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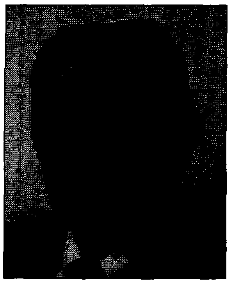

INMM has grown in a systematic and ordered manner due to the excellent guidance of former officers and Executive Committee members. We have had successful long-range planning committees and other committees that have helped us establish the organization as it is today.

In addition to their usual areas of interest, we have asked each of the six INMM Technical Divisions—International Safeguards, Materials Control and Accountability, Nonproliferation and Arms Control, Packaging and Transportation, Physical Protection, and Waste Management—to determine how it can contribute to the national problem of combating terrorism. Most of the divisions will address this important issue at their Sunday afternoon division meetings at the 43rd INMM Annual Meeting in Orlando, Florida, in June—some may also have papers on this topic during the regular sessions.

During our meeting in November 2001, the INMM Executive Committee agreed that it was time to update our planning process, create a strategic plan, and determine the future course for the Institute. We would like to create a vision of what the organization should look like in five years, ten years, and beyond. Should we continue as we are or are there important changes we should make?

During the March 2002 Executive Committee meeting, we devoted a day to discussing ideas for a strategic plan. We believe that plans are more meaningful and will receive more member support if the entire membership is given the opportunity for input. I recognize that many of you cannot attend the Executive Committee meetings, but I want to emphasize that all INMM members are welcome to attend. The Executive Committee meets three times a year—usually on the day before the opening of the annual meeting, in November, and in March. The November meeting usually focuses on the budget for the upcoming year; the March meeting is held in conjunction with the Technical Program Committee meeting.

In order to allow all of you to have input into the strategic planning process, you can contact any of the officers or headquarters staff with your thoughts and suggestions—their names and contact information is available on the INMM Web site at http://www.inmm.org. Also, we plan to have a time during the annual meeting when we will brief you on the status of the preliminary planning and ask for your input. This meeting is planned for the evening of Wednesday, June 26. The time and location will be noted in the meeting program.

Please give this some thought. We are looking for both short- and long-term suggestions about every aspect of INMM. Think about how the annual meeting, the division workshops, the *Journal,* chapters, divisions, standing committees, or headquarters staff could serve you better and help move the field of nuclear materials management forward.

As I have mentioned before we are concerned that we are not attracting more young people into INMM and are developing plans to help correct this problem. We also want to examine the ways we generate our operating funds (dues increases, more workshops, outside sponsorships, annual meeting registration fees).

We are not looking for change for change's sake; we are trying to determine if changes could make the organization better and to have as much consensus of the entire membership as possible.

Annual Meeting News

Planning for our 43rd INMM Annual Meeting, which is being held this year at the Renaissance Orlando Resort, Orlando, Florida, June 23-27, is also moving along very well. More than 300 technical papers have been submitted and these papers, coupled with our strong opening and closing plenary sessions, should make this annual meeting even bigger and better than past annual meetings.

I encourage you to make plans now to attend. Our annual golf tournament and division meetings are held Sunday, June 23. See Technical Program Chair Charles Pietri's article on page 69 for more information.

I encourage you to communicate with INMM headquarters, your division, chapter, and committee chairs, with any of the INMM officers and executive committee members, and with each other to share information and on all matters that will make our organization and profession better.

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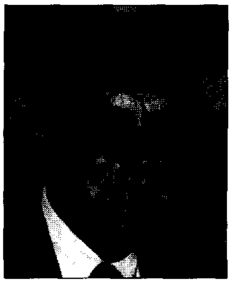
A Focus on Meetings



This issue of the *Journal* provides a variety of interesting articles and many of those are among the best presented at two important nuclear materials management events held in the last few months. The technical papers section of the *JNMM* begins with four award-winning papers from the Thirteenth International Symposium of the Packaging and Transportation of Radioactive Materials (PATRAM 2001) held in early September 2001 (see PATRAM Symposium Highlights on page 6).

After that, we have two papers that were presented at the INMM Spent Fuel Management Seminar XIX, held in January 2002, Waste Package and Material Testing for the Proposed Yucca Mountain High-Level Waste Repository by T. W. Doering and V. Pasupathi of Bechtel SAIC Co. LLC.

Those papers are followed by Proliferation Resistance: New Visibility and Myths by Bill Stanbro and Chad Olinger, both of Los Alamos National Laboratory. In addition, we are quite pleased to provide to you Senator Pete Domenici's November 19, 2001, presentation to the George Bush Presidential Conference Center at Texas A&M University, titled The Need for Nuclear Energy—Four Years After the Harvard Speech America's Energy Challenge—the Nuclear Answer. (Recall that we published Senator Domenici's Harvard speech in the spring 1998 issue of the *JNMM*).

The last article is one by Matt Bunn (Harvard University) and his father George Bunn (Stanford University) titled, Strengthening Nuclear Security Against Post-September 11 Threats of Theft and Sabotage. I heard a version of this paper at the IAEA's Symposium on International Safeguards: Verification and Nuclear Material Security, held in Vienna October 29-November 2, 2001. I believe these papers represent a broad range of interest that represents the typical INMM member.

In the spirit of strategic planning (see page 2), I believe it is responsible planning to consider the future of the *Journal*, and how it can be structured to best serve you, our members. This is not an easy task without input from our readers. Even with such input, it will not be easy. I need your thoughts and ideas.

Over the years we have attempted to bring to you the happenings of the Institute by including technical division and chapter reports, by including New Member listings, Member News, and just recently by including a wrap-up of the Executive Committee meetings. Also recently, we initiated Meet the Member—which profiles INMM members. These changes lead us to ask: Should we continue to include these types of articles, or should we focus only on technical and policy articles?

We also have instituted a peer review process that is functioning with what I consider to be good success under the leadership of Steve Dupree, the assistant technical editor. We have so far chosen not to identify those papers that have or have not been peer reviewed. Should we? I have discussed these types of *JNMM* issues with various members of the Institute, receiving mixed opinions. It doesn't take long to generate e-mail and send it off to me. I would appreciate your thoughts. Also, in his message, President J. D. Williams notes that he will have a strategic planning meeting for all members at the Annual Meeting on Wednesday, June 26. I plan to be there, and I hope to continue to receive input on the *Journal* at that time. But in the meantime, send the e-mails.

In closing, we would like to express our sincere sympathies to INMM Secretary Vince DeVito, who lost his wife Jeanne in early March. Jeanne was a strong supporter of Vince's involvement in the INMM and she was certainly one of the "first ladies" of the Institute. She will be missed.

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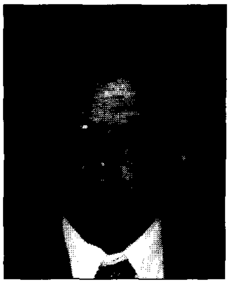
March EC Meeting Highlights



President J.D. Williams conducted the second INMM Executive Committee (EC) meeting in FY02 March 6–7 in Reno, Nevada. Treasurer Vince DeVito was unable to attend due to the death of his wife Jeanne on March 6. Our condolences go out to Vince and his family. The first day's meeting was a regular business meeting and the second day was devoted to strategic planning. The highlights follow. (Note: these are not the official INMM Executive Committee meeting minutes prepared by Executive Director Rachel Airth and approved at the EC.)

Standards Committees. INMM is responsible for two American National Standards Institute (ANSI) standards committees: Packaging and Transportation of Radioactive and Non-Nuclear Hazardous Materials (N-14), and Methods of Nuclear Material Control (N-15). N-15 Chair Joe Rivers, has decided to step down and a search is underway for his successor. If you are interested in volunteering as N-15 chair, either of the two division chair positions mentioned below, or other INMM positions, contact an EC member as soon as possible.

Waste Management Division. Chair Ed Johnson reported on the very successful Spent Fuel Management Seminar held January 9–11 in Washington, D.C. This event included 130 participants from eight countries, thirty speakers, five panelists, and seven sessions. And it was financially successful. Two of the papers are published in this issue of the *Journal of Nuclear Materials Management.*

Physical Protection Division. Chair Steve Ortiz reported on some difficulties in arranging topical workshops. Plans were in progress to have two workshops on vulnerability assessment but they have been cancelled due to political sensitivities post-September 11. If you have ideas and/or needs for other workshops contact Ortiz at sortiz@sandia.gov.

Packaging and Transportation Division. Chair Billy Cole's report noted that four papers from PATRAM 2001 are published in this issue of *JNMM.* Cole also has resigned after several years of service, so a search for his replacement is underway.

Nonproliferation and Arms Control Division. Chair Steve Mladineo has organized this technical division into three standing committees: Proliferation Assessment and Analysis (Paul Rexroth), Former Soviet Union Nonproliferation and Arms Control (John Smoot), and Global and Regional Nonproliferation and Arms Control (Fred Luetters). They are planning activities for the Annual Meeting and beyond.

Materials Control and Accountability Division. Chair Dennis Brandt has been working to organize workshops with the U.S. Department of Energy on MC&A objectives and insider vulnerability analyses. However these will not be held due to their sensitivities within the DOE safeguards communities. Brandt also announced his intention to step down after several years of service.

International Safeguards Division. Chair Jim Larrimore reported on plans for an ISD meeting on May 27 in Luxembourg before the ESARDA Annual Meeting. Jim and the ISD are planning another superb *JNMM* issue in summer 2002 with a dozen articles on the topical area of International Verification Beyond the NPT.

Division Meetings. All six technical divisions will hold meetings Sunday, June 23, at the INMM Annual Meeting. All meeting attendees are invited and urged to attend, participate, and volunteer.

Annual Meeting Committee. Technical Program Committee Chair Charles Pietri reported on the previous day's meeting to plan the technical sessions for the Annual Meeting. It's shaping up as another outstanding event: more than 300 papers in forty-three sessions evenly distributed from Monday morning after the Opening Plenary Session through Thursday morning prior to the Closing Plenary Session, with the Poster Session on Tuesday.

Communications Committee. Chair Jim Griggs announced major plans to further upgrade the INMM Web site. You may recall that the previous major upgrade occurred last year at the time of the Annual Meeting. The new features will include:

- Member's Only Area with online member directory
- Online Credit Card Transaction Processing (Annual Meeting registration, membership)
- Student Area (information brochure, student résumés, job openings)
- Employment Area (job openings, confidential member resumes)
- Online *JNMM* Article Submission
- Public Information Area (FAQs, Ask the Experts)

These functions should all be available by the end of 2002.

Government-Industry Liaison Committee. Chair Jim Lemley reported that committee members are busy planning the Annual Meeting Closing Plenary. Tentative topics are NRC nuclear facility security, IAEA physical protection activities, and New York City's September 11 response.

Membership Committee. Chair Scott Vance reported that membership renewals are running slightly ahead of last year. He noted that inexplicably only a minority of members indicated division interest areas. The 2002 Membership Directory should be mailed in early April. If anyone would like extra copies of the information brochure to use in recruiting new members, please contact INMM Headquarters at 847/480-9573.

Memorial Fund Outreach Committee. Chair Jim Tape is in the process of redefining the charter and activities of this committee. Member input is welcome.

Regional Chapter Reports. Five of twelve chapters provided reports: Northeast, Northwest, Southeast, Southwest, and Vienna. The four U.S. chapters all reported new activities to attract students.

Old Business

Operations Manual. Past President Debbie Dickman provided copies of the new draft INMM Operations Manual to the EC. This is the reference manual for all volunteer and headquarters staff positions and includes a description of duties and responsibilities for each job. Thanks to Debbie for her major effort.

Student Paper Initiative. The EC began this initiative with the regional chapters in November with a goal of sponsoring a student paper session at the Annual Meeting. Due to a late start this will not happen in 2002. Only the Southwest Chapter was ready to commit for this year, but the EC plans to continue to pursue this and expects considerably more participation in 2003.

New Business

Chair Appointments. The EC discussed possible candidates for the three vacancies noted above. No final selections were made. Candidates will be contacted and asked to provide their résumés and proposals on how they would conduct business as the chair.

