit operation process.[4] Because the disposal cost is the highest among all the process options in the LLW management system, the reduction of the waste volume

Table 1

Annual Cost and Radioactivity Distribution of the Alternatives

Alternative No.	Annual Cost (1992$)	Initial Radioactivity (Ci/ft^3)	Radioactivity at Disposal (Ci/ft^3)	RDF R/h
1	2,500,932	0.0038	0.013	0.12
2	2,424,543	0.0038	0.081	0.74
3	2,570,264	0.0038	0.018	0.16
4	2,527,398	0.0038	0.075	0.68
5	2,507,505	0.0038	0.069	0.63

Figure 4



can decrease the disposal cost dramatically. For example, for alternative 3, after calcination, the final waste volume is reduced from 20,000 ft^3 to 582 ft^3. Consequently, the number of drums needed for packaging is reduced to 145, which requires two shipments. The cement cost is also reduced to $12,420. Because of volume reduction, a cost savings was attained not only in disposal but also in packaging, solidification and shipment.

The number of alternatives that can be generated is dependent on the cost constraint. When the cost constraint was set as 20%, 30%, 40% and 50% higher than the least-cost solution, 82, 127, 171 and 205 alternatives were obtained, respectively.

Solid LLW management systems

Figure 2 shows the multistage, multioption flow diagram for a solid LLW management system. For the four types of solid waste, namely combustible/compactible (CB/CP), combustible/noncompactible (CB/NCP), noncombustible/compactible (NCB/CP) and noncombustible/noncompactible (NCB/NCP), 50% of the initial 40,000 ft^3 of waste was assumed CB/CP, 20% each was assumed CB/NCP and NCB/CP, and 10% was assumed NCB/NCP. The curie loading of the waste was 400 Ci. There are 24 possible combinations for the first type of waste, and six possible combinations for each of the second, third and fourth type of waste. As the total system cost is the sum of any one train of treatment-conditioning-disposal from all of the four types wastes, the total number of combinations becomes (24)(6)(6)(6) = 5,184. To obtain the alternatives from 5,184 combinations, the new system changes to four stages (for four types of waste). At the first stage, there are 24 annual cost values and six costs at each of the other three stages.

The least-cost solution was obtained first. The radiation constraint was set as 2 R/h. The BIE algorithm then eliminated 1,331 combinations from the original 5,184, i.e., the search effort was 74.32% of total enumeration (TE). The flow diagram of the least-cost solution is shown in Figure 5 (below). Below-grade silo was the disposal method for both CB/CP and CB/NCP waste. Shallow land burial was the disposal technique for the other two types of waste. Acid digestion was the transformation technology for the CB/CP waste. Waste volume after acid digestion, incineration, compaction and casting was 1,667 ft^3, 500 ft^3, 2,000 ft^3, and 2,424 ft^3 respectively. Thus, the total volume of disposed waste was reduced to 6,591 ft^3 from the initial waste volume of 40,000 ft^3.

A target annual cost was set at 10% above the least-cost solution and alternatives were generated. A radiation constraint was also set as 2 R/h. Fifty-two alternatives were obtained within the constraints. Pairwise difference among these alternatives was calculated, and the most different five alternatives were chosen. The flow diagrams of the five alternatives are shown in Figures 6-a through 6-e respectively (pages 29–31).

The maximum difference exists between alternatives 1 and 2 (10 units). The annual cost and radioactivity distribution of the alternatives are shown in Table 2 (page 28). Radioactivity at disposal for an alternative is the sum of the radioactivity after conditioning for the four types of waste. The maximum radioactivity is 0.08 Ci/ft^3 for alternatives 1 and 4. The maximum RDF is 1.86 R/h for alternative 1. Based on the calculations, there is a trade off between annual costs and RDFs. It can be seen that even though the annual costs are higher for alternatives 3 and 4, the RDFs are lower, which makes these two alternatives

Figure 5

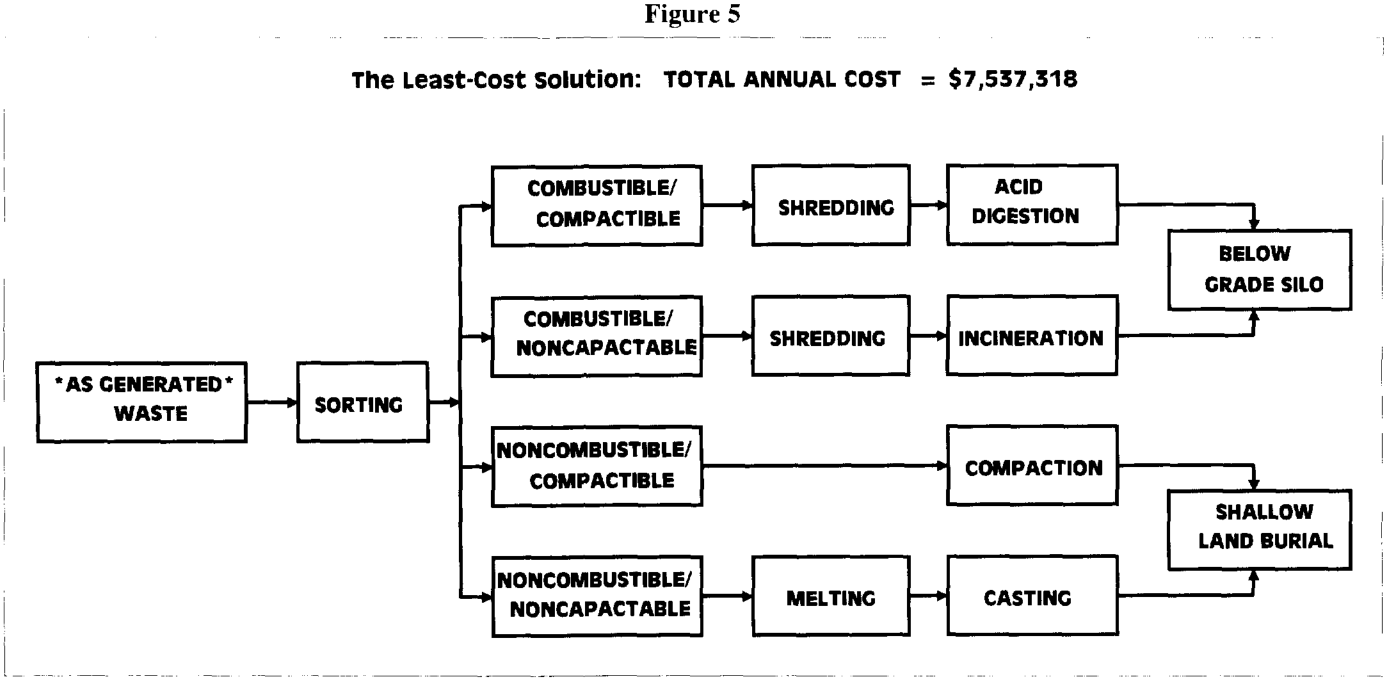


Table 2

Annual Cost and Radioactivity Distribution of the Alternatives				
Alternative No.	Annual Cost (1992$)	Initial Radioactivity (Ci/ft^3)	Radioactivity at Disposal (Ci/ft^3)	RDF R/h
1	7,932,259	0.0038	0.08	1.86
2	7,711,636	0.0038	0.05	1.16
3	8,087,393	0.0038	0.03	0.70
4	8,047,055	0.0038	0.03	0.70
5	7,930,455	0.0038	0.05	1.16

attractive when compared to the other alternatives.