Web Site Links. The EC discussed providing links from the INMM Web site to other nuclear-related Web sites. There was a recognized need to establish a policy and selection criteria to achieve this in and equitable and consistent manner.

N-14 Proposal. The N-14 standards committee submitted a proposal to use the INMM Web site as a tool for the authors and reviewers of its subcommittee standards. This will be evaluated by the Communications Committee with regard to cost and impact.

Hotel Tour. After the regular business meeting interested members of the EC were given a tour of the Reno Hilton hotel facilities by marketing staff. This property has 2,000 sleeping rooms and an abundance of meeting space. Reno and the Hilton are potential candidates for an INMM Annual Meeting in an out year (2007). If you have an opinion on Reno and this hotel for an annual meeting, please convey this to an EC member.

Strategic Planning. On March 7, the INMM Officers, Executive Committee, division chairs, committee chairs, and technical program committee members met in an all-day session to begin strategic planning. INMM President J.D. Williams introduced the planning process we will use and then led a series of open, fully engaged, thought-provoking discussions. We addressed what we would like INMM to become, things that we would like to change, and some things to do to achieve these goals and objectives. By the end of this first planning day we had identified four major planning focus areas and small groups to develop draft action plans for the November EC strategic planning meeting review and approval. These areas are:

- Awareness and communication
- Institute funding
- Students and new members
- Leadership development

The EC wants to provide an opportunity for all segments of our membership to provide input to this important INMM strategic planning process. To achieve this end, we will hold an open meeting Wednesday evening during the Annual Meeting—see the Final Program for time and location. This will consist of a brief summary of our March planning activities and we will devote the majority of time to receiving member input.

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PATRAM Symposium Highlights

■

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■

In this issue of the *Journal*, we are highlighting award-winning papers from the Thirteenth International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2001). The INMM was honored to host the 680 participants of PATRAM 2001, September 4-9, 2001, in Chicago, which was sponsored by the US Department of Energy and the International Atomic Energy Agency.

Koji Shirai's paper, "Demonstrative Rupture Test and Safety Evaluation of a Natural UF_6 Transport Cylinder at High Temperature," received the PATRAM Chairman's Award for Excellence. Shirley O'Rourke's paper, "Managing Transportation Quality," Thomas Quercetti's paper, "Analytical, Numerical and Experimental Investigations on the Impact Behavior of Packages for the Transport of Radioactive Material Under Slap Down Conditions," and Mike Krzaniak's paper, "The Effects of Type C Packaging on the Shipment of High Activity Co-60 Sources," all received the AOKI Award for Distinguished Oral Presentation. These four papers are reprinted here from the PATRAM 2001 Proceedings.

In Shirai's paper, he discusses the results of tests done to determine the effects of high temperature on UF_6 casks. In accordance with the revision of the IAEA regulation in 1996, the fire test became a requirement for the natural UF_6 transport container. When the UF_6 transport container is involved in a fire, packaged UF_6 can easily be transformed from solid phase to liquid or gas phase at a comparatively low temperature, and can cause an inner pressure increase. As the structural strength of the cylinder material (ASTM SA516 carbon steel) decreases with increasing temperature, it is very important to evaluate the thermal-mechanical behavior of UF_6 cylinder under realistic fire conditions.

Shirley O'Rourke's paper discusses the implementation of quality assurance programs during and after the design and testing of a transportation package. Although 10CFR Part 71 establishes quality-assurance requirements for the design and use of Type B packages, quality requirements do not end with Type B. The nuclear safety management rule, 10CFR830; DOE Order 414, and good business practices all reflect the need for managing the quality of all packaging and transportation processes.

Thomas Quercetti's paper discusses the hypothetical design tests in the IAEA regulations for the safe transport of radioactive materials, including drop tests onto an unyielding target to evaluate the packaging response to mechanical tests demonstrating the safety under accident conditions. The orientation of the packaging, i.e. point and angle of impact in the drop test must be chosen in a manner that maximum damage occurs with regard to the safety criteria. The safety criteria are the leak tightness of the lid closure system, the integrity of the container body, and the undercriticality of the containment. For most packagings the worst case is not a single event, represented by one drop test. Rather, most packaging drop tests consist of a series of tests at various orientations, including horizontal, vertical, corner, and oblique drops.

In Mike Krzaniak's paper, he explores the evolution of the Type C regulations, from the restriction of plutonium shipments by air to the expansion of all radioactive materials. It evaluates the effect of these regulations on the shipment of high activity Co-60 sources, used primarily for medical sterilization. It also describes the practical problems in designing heavy transport packages to Type C requirements, routing, and transport considerations. The additional possibility of shipping greater quantities requires low-dispersible material in Type B packages by air is considered. Finally, accident consequences are explored and cost benefit analyses are presented comparing the relative safety of Type A, Type B, and Type C shipments of Co-60 by air.

The complete proceedings for PATRAM 2001 are available from INMM Headquarters at inmm@inmm.org or from http://www.patram.org.

Demonstrative Rupture Test and Safety Evaluation of a Natural UF_6 Transport Cylinder at High Temperature

■

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■

Abstract

If a natural uranium hexafluoride (UF_6) transport container is involved in a fire test condition as described in the new requirements from the International Atomic Energy Agency (IAEA), packaged UF_6 can easily be transformed from solid phase to liquid or gas phase at a comparatively low temperature, and can cause an inner pressure increase. Therefore, it is very important to evaluate the thermal-mechanical characteristics of UF_6 transport containers under realistic fire conditions. Rupture tests with the 48Y-cylinders were performed in the joint research works (PEECHEURE Program) between Central Research Institute of Electric Power Industry (CRIEPI, Japan) and Nuclear Protection and Safety Institute (IPSN, France).[1] This type of cylinder seems to be deformed and ruptured near the stiffener ring due to creep deformation.

A series of material tests on small-scale specimens of the container material were performed to propose creep deformation formula and a rupture criterion. To assess the rupture possibility of the container, this proposed nonlinear creep material model was applied to the ABAQUS code and the numerical analysis was performed and compared with the rupture test results. Finally, according to the thermal-mechanical analysis for 48Y-clinders with the Japanese heat protection system, it can be concluded that this natural UF_6 transport system has enough safety margin for the new IAEA fire test requirement.

Introduction

UF_6, the raw material from which the fuel for nuclear power stations is obtained, is stored and transported in solid state in industrial containers called 48Y-cylinder. In 1996, IAEA revised the transport regulations for natural UF_6 transportation taking into account chemical and radiological hazards. A new fire test requirement (engulfing fuel fire of 800°C for half an hour, for a steel emissivity of 0.8 and flame emissivity of 0.9) was imposed on this type of container. When the UF_6 transport container is involved in a fire, packaged UF_6 can easily be transformed from solid phase to liquid or gas phase at a comparatively low temperature, and can cause an inner pressure increase. The structural strength of the cylinder material (ASTM SA516 carbon steel for moderate- and low-temperature service) also decreases with increasing temperature.[2] Therefore, it is very important to evaluate the thermal-mechanical behavior of UF_6 cylinders under realistic fire conditions, especially the possibility of rupture of the cylinder.

Thermal-Hydraulic Analysis for IAEA Regulation

The UF_6 is a colorless solid at ambient temperature. The specific characteristics of the thermal behavior of UF_6 are its low temperature triple point (0.15 MPa, 64°C), phase change and volume expansion. If the fire test is imposed on the 48Y-cylinder, a very complicated heat transfer including boiling phenomena as shown in Figure 1 takes place. Commissariat A l'Energie Atomique (CEA) carried out several thermal-hydraulic numerical analyses and interpretations of physical phenomena of the 48Y-cylinder under the new fire test condition from the IAEA regulation revised in 1996 with the DIBONA-2D computer code.[3] This code was developed according to the acknowledgements obtained in the experimental joint research works (TENERIFE Program) performed by CRIEPI and IPSN from 1991 to 1996,[4] and can consider the specific physical phenomena as shown in Figure 1, such as expansion due to the density difference between solid and liquid UF_6, heat transfer during boiling, condensation of the vapor bubbles, equation of state of UF_6, and melting and sinking of solid. Figure 2 shows an example of the numerical results. It seems that a very complicated heat transfer including boiling phenomena will take place and lead to a rapid increase in pressure in the last ten minutes of the fire test.

Demonstrative Rupture Test with Full-Scale 48Y-Cylinder

According to the thermal-hydraulic numerical analysis results with the DIBONA-2D computer code under the fire test condition described in the IAEA regulation, it seems that a very complicated heat transfer including boiling phenomena will take place and lead to a rapid increase in pressure in the last ten minutes of the fire test. The ASME SA516 carbon steel for moderate and lower temperature service is now used as the structural material for natural UF_6 container. The structural strength of the container material decreases with increasing temperature. Therefore, it is very important to assess the safety of natural UF_6 transport container under realistic fire conditions, especially rupture possibility of the container due to the rapid increase in pressure.

PEECHEUR Program

In PEEHCEUR Program, three rupture tests of the full-scale 48Y-cylinders of different grades were performed to evaluate the mechanical characteristics under high pressure and at high temperature. Table1 and Figure 3 show the rupture test parameters and conditions. In each test, test containers were heated after being previously equipped and insulated, and pressurized with nitrogen until rupture took place. For test A and B, to simulate the extended regulatory fire test of the IAEA, a temperature distribution and a rate of pressure rise with respect to time were controlled in the same range as the calculated results by DIBONA code. In these tests, the test containers were filled to 80 percent volume with dry sand. For test C, to confirm the rupture characteristics at a lower speed with no thermal gradient, the empty container was uniformly heated and the internal pressure was gradually increased.

Rupture Test Results

Figure 4 shows the schematic of the test containers after the tests. According to these test results, this type of cylinder seems to be deformed and ruptured near the stiffener ring due to creep deformation. In test A, rupture occurred at a pressure of 52 bar. Large deformations had taken place on the upper shell and the stiffener had ruptured at the butt-weld, causing the shell to tear in a longitudinal direction. The width of the opening was 4cm at the base of the stiffener and 7 cm at its end, the length of the tear being approximately 20 cm.

Material Test

As ASME SA516 steel is not generally used for high-temperature work, material characteristics had not been available above 500°C. Tensile tests and creep tests with this material were executed under high temperature and at high-stress conditions, and the creep deformation formula and creep rupture criteria were proposed.

High Temperature Tensile Test

Tensile tests from room temperature up to 900°C were conducted using several base metal and seam-welded joints of SA516.[2] The strain rate of the test was $5\text{x}10^{-3}\text{min}^{-1}$ and over 0.2 percent proof stress was $6\text{x}10^{-2}\ \text{min}^{-1}$. Figure 5 shows an example of the test results. The tensile strength values and 0.2 percent proof stress decrease with increasing temperature. On the other hand, the values of the reduction area and elongation increase with increasing temperature. The position of rupture of seam-welded joints was the base metal at temperatures from room temperature up to 800°C, but at 900°C, the rupture position was the weld metal.

Creep Deformation Properties

Short-time uni-axial creep tests and interior pressure creep tests using cylindrical test pieces were conducted at 600-900°C and at various stress levels at each temperature (stress range:8-45 MPa) by using SA516 Gr.65 base metal, and the creep constitutive equation had been proposed especially paying attention to the high temperature service region beyond 700°C.[2] To extrapolate the creep deformation in lower temperature service region with high stress condition, additional creep tests were conducted at 550-700°C and at various stress levels at each temperature (stress range:15-60 MPa) and modified creep deformation formula are proposed as follows.

$$\varepsilon_C = \varepsilon_T + \dot{\varepsilon}_S\, t \qquad (1)$$

$$\varepsilon_T = \varepsilon^S_T \left[\, 1\text{-}exp\left\{-1.723(\dot{\varepsilon}_S\, t)^{0.528}\right\}\right] \qquad (2)$$

$$\varepsilon^S_T = exp(0.0592\bar{\sigma})\,exp\left(-\frac{5060}{T+273}+1.21\right) \qquad (3)$$

$$\dot{\varepsilon}_S = 7.262\text{x}10^{12}\,exp(0.339\bar{\sigma})\,exp\left(-\frac{2.063\text{x}10^{2}\bar{\sigma}+3.321\text{x}10^{4}}{T+273}\right),\quad T < 723^{\circ}C$$

$$(4)$$

$$\dot{\varepsilon}_S = 5.124\text{x}10^{9}\,exp(-0.641\bar{\sigma})\,exp\left(-\frac{2.266\text{x}10^{2}\bar{\sigma}-2.668\text{x}10^{4}}{T+273}\right),\quad 723^{\circ}C < T < 845^{\circ}C$$

Table 1. Rupture Test Parameters

Test	Material	Contents	Temperature	$P_{rupture}$	Ruptured position
A	Gr. 60	Dry sand	Lower surface: 200°C	52bar	Stiffener root at butt-weld
B*	Gr. 70		Upper surface: 620°C max.	53bar	Stiffener root at clearance hole
C	Gr. 70	Empty	Constant temperature at 620°C	40bar	Stiffener root at butt-weld

*Butt-welds of the stiffeners were inspected by radiation technique and repaired.

where, ε_c:creep strain (%), ε_T:transition creep strain (%), ε^S_T:saturated transition creep strain (percent), $\dot{\varepsilon}_S$:minimum creep strain rate (%/hour), t:time(hour), $\bar{\sigma}$:Mises stress (MPa), T:test temperature (°C)

Figure 6 shows the modified relationship between the test temperature and calculated minimum creep strain rate with the experimental values.

Creep Rupture Criteria

Interior pressure creep rupture tests using cylindrical test pieces were also conducted at 600-800 °C and at various stress levels at each temperature (Mises stress range: 30-140 MPa) using SA5 16 Gr.65 base metal, and the life-time formula had been also proposed especially paying attention to the high temperature service region beyond 700°C.[2] To estimate the lifetime adequately in lower temperature service region with high stress condition, additional creep rupture tests were conducted at 550-700 °C and at various stress levels (stress range:40-140MPa) and modified life-time formulae is proposed based on the Goldhoff-Sherby parameter method as follows:

$$log\ t_r = \left(\frac{1}{T+273} - 0.00139\right) . \left(\frac{\bar{\sigma}+63.26}{0.00651}\right) + 6.507 \quad (5)$$

where, t_r: rupture time (h).

Figure 7 shows the modified relationship between the Mises stress and rupture time. To evaluate the possibility of rupture of the 48Y-cylinder, according to the modified life-time formula represented by Equation 5, the rupture time was estimated by Robinson's law method. In this method, the rupture is assumed to occur when the sum of the creep damage factor exceeds the threshold value f_s as follows:

$$D_C = f_S . \Sigma\ (t_i / t_{ri}) \quad (6)$$

where, D_c: creep damage factor, t_i: time at certain constant condition, t_{ri}: rupture time calculated by equation (5), f_s:safety factor

To determine the safety factor of creep damage fs, creep rupture tests under varying stress conditions as shown in Table 2. As the minimum value of D_c was 0.28, the safety factor of creep damage f_s was set to 0.25 for the conservative estimation of rupture time.

Thermal-Mechanical Behavior of UF_6 Cylinder

Verification Analysis for Rupture Test

The modified nonlinear creep material model described above was applied to the ABAQUS computer code, and the three-dimensional numerical analysis was executed for the rupture tests performed by the PECHEEUR Program to verify this material model. Figure 8 shows the analysis results for rupture test A. It was found that considerable creep deformations are generated and the creep damage factor exceeds the proposed threshold value under the inner pressure between 4 and 5 MPa. As this finding is in good agreement with the bursting conditions obtained by the rupture test, it seems that the evaluation method proposed in this study will be sufficiently applicable to the safety analysis of transport of 48Y-cylinder subjected to high temperature and high pressure.

Mechanical Characteristics of the 48Y-Cylinder for IAEA Fire Test Requirement

The mechanical integrity of the natural UF_6 transport container under the IAEA fire test condition was assessed by the proposed analysis method. The thermal loading for IAEA requirement consists of transient temperature distribution and inner pressure applied on the inner surface of the shell, which follows values obtained in calculations of the DIBONA-2D code as shown in Figure 2. The additional heat

Table 2. Determination of Safety Factor F_s for Creep Damage Factor

Case	Temp.	Applied step-stress	Step time	Specimen	D_c
1	700°C	from 40 to 50 MPa	1.5 hr.	Base metal	0.38
2		from 50 to 60 MPa	0.40 hr.		0.28
3	600°C	from 115 to 130 MPa	0.70 hr.		2.40
4		from 125 to 140 MPa	.027 hr.		1.74
5	700°C	from 40 to 50 MPa	1.50 hr.	Welded	0.79
6		from 50 to 60 MPa	0.40 hr.		0.72
7	600°C	from 115 to 130 MPa	0.70 hr.		3.28
8		from 125 to 140 MPa	0.27 hr.		4.99

input from the stiffening ring of the cylinder was not taken into account.

Initial conditions are as follows.

- Initial Temperature: 38 degrees
- Initial Pressure: 0.044MPa for saturated pressure of UF_6 solid at 38 degrees
- Atmospheric Pressure: 0.1MPa
- UF_6 Dead Load: Modeled by hydraulic pressure on the inner surface
- Cylinder Dead Load: Mass density is set to 7.85g/cm^3

Figure 9 shows the deformation around twenty-seven minutes thermal loading. As the considerable temperature difference in the circumferential direction exists near UF_6 surface level, highly stressed region (Mises stress exceeds 180Mpa) is occurred and the maximum equivalent creep strain is reached to 40 percent. It is found that creep damage factor also exceeded 0.25. As a result, due to the considerable creep deformations, rupture possibility of the natural UF_6 transport container in the IAEA fire test condition will be possibly high without thermal insulation system.

Safety Analysis of Insulated 48Y-Cyliner Under IAEA Conditions

In Japan, 48Y-cylinders are transported with the heat protect system considering the hypothetical fire conditions as shown in Figure 10. To evaluate the safety of insulated transport container for natural UF_6 with the Japanese heat-protective covers, the thermal-mechanical analysis was performed with ABAQUS code considering the fire test condition specified by the IAEA regulation in 1996.

Figure 11 shows the time histories of the steel, valve and internal pressure. Maximum temperature of the container and the internal pressure are 584°C and 0.4MPa, respectively. Moreover, as maximum temperature of the filling valve is below 200°C, the leakage of UF_6 can be avoidable. Figure 12 shows the distribution of the equivalent creep strain at the thirty minutes thermal loading. Only 0.02 percent creep strain is occurred. Finally it can be concluded that the natural UF_6 transport container with the Japanese heat cover system has enough safety margin for the IAEA fire test requirement.

Summary

IAEA, in accordance with the revision of the regulation in 1996, established regulations for UF_6 transportation taking into account chemical hazards. The fire test (800°C for thirty minutes) became a requirement for the natural UF_6 transport container. CRIEPI and IPSN had already terminated the first joint research work (TENERIFE Program) to make clear the thermal-physical behavior of UF_6 in a transport container under fire condition and confirmed the occurrence of the rapid increase in interior pressure. On the other hand, ASTM SA516 carbon steel for moderate—and low-temperature service is now used as the structural material for this type of cylinder. As the structural strength of the cylinder material decreases and creep effect does not also become negligible with increasing temperature, it is very important to evaluate the thermal-mechanical behavior of UF_6 cylinder under fire condition, especially the possibility of rupture of the cylinder. Therefore, CRIEPI and IPSN performed the rupture test with the large-scale container in the second joint research work (PEECHEUR Program) to clarify the mechanical characteristics of the container under high pressure at high temperature. Moreover, according to the various material tests with ASTM SA516 carbon steel at high temperature performed by CRIEPI, the formulation of the material model considering the creep effect and rupture criteria were proposed, and this constitutive model was applied to ABAQUS code. According to the numerical results, the mechanical phenomena of the cylinder under the IAEA fire test requirement was investigated and the safety margin for the rupture of the insulated 48Y-cylinder was verified.

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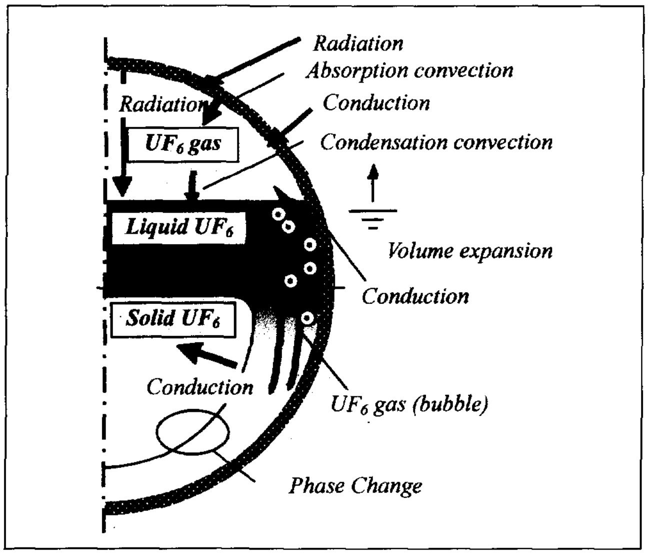


Figure 1. Diagram of heat transfer in the cylinder

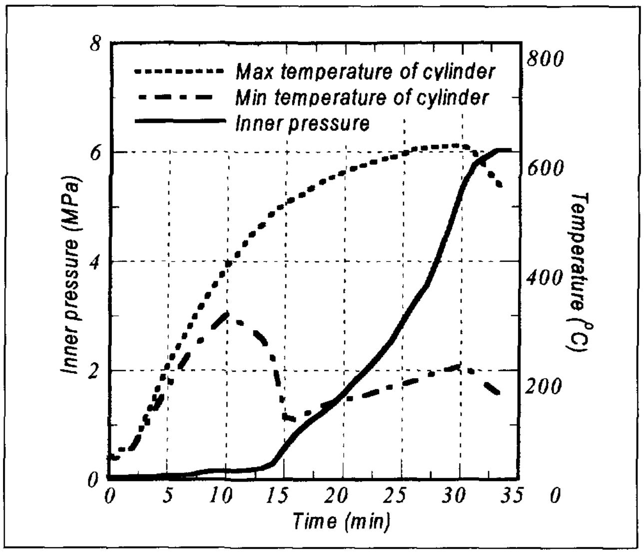
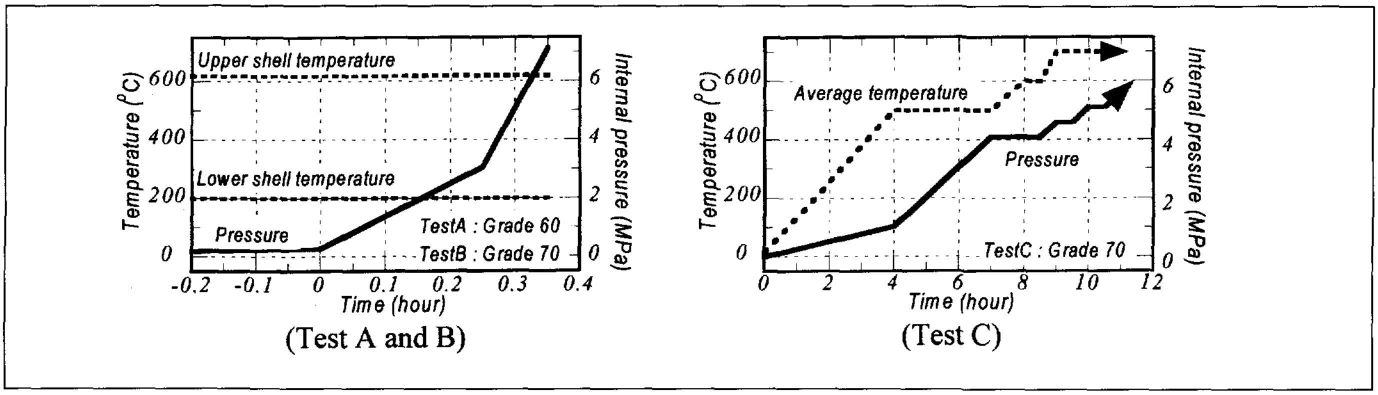