As shown in Figure 6-a through 6-e, for alternative 1, acid digestion is the transformation technology for CB/NCP wastes. Tumulus is the common disposal method for CB/CP and CB/NCP wastes.

In alternative 2, molten salt is the transformation technology for CB/NCP wastes. Above-grade vault is the common disposal method for CB/CP and NCB/NCP wastes. Below-grade vault and deep trench are the disposal technologies for the second and third type of wastes respectively.

In alternative 3, shallow land burial is the disposal method for CB/NCP and NCB/NCP waste. Below-grade silo is the disposal technology for CB/NCP waste and above-grade vault is the disposal method for NCB/NCP waste. Deep trench is the disposal method for NCB/CP wastes. Compaction is the transformation technology for CB/CP wastes.

In alternative 4, shallow land burial is the common disposal method for CB/CP and CB/NCP wastes. Below-grade silo is the disposal technology for NCB/NCP waste and tumulus is the disposal method for NCB/CP waste. Compaction is the transformation technology for CB/CP wastes.

In alternative 5, tumulus is the common disposal method for CB/NCP and NCB/CP wastes. Shallow land burial is the disposal technique for NCB/NCP wastes and above-grade vault is the disposal technology for CB/CP wastes. The annual cost of each of the alternatives were greater than $7 million. The high cost resulted from the fact that solid LLW consists of four types of wastes, and each of these types of waste need to be treated separately.

Alternatives were also generated by setting the cost constraints as 20%, 30% and 40% above the least-cost solution. When the cost constraint was set as 20% above the least-cost solution, 58 alternatives were obtained and the BIE algorithm eliminated 3,866 combinations from the original 5,184 to obtain these alternatives. Sixty-nine alternatives were obtained when the cost constraint was set at 30% above the least-cost solution. The number of combinations eliminated was 3,855. When the cost constraint was set at 40% above the least-cost solution, the number of alternatives obtained was 83. Radiation constraint was set as 2 R/h each time. The most different alternatives for each of the constraints set can be obtained and examined using the pairwise comparison.

Summary and conclusions

Low-level radioactive waste management system is a very complex multistage, multioption problem. In this study, realistic multistage, multioption treatment, conditioning, and disposal schemes for both liquid and solid LLWs were developed. The annual costs for each unit operation process were determined from appropriate user input data. With the cost calculation, radioactivity distribution in the waste stream was also calculated. The least-cost solution and the most different alternatives were then generated based on the modeling-to-generate-alternatives methodology.

These generated alternatives would give a broad range of understanding and insight about the problem and hopefully help decision makers in their planning processes. The alternatives generated will also help waste generation facilities compare the performance and cost of their existing treatment and disposal scheme with other potential alternatives. The proposed approach recognizes that an LLW problem cannot be completely represented by the model, and hence the least-cost solution from an optimization model of the system may not provide the best solution for the real problem. In this case, it is then desirable to use the model to generate attractive alternatives for examination and evaluation.

In this study, the most commonly used treatment, conditioning and disposal methods were considered to generate alternatives. Other treatment, conditioning and disposal methods can also be included in the model and be evaluated. For example, in addition to the natural circulation evaporators in this study, other kinds of evaporators can be used for processing liquid LLW, namely natural circulation evaporators, vapor compression evaporators, wiped film evaporators, etc. Similarly, there are different kinds of incinerators, compaction and filtration devices that can be evaluated. If all of the possible types of unit operation processes are considered, the number of possible alternatives generated will be substantially large. Thus, the planner has to evaluate the trade-off between the complexity of the model and the comprehensiveness of the processes to select the number of processes for evaluation.