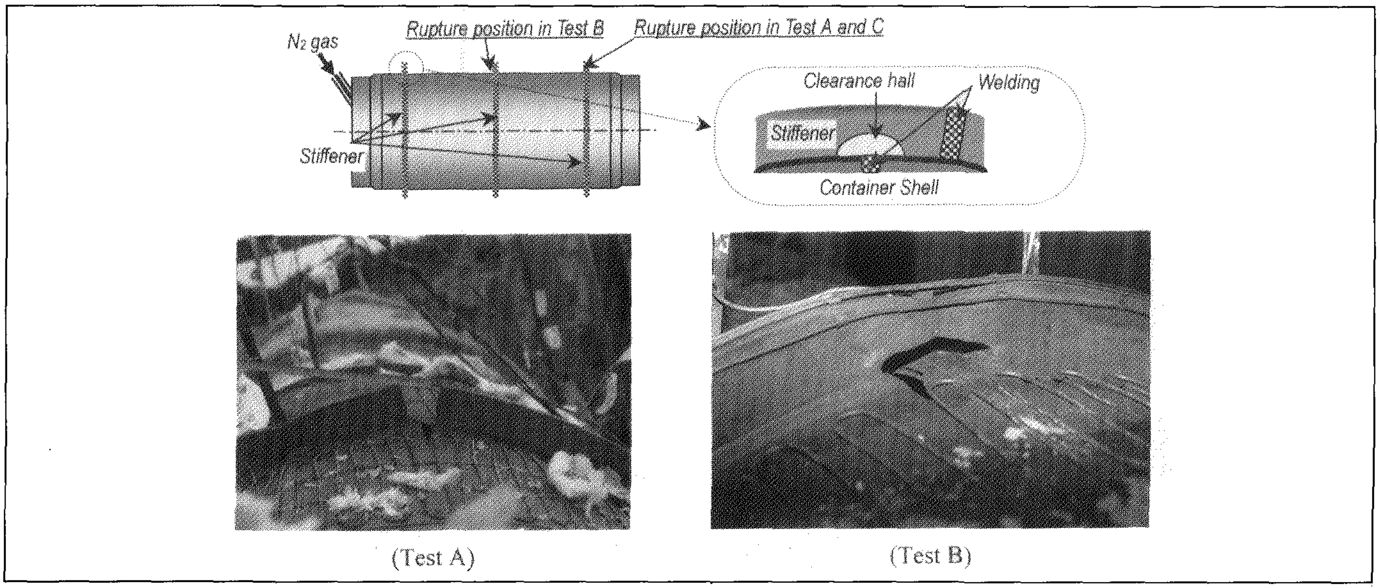
Figure 2. Fire test analysis results



(Test A and B)

(Test C)

Figure 3. Rupture test conditions



(Test A)

(Test B)

Figure 4. Test container after rupture test

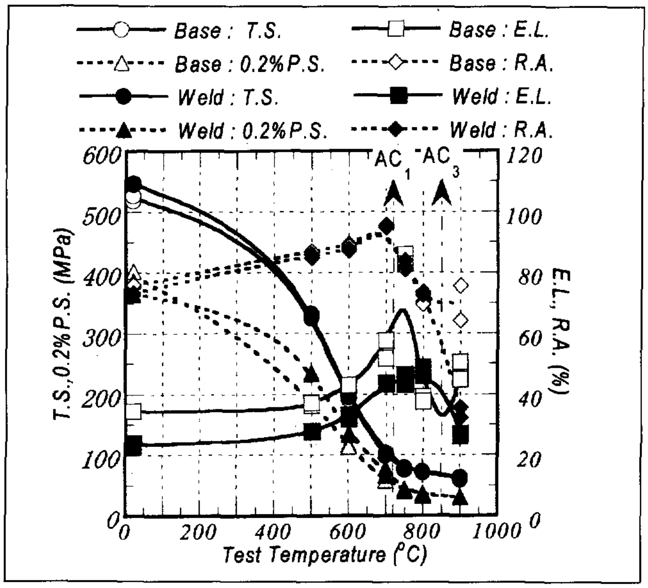


Figure 5. Tensile properties of SA516 steel (Grade 65)

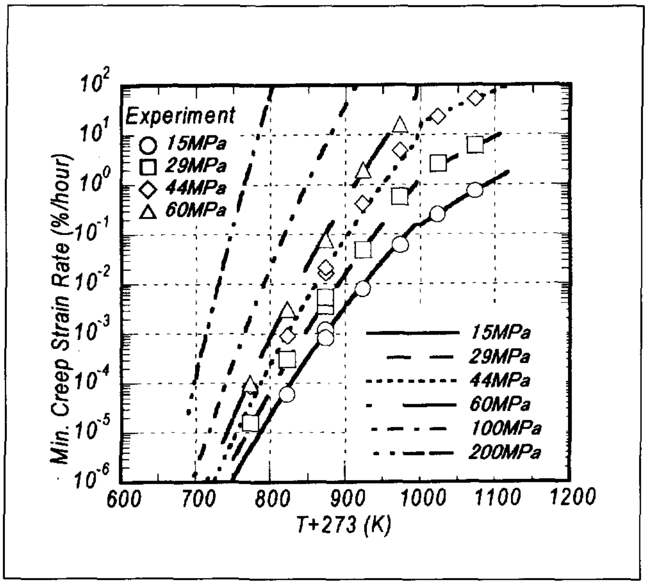


Figure 6. Modified relationship between test temperature and min. creep strain rate

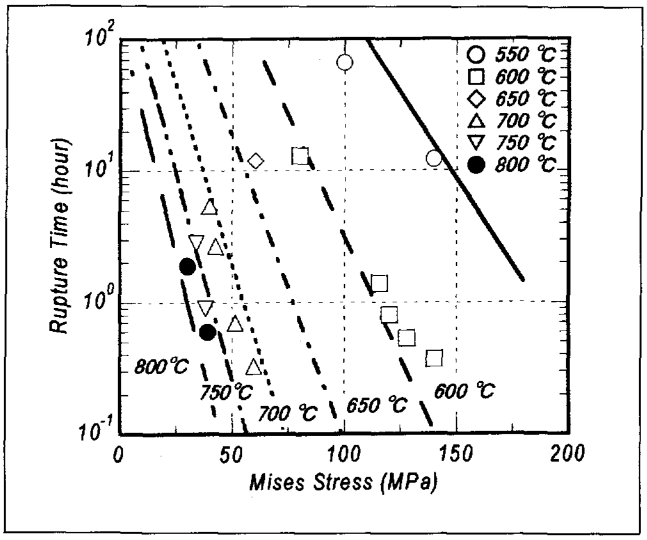


Figure 7. Modified relationship between Mises stress and rupture time

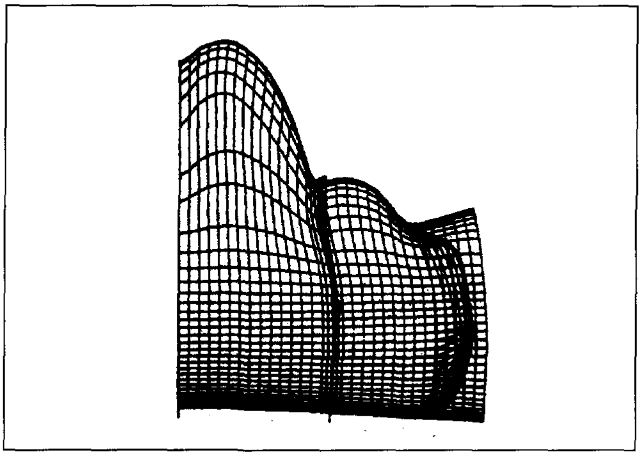


Figure 9. Deformation around 27 minutes thermal loading (magnification of 10 times)

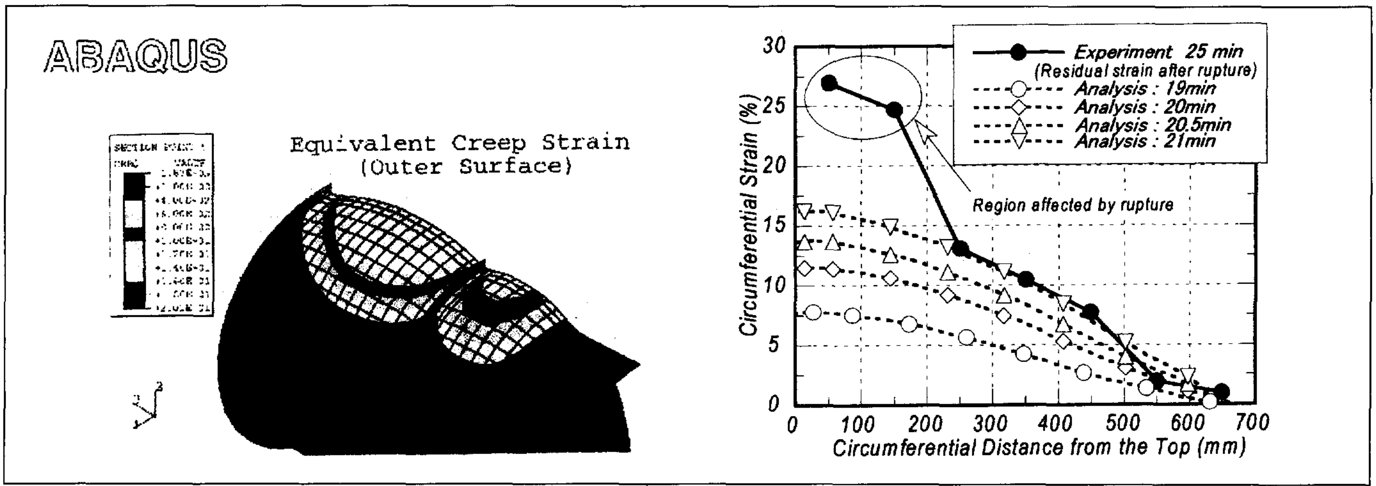


Figure 8. Distributions of equivalent creep strain and circumferential strain distribution calculated by ABAQUS code for the rupture test performed in PEECHEUR program

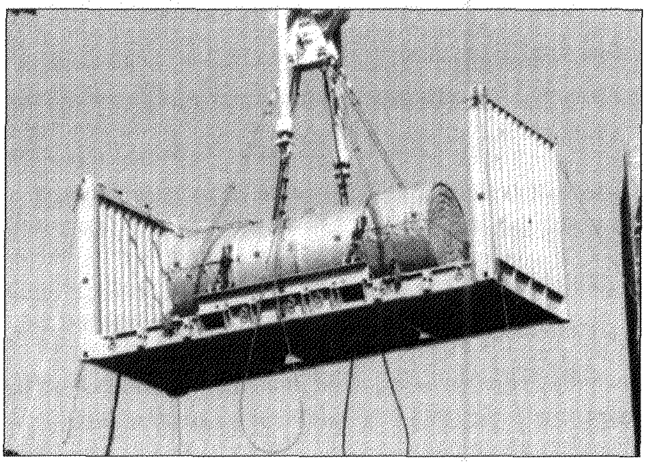


Figure 10. Insulated 48Y-cylinder equipped with the Japanese heat-protected covers

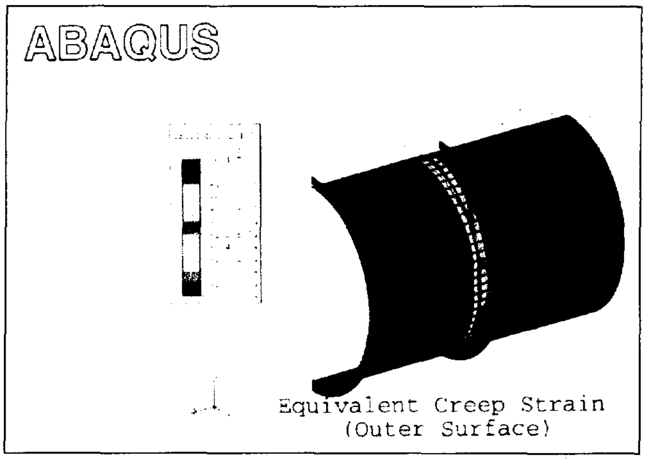


Figure 12. Distribution of the equivalent creep strain at the 30 minutes thermal loading for 48Y cylinder with heat cover system

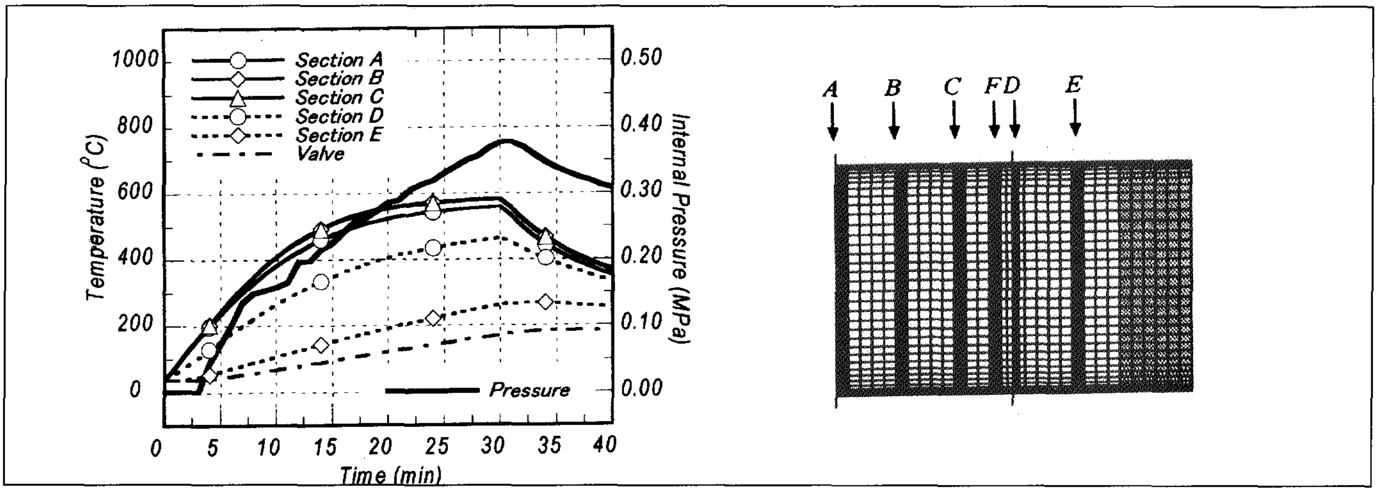


Figure 11. Time histories of the steel valve, and internal pressure of the insulated 48Y-cylinder

Managing Transportation Quality: The Whole Quality Picture, Not Just Type B Packaging

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■

Abstract

There has been a long-standing quality program described in 10 CFR Part 71, for Type B packaging. In addition, Title 49 CFR Parts 173.474 and .475 define quality controls for packaging and pre-shipment examination. However, at many facilities, this is the extent of the quality program. The purpose of this paper is to discuss other components of an effective quality program and their role in regulatory compliance.

Introduction

At the onset of the nuclear age, experts realized that the perils presented by radioactive materials called for a standard for construction, operation, and qualification of personnel for nuclear facilities that was more rigorous than anything previously used. NQA-1 became the standard. While the rigor of NQA-1 needs to be graded, as a standard, it describes the infrastructure that should be the basis of an effective quality program for the packaging and transportation of hazardous materials. Unfortunately, NQA-1 has been relegated to the world of Type B packaging and nuclear facilities.

The U.S. Department of Energy promulgated regulations in 10 CFR Part 830 that require a quality program for all nuclear activities, including packaging and transportation of radioactive materials. Virtually the same requirements have been in place for all activities that affect safety since 1982 (DOE Order 5700.6). Using the NQA-1 standard at least as a reference can provide guidance in identifying issues that need to be addressed.

Packaging Program

It is generally agreed upon that the first safety system for transportation is the packaging. The bottom line is that if the package doesn't leak, then the physical risk of any hazardous material has been contained.

The U.S. Department of Transportation has made it clear that packaging is the responsibility of the shipper; therefore the shipper (or offeror) must ensure that the packaging quality program is implemented and that records are maintained in support of each packaging configuration. Direction from DOT's enforcement team indicates that regardless of the manufacturer's markings on a packaging system or component, the shipper must have records to validate its use in the tested configuration. For packagings that do not require testing, such as those used for limited quantities, the shipper must still be able to demonstrate that the packaging will meet the conditions normally incident to transportation even though those conditions are nowhere defined.

Safety analysis reports for packaging (SARPs) are used to document the integrity of Type B packages, however no such direction is available to define documentation requirements for packages used for less than Type B quantities or for other hazardous materials. However, quality assurance and DOT requirements demand that the shipper be able to provide evidence that any packaging configuration in use has been tested or otherwise evaluated against criteria representative of the normal conditions of transportation.

Type A Packages

Los Alamos National Laboratory has developed a standard for documentation of Type A packages. Required content of the data package for each packaging configuration includes:

Design Specification

The design specification contains clear and complete specifications for the packaging as a whole and for each component of the packaging. It also includes material requirements, drawings for each component and the whole, and assembly drawings and instructions. Evidence of design review by personnel with the expertise to evaluate the design, other than those who have been directly associated with the design, are also included in the design specification package.

Procurement Specification

A whole-package procurement specification must be developed, including quality or other special requirements applicable to the packaging, such as marking, testing data, and accompanying documentation. If any parts or components of the packaging may require replacement or maintenance, the procurement specification shall include the specification for each part/component. Maintenance requirements should be specified to ensure that if a statement of work for maintenance activities is generated, it completely describes the maintenance activities to be performed.

Test Requirements
The test requirements shall be identified and described. The equipment used and the environment where testing is to be conducted should also be described. For example, the physical configuration of a "hard, unyielding surface" for drop tests should be included. Drawings, pictures, or videotapes should also be included if available.

Written Summary of the Qualifications of the Testing Individuals/Organizations
The summary shall include the basis for qualification of the personnel managing and performing the tests, results of a review of the test procedures, and verification that the tests were performed under the control of a documented quality program. A description of the test procedures, pass/fail criteria, the records to be maintained following testing, and a description of the methodology used to document pre-or post-test modifications to the packaging shall also be included.

Description of the Package and its Contents as Tested
The configuration and content, including physical form of the test media, shall be described. Details, such as loading, internal packaging, cushioning, blocking and bracing, or absorbent materials, closure mechanism, and drawings shall be included.

Results of Testing
A written description of the results of testing shall be completed. Any defects or potential failure points shall be identified. Any modifications to the packaging or the test process made during testing or test preparation shall be included. Pictures, video tapes, etc. should be included, when available, to provide visual evidence of the test results.

Written Evaluation of How the Packaging Meets Regulatory Requirements
A written description, item by item, shall be prepared describing how the tested packaging configuration meets each of the package's performance requirements. The description shall be prepared by a person qualified to evaluate test results and shall be signed and dated.

Pre-use Inspection Checklist
A pre-use inspection checklist identifying all the salient characteristics that, if not in the same condition as tested, could cause package failure. Items, such as nuts or bolts, that could be inadvertently replaced or switched and that could be replaced with counterfeit materials, shall be clearly described so that the user can verify that all parts are as tested. The checklist should identify any parts or components of the packaging that may be subject to degradation during storage or after repeated use, criteria for accepting or rejecting surface damage, and parts or components that need frequent inspection to determine maintenance status. Components that could easily be damaged during the packaging's assembly or loading should also be identified.

Specification for the Allowable Contents for the Packaging
Although this information may be prescribed in the certificate, this is a separate document that clearly describes the content, physical form, chemical form, quantity limits, and configuration of the package as tested. The only allowable content and configuration is based solely upon the test configuration.

Configuration, Loading, and Closure Instructions for the Packaging
All instructions necessary to ensure that the package contents are limited to the tested physical form, loaded and cushioned or braced, internally packaged, and closed as tested shall be included. Torque values for fasteners shall also be identified.

Maintenance Requirements and Instructions
Requirements for maintenance and any instructions for maintaining or replacing components shall be described. A requirement for a written verification by the user that maintenance has been successfully completed and that the container has been returned to service as originally tested shall be included. The user shall maintain this written verification in his/her container records.

Any Additional Information or Instructions
Any additional instructions or requirements of which the user or a procurement officer should be aware shall be included.

Certificate of Conformance
A certificate of conformance, similar to that generated by regulatory agencies, that certifies the packaging's conformance to requirements is the final document in the data package. Test requirements that have been met, description of content, special conditions, communications requirements, etc., should be included in the certificate. The certificate shall be signed by the transportation program manager, or designee, only after verification that the data package's content is complete and that all regulatory requirements have been met.

Limited Quantity Packages

Limited quantity packages do not require testing, however they must meet the basic packaging requirements of 49 CFR 173.24 and 172.24a. The shipper must be able to demonstrate that the package will meet the normal conditions of transportation.

One way in which that may be done is through historical data. If the shipper maintains comprehensive records regarding the packaging configuration of each limited quantity package that has been shipped or transported, these records can support the shipper's claim. For example, if the shipper can provide evidence that of 200 shipments of a specific package configuration, there has been no evidence of leakage, then the assumption can be made that the package has met conditions of normal transportation. However, if there is no objective evidence available that clearly describes the configuration of packages used and their record of usage, then the packaging should be tested and documented. Test criteria should include any conditions that might be encountered in transportation. For example, if it is a package that is being transported within a limited area, maybe within a facility's boundaries, the testing should include conditions that simulate the environment, normal modes of shipment, potential drops from a dock or the bed of a truck, and normal handling. If the packaging configuration is to be used for cross-country shipments, then the criteria for testing should include any conditions that might be encountered during transport, including weather, climatic conditions, and any other factors that could reasonably be anticipated. Part of the data package for a limited quantity package should also include records from the review performed to determine the conditions to which the package might be subjected.

In either case, through historical records or through evaluation and testing, records shall be maintained on the integrity of even packagings for limited quantities of radioactive materials.

Performance test requirements found in 49 CFR Part 178, Subpart M provides some general guidance on testing that might be performed to evaluate packagings for limited quantities.

Test requirements for small quantity exceptions for non-radioactive materials are described in 49CFR Part 173.4. These might also provide a basis for testing of packagings for limited quantities of radioactive materials.

Other Quality Requirements for a Transportation Program

In addition to the controls on packaging, a transportation quality program must include training. DOT requirements for training are clear and very basic, however additional training should be provided regarding specific procedures and quality assurance program requirements. Workers performing packaging activities must be trained in procedures developed for each specific packaging configuration. Training of all kinds must be documented and any recurrent training requirements must be completed.

Transportation quality programs must also address other issues that may not be as straightforward as packaging and training. Process reviews to evaluate and improve procedures/processes are important and provide a methodology to identify and implement corrective actions where needed. Using personnel who have no real understanding of the process gives the opportunity to view it through fresh eyes. The DOE's Integrated Safety Management (ISM) process requires evaluation of the results of performing processes, as required by quality criteria.

Maintenance of records provides the objective evidence needed to demonstrate compliance with requirements. Indexing and verifying/validating records completes the records maintenance program and enables the user to track and substantiate important data. Records must be controlled to ensure their completeness and credibility.

The use of a controlled document system to prepare, review, distribute, and modify documents ensures that each document is prepared in a consistent manner and that each user is in possession of the most recent version of the document. Reviewers have the opportunity to provide input to improve the quality of the document and the process.

Work procedures that affect safety should be prepared to identify hazards, hazard mitigation processes, and conditions for operations. A walk-down of each procedure should be performed to verify the process and find opportunities for improvement or to identify deficiencies.

In the design and development of any packaging system, whether Type B or less than Type B, designs must be developed, verified, reviewed, and controlled. Design changes should also be verified and reviewed and the design documentation for packaging systems in use must be clearly modified and validated.

Procurement actions for packaging systems and components should only include vendors who have been qualified for the item(s) being procured and whose qualification status is current. The provision of accurate and complete specifications, including any quality, documentation, testing, or certification requirements, is absolutely essential. Vendor qualification procedures should be developed to allow flexibility in qualifying vendors based on the rigor required for the items being procured.