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Figure 6-a

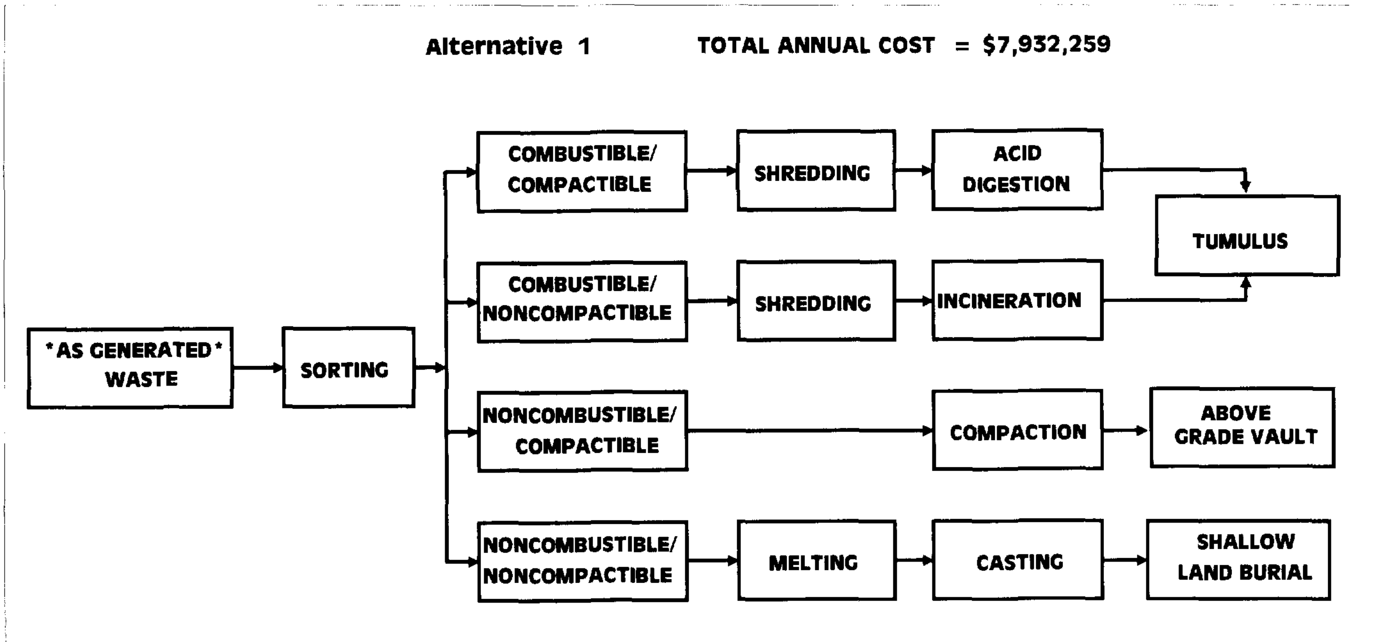


Figure 6-b

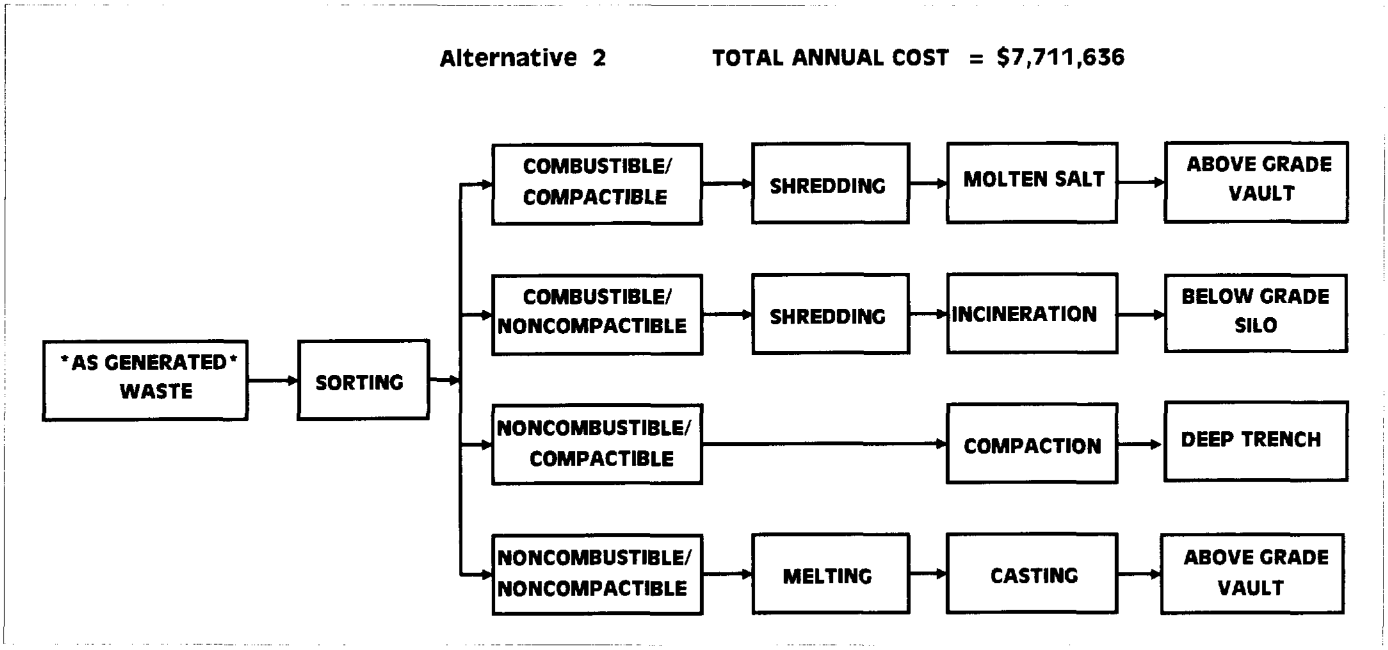


Figure 6-c

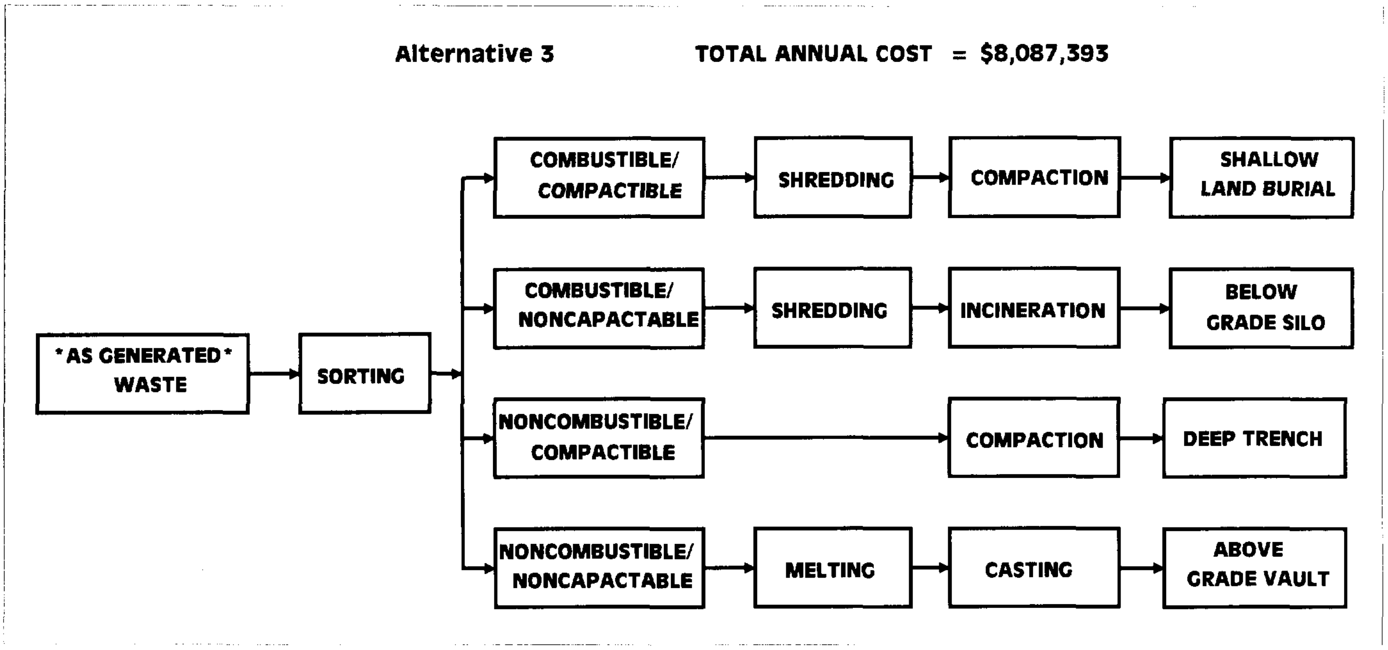


Figure 6-d

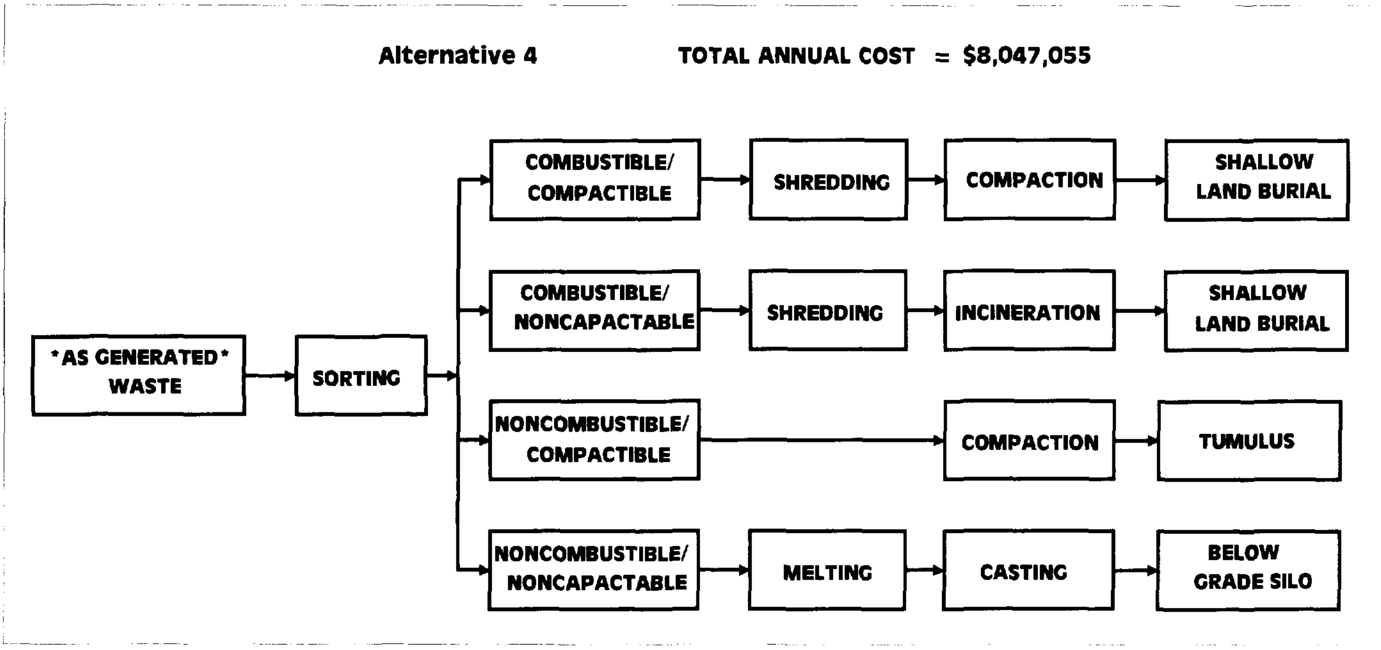
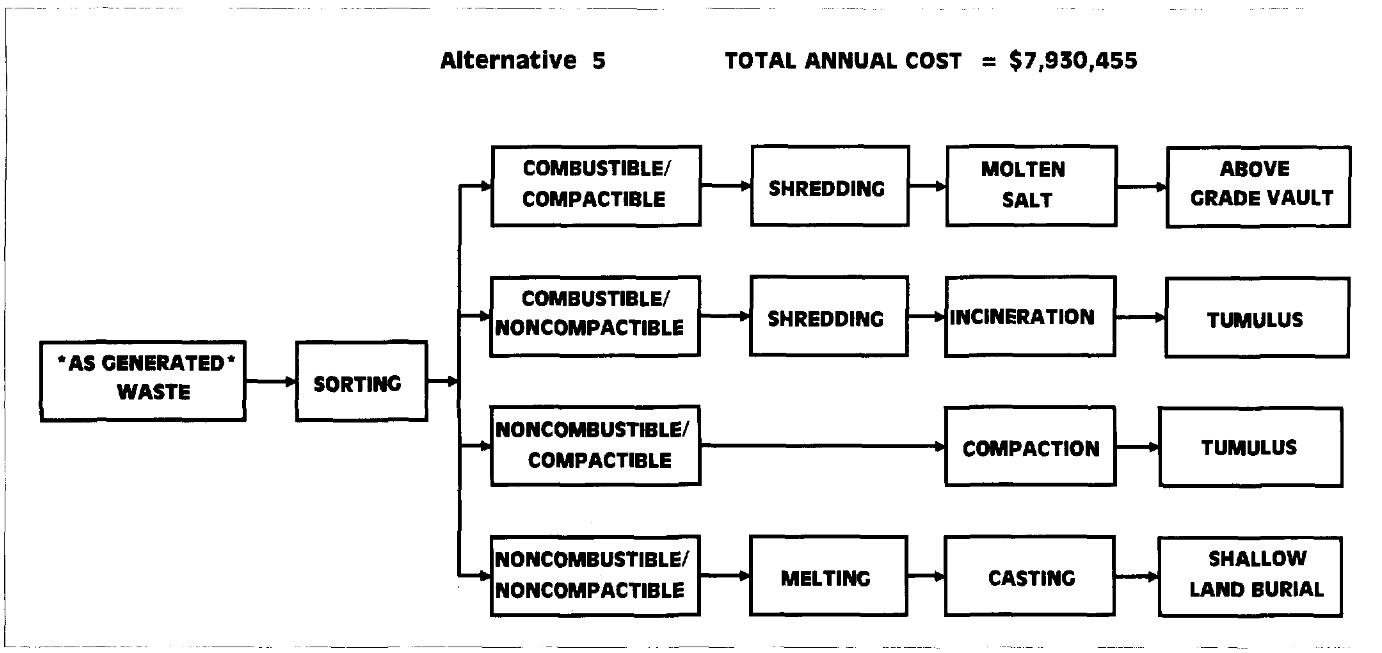


Figure 6-e



Vitrification of Simulated Medium- and High-Level Canadian Nuclear Waste in a Continuous Transferred Arc Plasma Melter

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Abstract

A continuous, laboratory-scale, 40-kw, transferred arc plasma melter was designed and built for the vitrification of nuclear waste. Borosilicate glass, high silica glass and sphene glass–ceramic were successfully melted with the waste using argon and argon–oxygen transferred arcs. The use of both direct heating and indirect heating was examined. The loss of total glass weight and the elemental losses of Na, Cs, U and Nd were examined as a function of operating conditions. The losses of Cs during melting were from 25 wt% to 73 wt% and depended on operating conditions. The loss of Cs during melting could be minimized by decreasing the plasma power, increasing the feed rate, using indirect heating rather than direct heating and choosing suitable waste compositions. The injection of oxygen and the addition of zeolite to the glass formers did not significantly reduce Cs losses.

1. Introduction

In a previous paper[1], we reported on the vitrification of simulated nuclear waste in a transferred arc melter operating in a batch mode. In this paper we present experimental results on the vitrification of similar materials in a continuous transferred arc plasma melter. The objectives of the work were to demonstrate the continuous plasma melting of simulated Canadian medium- and high-level nuclear wastes into borosilicate glass, high silica glass and sphene glass–ceramic, as well as to investigate the losses of waste components in the melting process.

2. Experimental equipment and procedures

The continuous transferred arc plasma melting system shown in Figure 1 (page 33) was described in detail elsewhere.[2] It was powered by a 40-kw dc welding power supply with an open circuit voltage of 320 V. Argon was used as the main plasma gas, but oxygen was also added to increase the oxygen potential in the melter in an attempt to reduce cesium losses. The glass or ceramic components were premixed simulated waste and fed continuously to the melting crucible using a vibrating spiral feeder (Tafa model 104B). The ratio of glass former to simulated waste was 7:3. The solids were fed with a small amount (1-3 L/min) of argon conveying gas.