Upon receipt, packaging systems and components must be inspected to a rigor commensurate with the system's intended use, welds verified, and an inventory taken to ensure that all required components have been received. Fasteners or other parts that are subject to counterfeiting must be inspected. Qualified workers must perform inspections and documentation must be maintained to provide objective evidence that inspection and acceptance has been accomplished. Instrumentation used to inspect packaging systems, either upon receipt, prior to use, or prior to shipment must be calibrated and documented.

Finally, transportation and/or line managers must maintain an active internal assessment program to ensure that all requirements continue to be met.

Conclusion

While packaging is the key component to the management of quality within a transportation program, it is not the only factor. An effective transportation program must include all the necessary controls and records to ensure that work is performed by qualified workers, designs are clear, complete, and controlled, and that items are procured from qualified vendors according to established specifications and inspected and documented upon receipt in order to track vendor performance. With these components in place, the quality of a transportation program can be objectively evaluated with an end result of transportation excellence.

Analytical, Numerical, and Experimental Investigations on the Impact Behavior of Packagings for the Transport of Radioactive Material Under Slap Down Conditions

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Abstract

This paper decribes a methodical way to find critical drop angles or better a range of drop angles for oblique drops of packages used for the transport of radioactive materials.

Introduction

Concerning approval design tests, the IAEA regulations for the safe transport of radioactive materials specify 9m drop tests onto an unyielding target to evaluate the packaging response to mechanical tests demonstrating the safety under accident conditions. The orientation of the packaging, i.e. point and angle of impact in the drop test, must be chosen in a manner so that maximum damage occurs with regard to the safety criteria. The safety criteria are in particular the leak tightness of the lid closure system, the integrity of the containment components (body, lids, lid screws), and the subcriticality of the fissile contents. For most packages, the worst case is not a single event, represented by one drop test. The worst case for the safety criteria integrity of the container body must not be automatically the worst case for the criteria of leak tightness, etc. For this reason most package drop tests may consist of a series of tests at various orientations so that every safety relevant component suffers maximum damage. Possible orientations are the horizontal, the vertical, the corner, and the oblique drop.

The oblique drop, subject of this paper, does not impact the target with the container center of gravity directly above the point of impact like in a corner drop, so that after a primary impact of one container head, the container is set into rotation. This causes a second impact onto the other end of the container with an impact velocity possibly much higher than the velocity reached from the free drop of 9 meters.

In order to evaluate the different safety criteria, one of the difficulties is to evaluate the effects of slap down impacts depending on the chosen angle. To solve this problem, BAM had undertaken an analytical analysis of the slap down kinematics. We assumed that the package behaves like a rigid body, and looked at four borderline cases of impact conditions, an ideal elastic or plastic impact, with friction (perfectly rough impact) or without friction (perfectly smooth impact) between container and target during primary impact. In two cases we didn't find closed analytical formulas but got numerical solutions using the software program MATHEMATICA. The derivation of our solutions for the different borderline cases were discussed in detail in the next chapter. After that we will present our finite element calculations and some experimental results with the aim to check our analytical solutions. Based on these analyses we are able now to define much more precisely the worst-case drop angle that should be used to get high-structure loading in a real drop test or in a numerical three-dimensional drop simulation.

Analytical Model

The analytical model describes the impact of an uniform rigid rod of length l, mass m, and moment of inertia about the mass center S of $\theta_S = (ml^2)/12$ on a rigid, horizontal plane, as shown in Figure 1. The x-axis is chosen tangential, the z-axis normal to the contact surface in the contact point L. It is presupposed, that the model copies in a good estimation the rigid body characteristic of a real container (See Experimental Results).

The rod impacts at first the rigid target with its left end L under the impact angle φ_0 with the velocity $\vec{v}_{S_0}=\{\dot{x}_{S_0}, \dot{z}_{S_0}\}$. After this impact the mass center S has the final linear velocity

$\vec{v}_{S_2}=\{\dot{x}_{S_2}, \dot{z}_{S_2}\}$ and the final angular velocity ω_2. Further the rod executes a plane motion in the gravity field, described with the velocity of mass center S $\vec{v}_S(t)=\{\dot{x}_S, \dot{z}_S\}$ and the angular velocity $\omega(t)$ about S since it impacts a second time with its right end R. This second impact is the so-called slap-down impact.

During the primary impact, at the time $t=t_0$ the principle of linear and angular momentum provides the relations

$$I_x=m(\dot{x}_{S_2}-\dot{x}_{S_0}) \quad (1)$$

$$I_z=m(\dot{z}_{S_2}-\dot{z}_{S_0}) \quad (2)$$

$$\theta_S(\omega_2-\omega_0) = I_z x_S - I_x z_S = I_z\frac{l}{2}\cos\varphi_0 - I_x\frac{l}{2}\sin\varphi_0 \quad (3)$$

where I_x is the normal and I_z the tangential impulse, produced by the collision ([1], [2]). The initial conditions for an IAEA 9 m drop at time $t=t_0$ are

$$\omega_0=0,\ \dot{x}_{S_0}=0,\ \dot{z}_{S_0}=-v_0,$$

where v_0 is the initial impact velocity and ω_0 the initial angular velocity.

The velocity $\vec{v}_L=\{\dot{x}_L, \dot{z}_L\}$ of the rod's left end L is given in general form, with $\omega=\dot{\varphi}$ by the equations

$$\dot{x}_L=\dot{x}_S-\omega z_S=\dot{x}_S-\omega\frac{l}{2}\sin\varphi\ ;\ \dot{z}_L=\dot{z}_S+$$

$$\omega x_S=\dot{z}_S+\omega\frac{l}{2}\cos\varphi \quad (4)$$

Using the coefficient of restitution k as defined in [3], as ratio of final to initial normal velocity in point L, this component of the velocity after the first impact can be expressed by the formula

$$\dot{z}_{L_2}=-k\,\dot{z}_{L_0}, \quad (5)$$

where $\dot{z}_{L_0}$ is the z-component of the velocity of point L before the first impact and $\dot{z}_{L_2}$ after the first impact, at time $t=t_2$. The coefficient of restitution k describes the degree of plasticity of the collision. The impact is perfectly plastic for $k=0$, partially elastic for $0<k<1$ and perfectly elastic for $k=1$.

The normal velocity of mass center $\dot{z}_{S_2}$ at time $t=t_2$, using equation (4) and (5) is now given by

$$\dot{z}_{S_2}=kv_0-\omega_2\frac{l}{2}\cos\varphi_0.$$

If the impact is frictionless—perfectly smooth[1]—the impulse has only a z - component I_z, the horizontal component is zero

$$I_x=0$$

so that no change in the horizontal velocity of the center mass occurs

$$\dot{x}_{S_2}=\dot{x}_{S_0}=0$$

which means that it moves only in vertical direction, as shown in Figure 2.

If the impact is perfectly rough[1] (Figure 3), the impulse consists of a z - component I_z and a horizontal I_x, no motion in horizontal direction can occur for point L during and after impact:

$$\dot{x}_{L_2}=0 \Rightarrow (4) \Rightarrow \dot{x}_{S_2}=\omega_2\frac{l}{2}\sin\varphi_0.$$

The final angular velocity ω_2 and linear velocity $\vec{v}_{S_2}$ of mass center S solving the equations (1) to (5) are summarized in Table 1.

After the first impact the motion of the rod can be described by a translatory motion of the mass center while rotating about its center of mass in the field of gravity. The gravity force is the only working outer force during executing a plane motion. In the case of rebounding of the rod end L (restitution coefficient k > 0), the time at which second impact (slap down) occurs is defined by the condition for the z - coordinate of the right end R with

$$z_R(\tau_*)=\frac{l}{2}\cos\varphi_0+\dot{z}_{S_2}\tau_*-\frac{g\tau_*^2}{2}+\frac{l}{2}\sin(\varphi_0-\omega_2\tau_*)=0 \quad (6)$$

where $\tau_*=t_*-t_2$ is the time period between first and second impact and z_R is the z-coordinate of the right end R. Equation 6 was solved numerically using the meathod in reference 3. The final linear slap down velocity of the right rod end R $\vec{v}_{R_*}(t_*)=\{\dot{x}_{R_*}, \dot{z}_{R_*}\}$, the mass center S $\vec{v}_{S_*}(t_*)=\{\dot{x}_{S_*}, \dot{z}_{S_*}\}$, and the final angular velocity ω_* are summarized in Table 2.

In the case of no rebound ($k=0$) the angular velocity can be calculated directly with the law of conservation of energy after e.g. reference 2.

Results from Analytical Calculation

The equations governing the linear and angular velocity of the slap-down impact end R, were evaluated for the borderlines perfectly smooth impact and perfectly rough impact each with $k=0$ and $k=1$ (see Table 1). The numerical calculation was carried out with an initial velocity v_0 of 13.3 m/s resulting from a 9m drop and a rod length l of 4,750

Table 1. Final Angular and Linear Velocities After First Impact

	Perfectly Rough Impact	Perfectly Smooth Impact
ω_2	$\frac{3(1+k)}{2l}v_0\cos\varphi_0$	$\frac{6(1+k)}{l(3\cos^2\varphi_0+1)}v_0\cos\varphi_0$
$\dot{x}_{S_2}$	$\frac{3(1+k)}{4}v_0\cos\varphi_0\sin\varphi_0$	0
$\dot{z}_{S_2}$	$[k-\frac{3(1+k)}{4}\cos^2\varphi_0]v_0$	$\frac{(3\cos^2\varphi_0-k)}{(3\cos^2\varphi_0+1)}v_0$

mm varying the impact angle.

The length is related to a cask for transport of fresh fuels, ANF-10, with that BAM had carried out a 9m drop test with an impact angle of 15 degrees[5]. The variation of lengths between 2m and 6m didn't show significant differences in kinematic results, so that the presented results for l = 4750 mm are representative for the mentioned range.

Figures 4 and 5 show the magnitude $\left|\vec{v}_{R*}(t_*)\right|$ (in the following text v_{R*}) the horizontal component $\dot{x}_{R*}$ and vertical component $\dot{z}_{R*}$ of the slap-down velocity of end R for smooth and rough impact depending on impact angle. From reason of presentation, the velocity components in the figures 4 and 5 are shown as absolute values. But the direction can easily be seen in figures 2 and 3.

The case of a smooth and perfectly elastic impact causes naturally a much higher v_{R*} than a perfectly plastic impact (Figure 4) and for both cases a significantly higher velocity than the initial velocity 13.3 m/s resulting from the 9m drop height. In a wide range between 5° and 45° v_{R*} for $k = 0$ and $k = 1$ isn't much changing.

The rough impact (Figure 5) shows a relatively sharp decline of v_{R*} for $k = 1$ and an increasing impact angle. For $k = 0$ v_{R*} has up to 25° only a slight decrease in magnitude and then for angles greater 25° the decrease becomes gets significant.

Regarding the results of the four borderlines, the comparison between the velocities (Figure 7) shows that the perfectly elastic, smooth impact yields the highest impact velocity. The maximum velocity isn't much changing in a wide band of impact angle except for the rough impact with $k = 1$.

Figure 8 shows the ratio of final to initial kinetic energy depending from impact angle. In the case of impacts with $k = 1$ and impact angles up to nearly 40 degrees, the ratio is in a range between 1 and 1.05. The reason is, that the second impact has additional energy from the rotation of mass center S from its elevated position. Also we see that as well in a perfectly plastic impact ($k = 0$) and impact angles up to 30 degrees the kinetic energy remained for slap down is 70 percent to 80 percent of the initial kinetic energy.

Finite Element Calculation

The finite element (FE) calculation was used to check our analytical models and for further investigations in the structure dynamics of slap-down impacts.[5] The calculations by varying the impact angle were carried out with ABAQUS/EXPLICIT[6].