The melter cathode was a water-cooled piece of conical thoriated tungsten as is normally used in small dc plasma torches. It was surrounded by an annulus for gas injection and an auxiliary anode connected to the power supply by a water-cooled resistance of 1.3 ohms. This allowed the cathode to be used as a dc nontransferred arc plasma torch if the material in the crucible was not sufficiently hot to conduct electricity. The arc length was 4.5 cm. The anode, which served as the melting crucible, consisted of three sections. An outer section, which may be water-cooled as needed, a graphite section to contain the melt and collect the plasma current, and an alumina tube section to contain the melt in the upper section of the crucible and avoid the plasma arcing directly to the graphite. The inside diameter of the crucible was 35 mm. This size was chosen as being large enough to test the concept of the melter at a laboratory scale before proceeding to pilot or full-scale experiments.

To start an experiment, the arc was struck to an empty crucible and feeding commenced. Once the molten product reached the desired level in the crucible, a motor drive was started to withdraw the crucible bottom into a tank section. The crucible bottom was water-cooled so the product started to solidify upon leaving the hot crucible. The level of the molten product surface was kept constant by adjusting the ingot withdrawal rate. The arc could be transferred, to either the graphite (indirect heating) or the molten product (direct heating).

A magnetic coil to rotate the plasma arc surrounded the crucible and was coaxial with it. Its purpose was to keep a more uniform temperature on the molten product surface and to reduce the erosion of the anode when the arc was struck directly to the graphite anode. It also reduced fuming and increased the arc stability. Arc rotation was found to be beneficial on this laboratory-scale equipment and would be even more important in a production-scale unit. The magnetic coil increased the arc voltage since the rapidly moving arc experienced higher heat losses and the arc was magnetically stretched. Thus, the arc power was increased at constant current operation. A near-linear increase in voltage and power of 36% was observed as the coil current increased from 0 to 5 A. A coil current of 5 A was normally used.

The plasma gas flow rate was 18 L/min in all experiments and the pressure in the melter was atmospheric. It had been shown previously that the gas flow rate did not affect losses from the product. The compositions of the materials used in this work are given in Tables 1 and 2 (page 34). The compositions of nuclear wastes from different sources are different. We used simulated Canadian nuclear waste[3], which contained only natural uranium and no other radioactive species. The glass formers were premixed with the simulated waste and formed particles with a diameter of about 2 mm to avoid dispersion or elutriation by the plasma. A two-wavelength pyrometer (Milletron Thermoscope) operating at wavelengths of 0.78 mm and 0.83 mm was used to measure the surface temperature of the molten product. Elemental concentrations in the raw materials and products were measured using neutron activation analysis. The results presented below were all based on steady state operation.

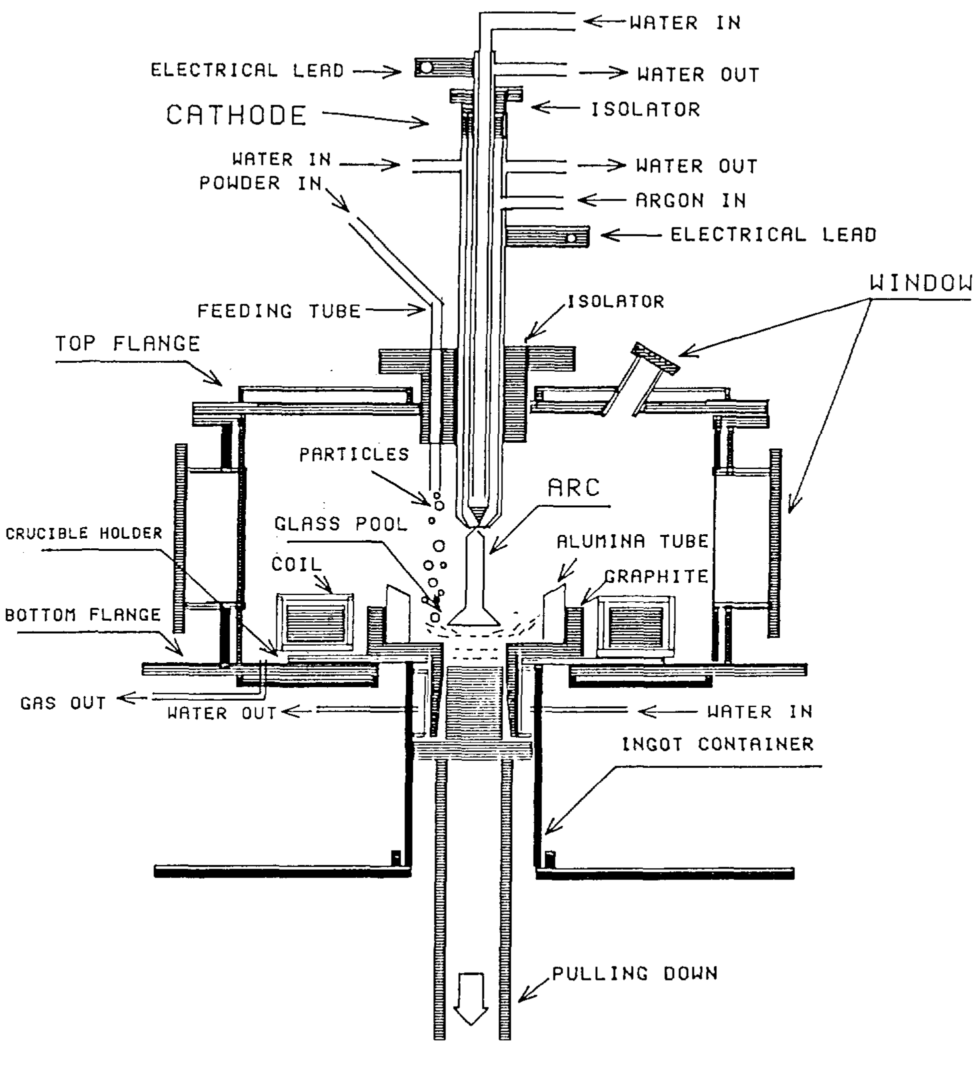
3. Results and Discussion

3.1 General observations

Both direct heating and indirect heating were examined. In direct heating, the plasma arc directly touched the molten product surface. In this case, the arc stability was lower because the unmelted particles caused localized cooling of the surface and greatly reduced its electrical conductivity. In indirect heating, the plasma arc struck the graphite anode, resulting in a more stable arc. Direct heating produced higher losses by volatilization, e.g., for pure borosilicate glass under identical conditions of 25 g/min solids fed and a current of 100 A, the sodium losses were 38% for direct heating and only 13% for indirect heating. Direct heating of borosilicate glass with waste gave a Cs loss of 79% while indirect heating reduced this loss to 73%. The following results are all for indirect heating.

The ingots formed in the melter were visually homogeneous and the concentrations of U, Nd and Cs were shown to be independent of sample location within the ingot for all products. X-ray diffraction analyses showed that the glasses were essentially amorphous, but the sphene glass-ceramic exhibited a distinct crystal structure even in the absence of additional heat treatment.

Figure 1: Transferred arc continuous plasma melter.



3.2 Total losses by volatilization and melt surface temperature

In all vitrification processes, the loss of radioactive components by volatilization is of major concern. High losses complicate the gas handling system and increase the cost of the process by requiring the recycling of some waste elements. We examined overall losses, as well as the loss of specific elements during melting. Figure 2 (page 35) shows the total weight loss from borosilicate glass, high silica glass and sphene glass-ceramic with simulated waste as a function of plasma current for constant feed rates. The feed rates were chosen to give complete melting at the lowest currents used in these experiments. The total weight losses from all these increased as the plasma current was increased.

A two-wavelength pyrometer was used to measure the temperature on the surface of molten product. Because the strongly radiating plasma would interfere with these measurements, a cooling curve, obtained after the plasma arc was shut off, was extrapolated to the time of arc extinction to yield the product surface temperature. Figure 3 (page 35) shows these temperatures as a function of plasma current. The temperature of borosilicate glass with waste increased from 1,260 K to 1,320 K as the plasma current was increased from 65 A to 120 A. The temperature of sphene glass-ceramic with waste increased from 1,690 K to 1,900 K as the plasma current was increased from 90 A to 125 A. And, the temperature of high silica glass with waste increased from 1,810 K to 1,970 K as the plasma current was increased from 100 A to 125 A. It is most probable that the increased losses observed with increasing currents are due to the increased surface temperatures.

3.3 Behavior of individual elements: The effects of plasma current and feed rates

Figures 4, 5 and 6 (pages 35-36), show the enrichment or depletion of the elements Cs, Na, Nd and U as a function of plasma current for the three waste forms (C = final/initial concentration of an element). Figure 7 (page 36) shows the cesium losses as a function of current for the three waste forms. The variations of C_{Cs} were most important. With borosilicate glass plus waste, C_{Cs} decreased from 0.75 to 0.27 (i.e., the losses increased from 25% to 73%) as plasma current was increased from 65 A to 100 A. A further increase in current to 120 A had no effect. With sphene glass-ceramic plus waste, C_{Cs} decreased from 0.75 to 0.48 as plasma current was increased from 75 A to 125 A. With high silica glass plus waste, the C_{Cs} decreased from 0.55 to 0.40 as plasma current was increased from 100 A to 125 A.

In sphene glass-ceramic, C_{Na} was greater than 1.0 and C_U was about 0.85, while in borosilicate glass, C_{Na} was much less than 1.0 and C_U was about 1.0. These results indicate that the losses of elements were not only a function of temperature but also of waste form composition.