Corresponding to the analytical model the rod in the FE calculation was defined as RIGID BODY[6] (modelled by HEX8 elements) with a length of 4,750 mm. The target was modelled as rigid. Due to the rigid body definition only the perfect elastic smooth and rough impacts could be simulated directly. The results show a very good conformity with those obtained from the analytical model. Figure 9 shows for example the slap down velocities for the smooth impact in comparison between FE calculation and analytical calculation. The small difference between the curves is caused by the cross-section of 10 mm x 10 mm used for the rod in the FE calculation. A cross-section going to zero would match the thin rod in the analytical model and would cause two identical curves.

Other cross-sections used in the FE calculation such as 500 mm x 600 mm, according to the outer dimensions of the container ANF-10[7] showed little differences in results up to

Table 2: Equations Governing the Linear and Angular Velocity at Time t* of the Slap-Down Impact.

	$k>0$	$k=0$	
	Rough/Smooth Impact	**Rough Impact**	**Smooth Impact**
ω_*	ω_2	$\sqrt{\omega_2^2+\frac{3g}{l}\sin\varphi_0}$	$\frac{1}{2}\sqrt{3\cos^2\varphi_0+1\omega_2^2+\frac{12g}{l}\sin\varphi_0}$
$\dot{x}_{S_*}$	$\dot{x}_{S_2}$	0	0
$\dot{z}_{S_*}$	$\dot{x}_{S_2}-g\tau_*$	$-\omega_*\frac{l}{2}$	$-\omega_*\frac{l}{2}$
$\dot{x}_{R_*}$	$\dot{x}_{S_*}+\omega_*\frac{l}{2}\sin(\varphi_0-\omega_*\tau_*)$	0	0
$\dot{z}_{R_*}$	$\dot{z}_{S_*}-\omega_*\frac{l}{2}\cos(\varphi_0-\omega_*\tau_*)$	$-\omega_* l$	$-\omega_* l$

Table 3. Cask drop from a height of 9m. Impact angle 15 degrees. Comparison between experimental and analytical results.

Cask		Experimental Results		Analytical Results	
Name	Geometry	Mass m	Slap-down velocity	Qualitative specification of first impact	Slap-down velocity
ESBB	l = 4538 mm; Ø 150 mm	315 kg	(≈25 m/s	rebound; $k > 0$	rough, $k = 1$: 25 m/s
ANF-10	l = 4725 mm; ❑ 667 mm x 565mm	1429 kg	(≈23 m/s	rebound; $k > 0$	rough, $k = 1$: 25 m/s
ANF-18	l = 5512 mm; ❑ 960 mm x 792 mm	4466 kg	(≈21-24 m/s	rebound; $k > 0$	rough, $k = 1$: 25 m/s
CASTOR VHLW	l = 4486 mm; Ø 1156 mm	20950 kg	(≈20 m/s	$k \rightarrow 0$	rough, $k = 0$: 20 m/s

a 40 degree impact angle. Beyond 40 degrees the decrease is higher.

Comparison Between Experimental and Analytical Results

The experimental data to compare with calculations is obtained from drop tests with various casks onto a rigid target from a height of 9m. The impact angle in each drop was 15°. The casks considered have lengths between 4,500 mm and 5,500 mm and masses between 315 kg and 20,950 kg. The cross-section dimensions are small in relation to their length.

Figure 10, for example, shows a CASTOR VHLW equipped with shock absorbers after the 9m declined drop test. The shock absorber on the end that hits first is less damaged then the opposite end slapped down on the impact target.

The other drop tests we compared were performed with different types of new package designs for the transport of fresh fuel called ESBB, ANF-10 and ANF-18. The design of the packages and the drop tests are described in Figures 7, 8, and 9.

The sequence of a typical slap down impact is shown in Figure 11 at the example ANF-18. The package was dropped from a height of 9m in a 15° declined position. In Figure 12 we see the corresponding and, in principle for the most slap-down impacts, typical accelerometer signals of the package first end and slap-down end. The according velocity-time curves, obtained by integration are shown in Figure 13. The container end that hits first the target was decelerated during a few milliseconds from the initial velocity 13 m/s to zero and remains in contact with the target, while the opposite end accelerates from initially 13 m/s to 21 m/s in a time period of 10 milliseconds. After 60 ms at time t = 70 ms the cask's opposite end hits with nearly 24 m/s in a slap-down impact the target.

The drop tests showed that sliding between the end of the cask hitting first does not occur during the impact (see also Figure 10). The impacts are rough. If the impact were frictionless (smooth impact) the first end would slip out under the falling cask and the cask would rotate about its center of mass (see Figure 2). Therefore the analytical results for the smooth impact have a more theoretical value. However the equations for the rough impact with $0 < k < 1$ are a suitable tool to describe in a good estimation the kinematic of the package in a real drop test situation.

The slap-down velocities of various packages taken from deceleration measurements in 9m and 15° inclined drop tests are compared with the analytical results in Table 3.

The first impact caused a clear rebound of the first three packagings so that, for the comparison, k is set to 1 in the analytic calculation. For the CASTOR VHLW cask with its impact limiter k is set to 0. The theoretical and measured slap-down velocities are close together.

Summary

This paper describes a methodical way to find critical drop angles or better a range of drop angles for oblique drops of a packaging used for the transport of radioactive materials. In a first step the packaging is idealised as a rigid body which can have four different borderline cases of impact contact conditions (ideal elastic or ideal plastic impact, with or without friction between container and target during primary impact). This analytical model has the benefit that parameter studies can be done easily, i.e. by changing the degree of plasticity of the collision using the coefficient of restitution k. Knowledge about the size of the contact force or the impact time is not necessary. Secondly, it is important to know the total amount of kinetic energy remained in the packaging shortly before the second impact happened. Both information, the range of useful drop angles and the remaining kinetic energy for the second impact, are important for a well-founded choice of a test drop angle or for doing a large-scaled three-dimensional numerical analysis of the structure loading in case of a slap-down event.

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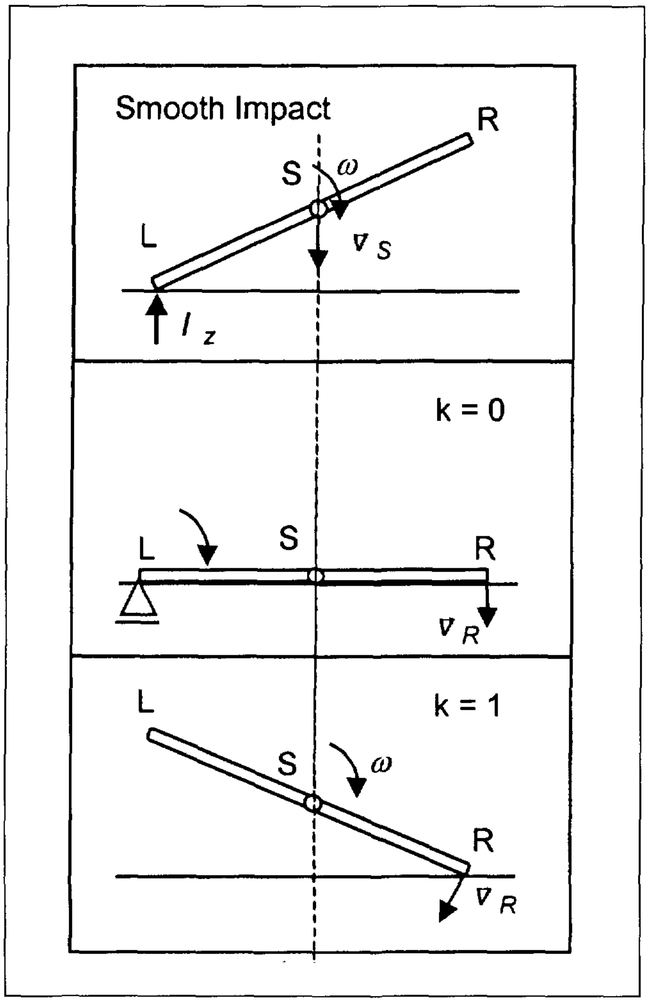


Figure 2. Smooth impact of k = 0 and k = 1

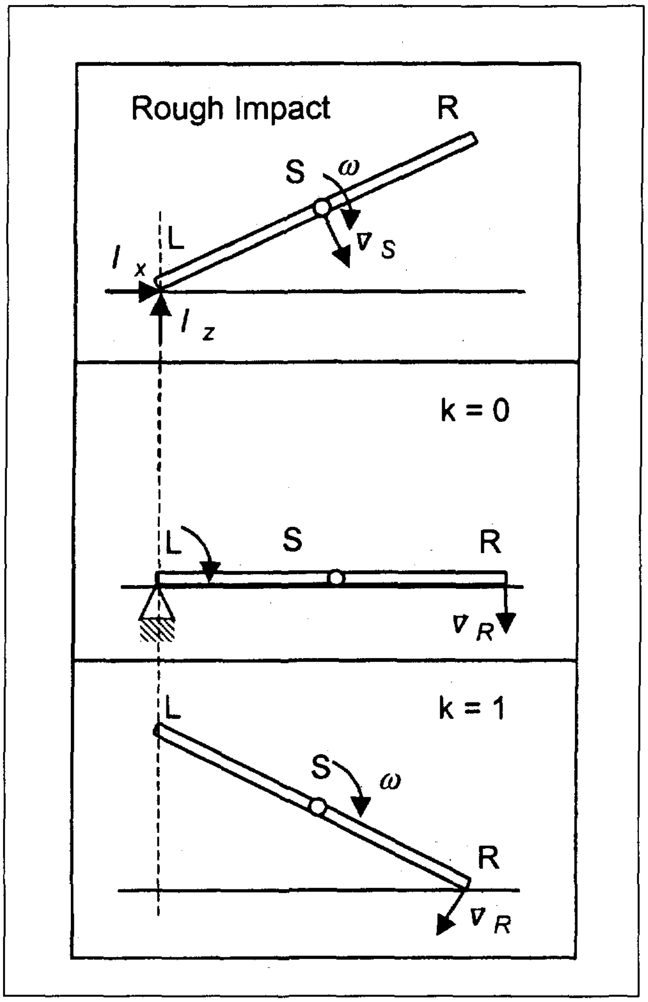


Figure 3. Rough impact of k = 0 and k = 1

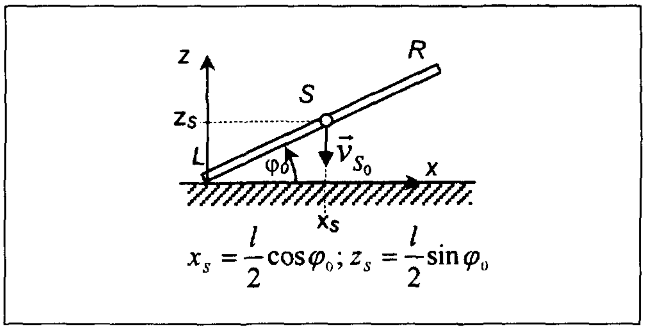


Figure 1. Impact of a rigid bar onto a rigid horizontal plane

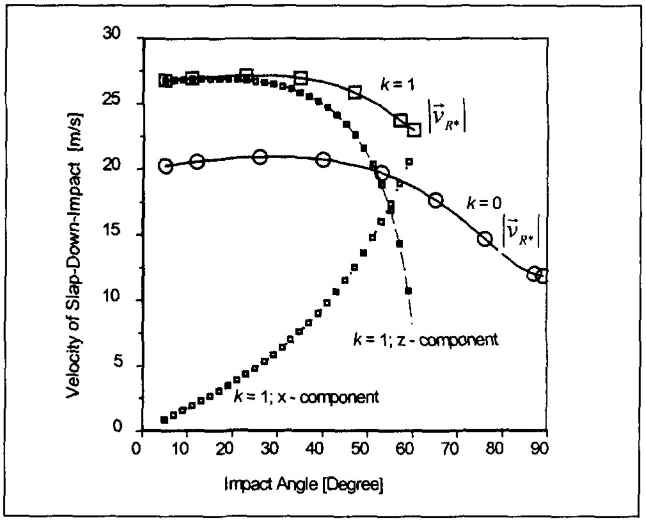


Figure 4. Perfectly smooth impact. Calculated velocity components and magnitude of the slap-down impact for a rod with length 4,750 mm