The effect of feed rate on the changes in elemental composition during melting was tested for all three products; C_{Cs} was most strongly affected and increased as the feed rate increased (i.e., losses decreased as the residence time in the melter decreased). The results for high silica glass are shown in Figure 8 (page 36). The results for other products were similar. The cesium losses for all three waste forms are shown as a function of feed rate in Figure 9 (page 36). It is clear that in all cases the losses were reduced as the feed rate increased; the changes were essentially linear. The feed rates used at constant current (and power) were limited to those that would produce a homogeneous melt product.

Changing the initial concentration of waste materials in glass formers also produced a significant effect on the loss of cesium. The results are summarized in Figure 10 (page 37). In borosilicate glass (melted at 100 A at 25 g/min), the loss of Cs increased from 42% to 73% as the initial waste

Continued on page 38

Table 1: The compositions of waste forms.

Composition	Borosilicate (wt%)	High Silica (wt%)	Sphene (wt%)
SiO_2	58.8	79.54	53.02
Al_2O_3	4.1	7.53	8.05
Na_2O	7.9	----	6.33
B_2O_3	18.2	4.69	----
CaO	5.2	----	14.30
ZnO	3.2	----	----
Li_2O	2.6	----	----
P_2O_3	----	8.24	----
TiO_2	----	----	18.30

Table 2: Composition of simulated nuclear waste.

Composition	UO_2	Nd_2O_3	MoO_3	ZrO_2	Fe_2O_3	Cs_2O
(wt%)	6.83	24.72	20.26	10.03	8.34	8.32
Composition	BaO	CeO_2	NiO	CoO	Cr_2O	
(wt%)	8.13	7.82	3.11	1.41	1.02	

Figure 2: The effect of plasma current on overall weight loss.

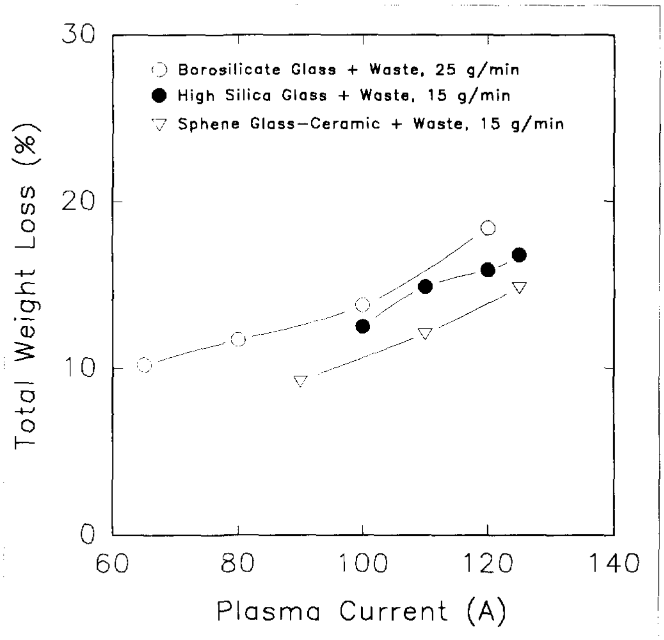


Figure 3: The effect of plasma current on melt surface temperature.

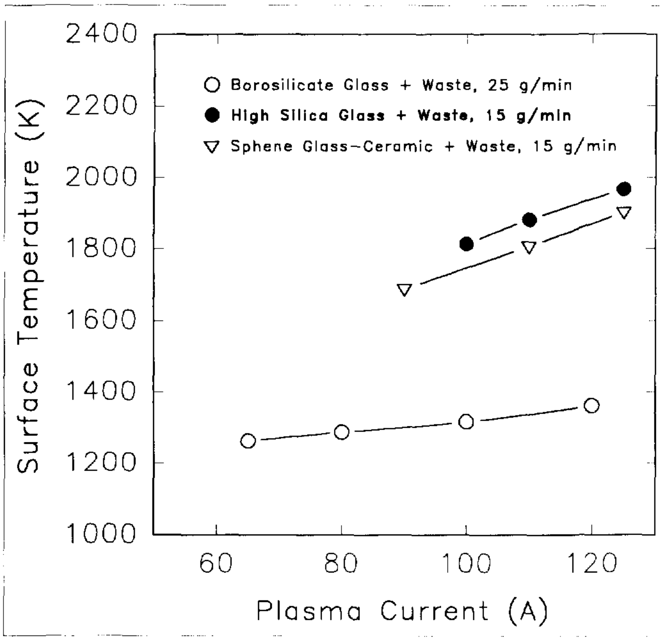


Figure 4: The effect of plasma current on element enrichment or depletion in borosilicate glass at a feed rate of 25 g/min.

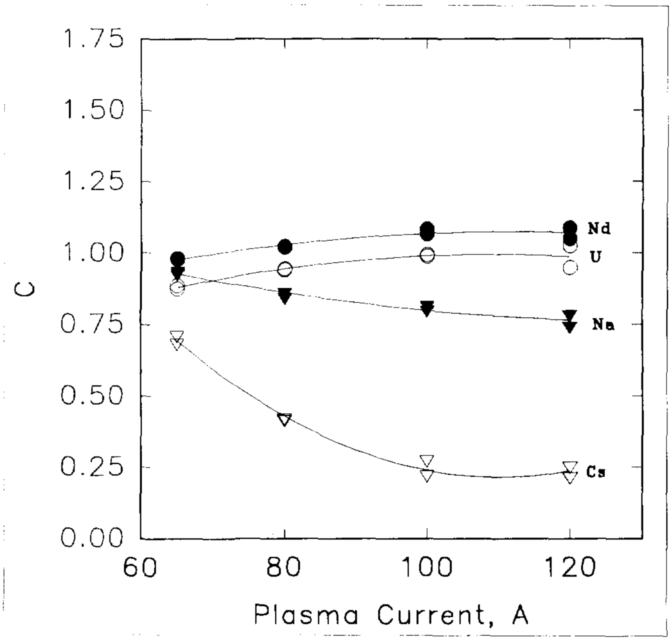


Figure 5: The effect of plasma current on element enrichment or depletion in high silica glass at a feed rate of 15 g/min.

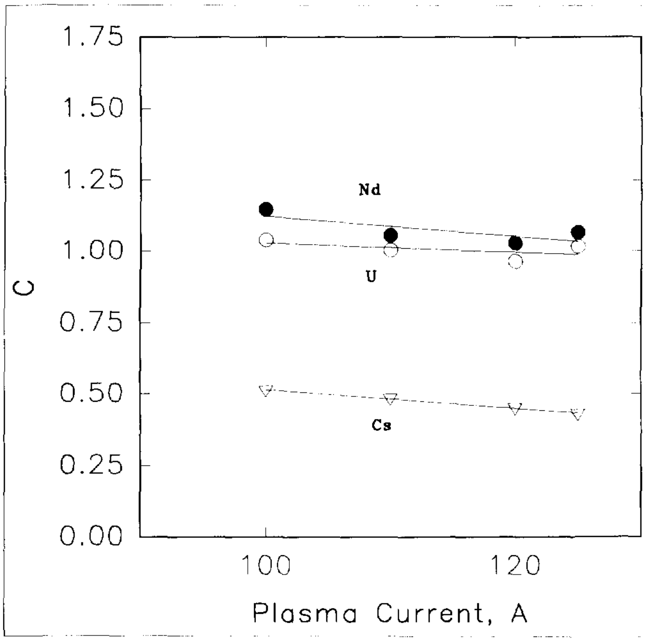


Figure 6: The effect of plasma current on element enrichment or depletion in sphene at a feed rate of 15 g/min.

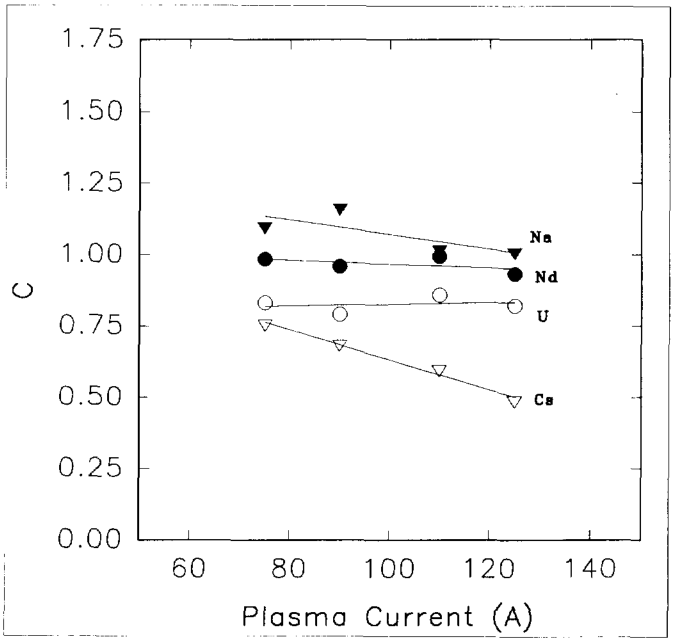


Figure 7: The effect of plasma current on cesium losses for different waste forms.

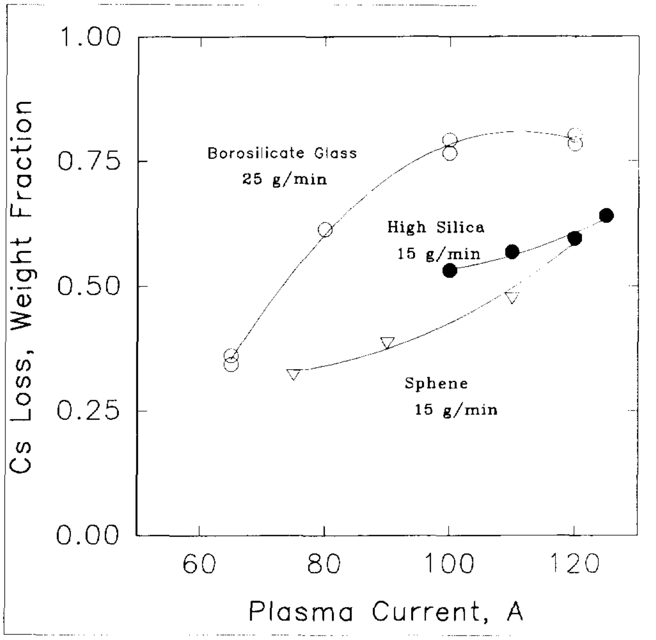


Figure 8: The effect of feed rate on element enrichment or depletion in high silica glass at a current of 110 A.

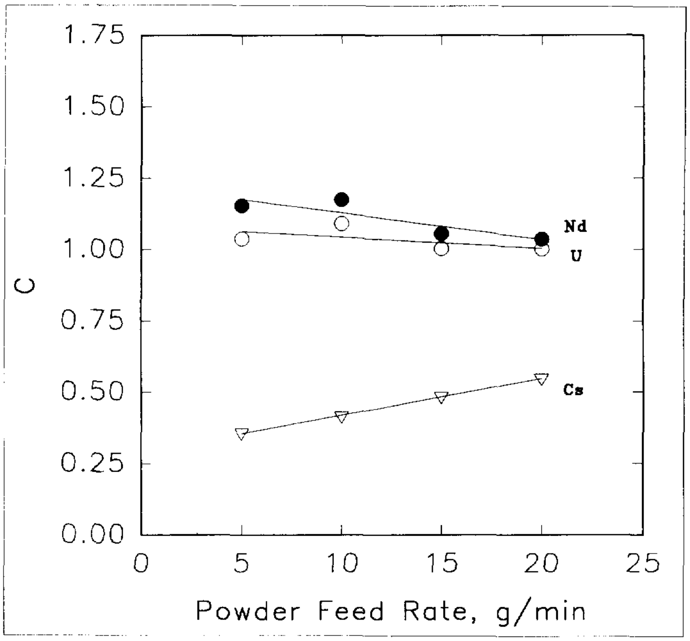


Figure 9: The effect of feed rate on cesium loss in all three waste forms.

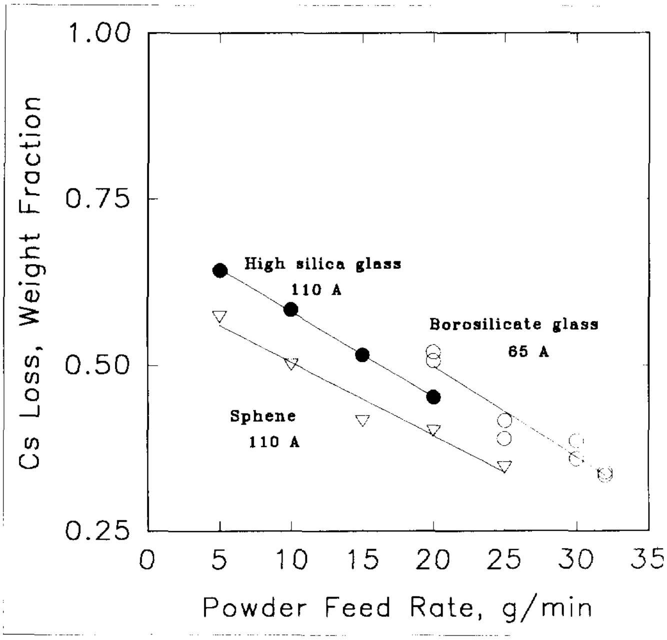


Figure 10: The effect of initial waste concentration on cesium loss in all three waste forms.

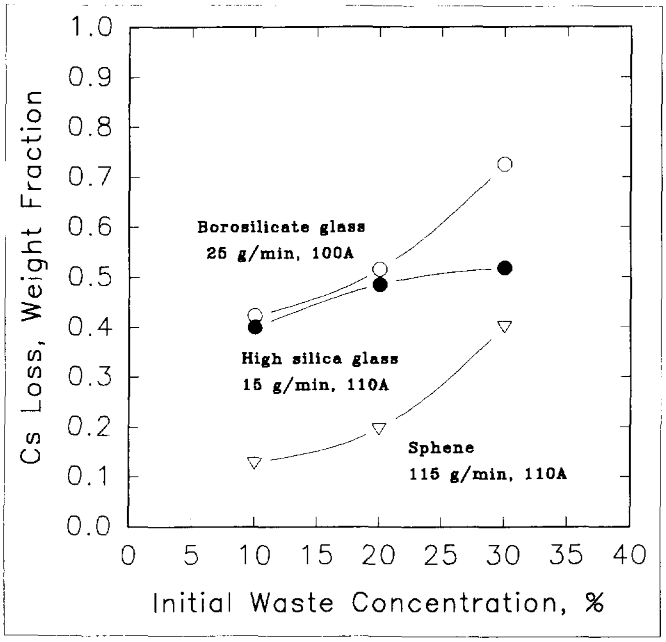


Figure 11: The effect of oxygen addition to the plasma gas on cesium losses in the processing of borosilicate glass waste at a feed rate of 25 g/min and a current of 100 A.

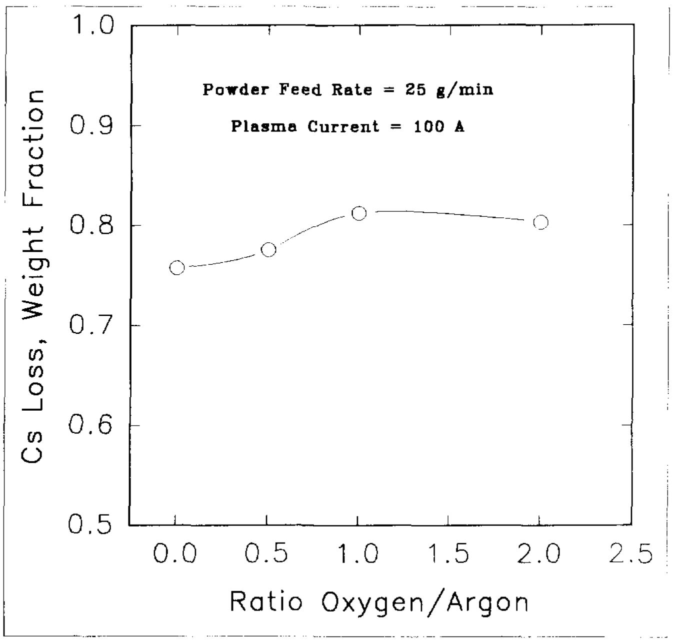
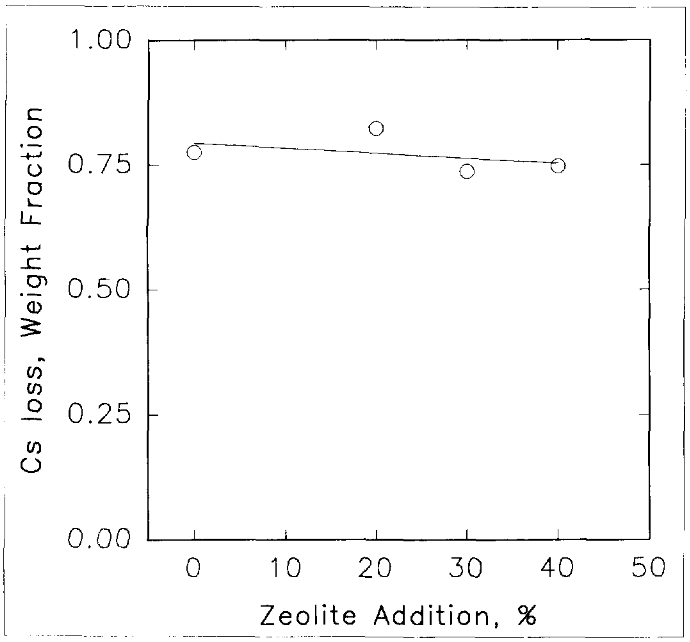


Figure 12: The effect of zeolite addition on cesium losses in the processing of borosilcate glass waste at a feed rate of 25 g/min and a current of 100 A.



concentration increased from 10 wt% to 30 wt%. With high silica glass (110 A and 15 g/min), the losses increased from 40% to 52% for the same interval. For sphene operating under the same conditions as high silica glass, the losses of Cs increased from 13% to 40%. The greatest change was thus with the borosilicate glass. The volatility of Cs is due to the decomposition of Cs_2O, according to the decomposition reaction:

$$Cs_2O = Cs\ (gas) + CsO\ (gas)$$

Thermodynamic computations based on free energy minimization predicted that at 1,500 K, 66.8% of the initial Cs would be in the vapor form.

3.4 The effect of oxygen addition

The addition of O_2 to the system can, in principle, reduce Cs losses; at 1,500 K, the addition of 5 moles of argon and 2 moles of oxygen would reduce Cs losses to only 2.0%. This approach was tested in our system for Ar/O_2 ratios of 0 to 2. The results are shown in Figure 11 (page 37) for borosilicate glass. Surprisingly, the addition of oxygen had no positive effect on Cs losses. This was primarily because the addition of oxygen into the plasma gas led to increased voltages and plasma powers at the same current (e.g., as the ratio of argon to oxygen increased from 0 to 2.0, the arc voltage went from 56 V to 82 V). This increased the melt temperature and negated any advantage the higher oxygen potential may have given.

3.5 The effect of zeolite addition

Osaki and Yokoi[4], in their study of the plasma melting of various types of nuclear waste samples, reported that the addition of zeolite to metallic waste can reduce loss of Cs from 100% to 5%. The reasons cited for this beneficial behavior were the acidity and high viscosity of molten zeolite. Some experiments were carried out in which mixtures of simulated waste, borosilicate glass and zeolite [$86(Na_2O)\ 86(Al_2O_3)\ 106(SiO_2)$] were melted at 100 A and 25 g/min. The initial zeolite concentration was varied from 0% to 40% and the ratio of borosilicate glass to waste was kept at 7:3. The results are shown in Figure 12 (page 37); there is considerable scatter and only a very slight positive effect is noted from the addition of zeolite. The C_{Cs} with 40% zeolite was 0.31, which was marginally higher than without zeolite (0.27).

4. Conclusions

A 40-kw transferred arc system with continuous feeding and product removal (casting) was operated to test the potential of this type of system for the vitrification of medium- and high-level nuclear waste. Mixtures of borosilicate glass, high silica glass and sphene glass-ceramic with simulated nuclear waste were successfully melted using an argon plasma. Overall weight losses, as well as the losses of elements Na, Cs, U and Nd, were measured as a function of operating conditions. The loss of Cs during melting was of major concern; this was minimized by decreasing the plasma power, increasing the feed rate and using indirect rather than direct heating of the product. The elements U and Nd were usually concentrated in the product during melting or behaved neutrally. The addition of oxygen to the plasma did not reduce the Cs loss because this increased the plasma power at constant current. The addition of zeolite to the glass former was only slightly beneficial in reducing cesium losses. Although the loss of cesium in the work reported here was high, a patented device can be used in conjunction with the plasma melter used here to recycle the volatile materials and thus reduce the overall losses.

Acknowledgments

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R.J. Munz is professor and chair of the department of chemical engineering, McGill University and associate director of the Plasma Technology Research Centre Université de Sherbrook–McGill University. He holds degrees in chemical engineering and has been active in thermal plasma research since 1970.

G.Q. Chen completed his doctoral studies in vitrification of nuclear waste using plasma technology.

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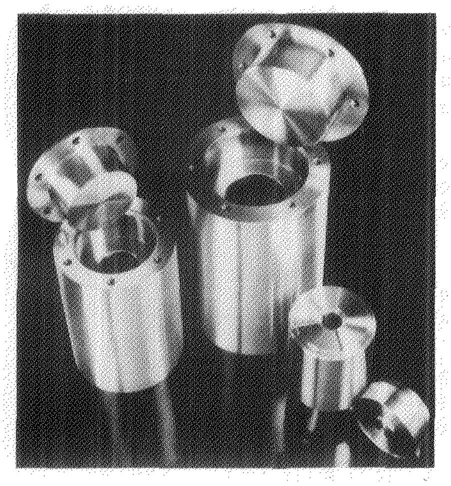

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