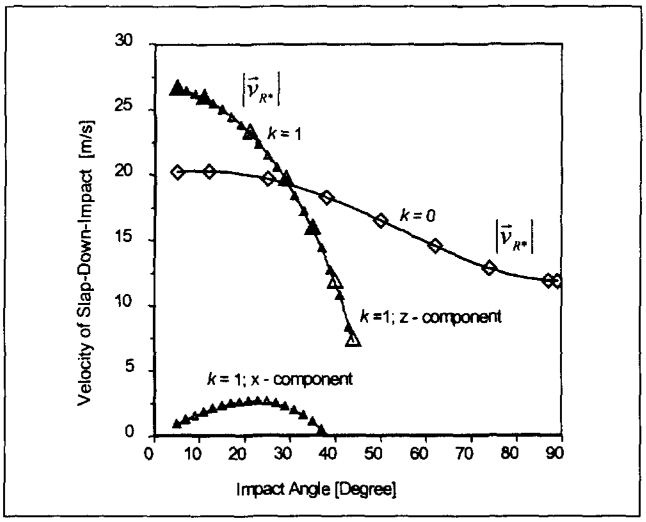


Figure 5. Perfectly rough impact. Calculated velocity components and magnitude of the slap-down impact for a rod with length 4,750 mm

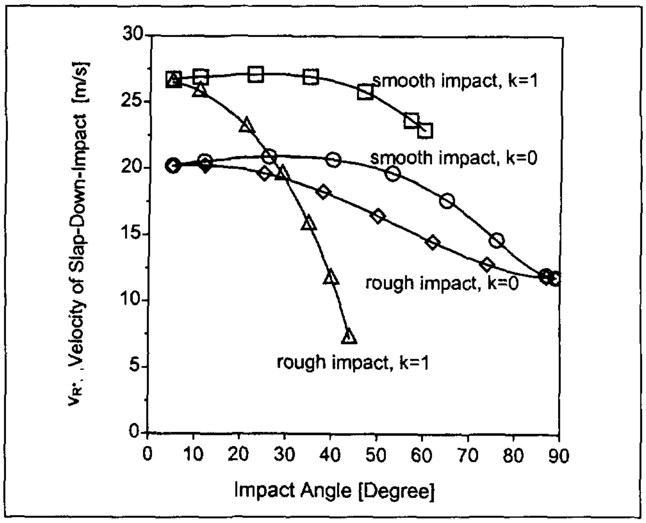


Figure 7. Comparison between smooth and rough impact. Magnitudes of the slap-down velocities

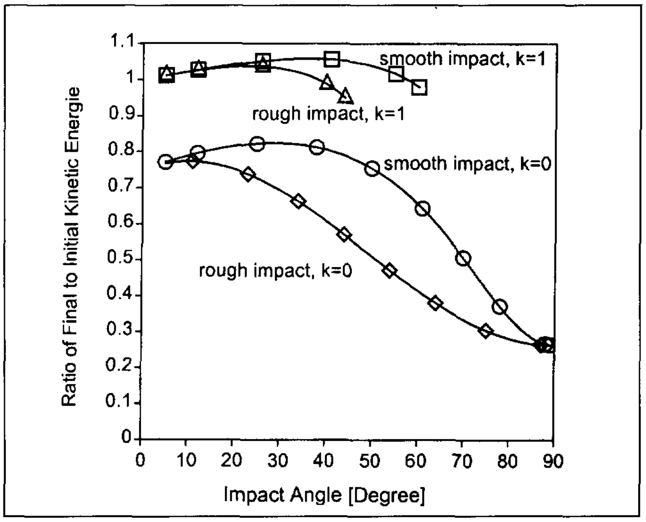


Figure 8. Comparison between smooth and rough impact. Ratio of final to initial kinetic energy

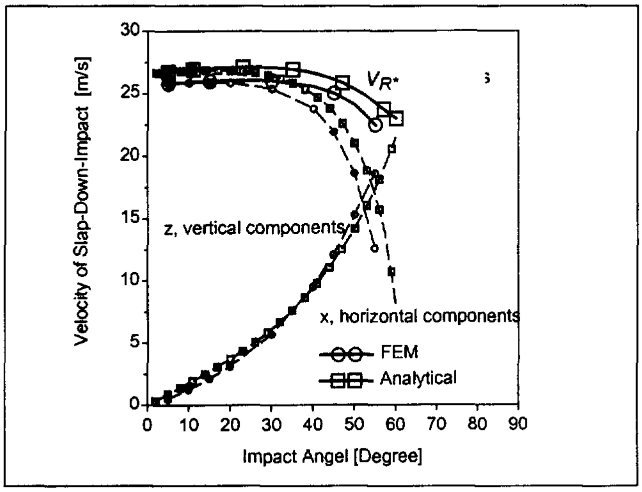


Figure 9. Comparison of analytical results with results obtained from FE calculation for perfectly elastic smooth impact

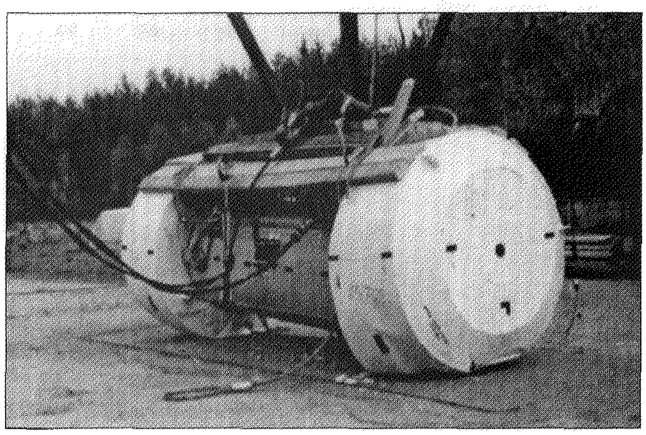
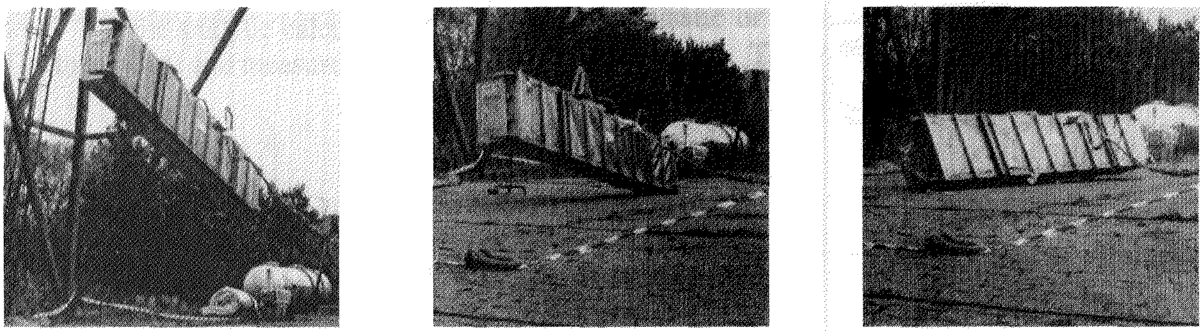


Figure 10. A CASTOR VHLW cask after the 15° declined, 9m drop test onto a rigid target. In the foreground the higher damaged shock absorber caused by slap-down impact.



a) Free Fall

b) First Impact

c) Slap-Down Impact

Figure 11. ANF-18. 9m and 15° declined drop test

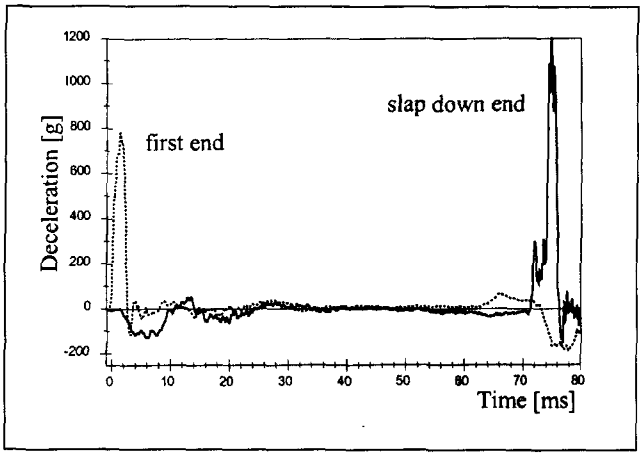


Figure 12. ANF-18. Deceleration signals

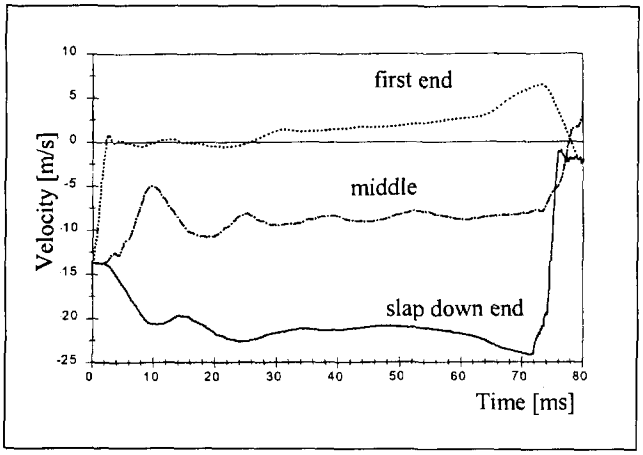


Figure 13. ANF-18. Velocity time curve

The Effects of Type C Packaging Regulations on the Shipment of High Activity Cobalt 60 Sources

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Abstract

High-activity Cobalt 60 sealed sources are used by the gamma processing industry for the sterilization of medical disposables. Typical shipments to industrial irradiators include PBq quantities of Cobalt 60. The implementation of the Type C requirements for air shipment has made shipments of typical quantities impractical. A case study is presented showing costs of compliance with these new requirements to be millions of dollars. Examples are also provided showing the importance of the air shipment. It is concluded that the benefits associated with this change in regulations have not been demonstrated and are outweighed by costs and other practical considerations.

Introduction

The gamma processing industry requires a reliable supply of high-activity Cobalt 60 sealed sources. Large industrial irradiators often contain PBq quantities of Cobalt 60. Medical disposables are the main products sterilized using gamma radiation. These are used in operating suites, hospitals, clinics, and other such applications.

The introduction of the International Atomic Energy Agency (IAEA) Safety Standards Series Regulations No. TS-R-1 (ST-1 Revised), Regulations for the Safe Transport of Radioactive Material 1996 Edition (Revised)[1] in January 2001 introduced the new Type C package category for the transport of large quantities of radioactive material by air. This new package category was incorporated into the International Civil Aviation Organization (ICAO) Technical Instructions for the Safe Transport of Dangerous Goods by Air[2] and the International Air Transport Association (IATA) Dangerous Goods Regulations.[3] IATA implemented the provisions and requirements set in the IAEA's TS-R-1 regulations on July 1, 2001. The implementation of these regulations has made the air transport of these sources impractical.

This paper explores the Type C requirements and their applicability to the shipment of high-activity sealed sources. It discusses the evolution of the requirements, addresses how one might design a Type C package for Cobalt 60, and assesses the issues and alternatives associated with the change in regulations. It also describes some practical problems associated with marine and road transport for these types of packages.

The Type C Requirements

Paragraph 416 of the IAEA TS-R-1 states, "Type B(U) and Type B(M) packages, if transported by air, shall meet the requirements of paragraph 415 and shall not contain activities greater than the following:

a) for low dispersible radioactive material — as authorized for the package design as specified in the certificate of approval,
b) for special form radioactive material — 3000 A1 or 100 000 A2, whichever is the lower; or
c) for all other radioactive material — 3000 A2."

Table I of the regulations[1] indicates that, for Cobalt 60, the A1 and A2 values are 400 GBq. Therefore the maximum activity for a Type B(U) package transported by air is 1,200 TBq.

Typical shipments of high-activity Cobalt 60 sources include packages loaded to 7.4 PBq. Typical irradiator sources have an activity of 370 TBq. Therefore, Type B(U) packages shipped by air are now limited to about three radioactive sources per package with a total package activity of about one-sixth of current package capacity.

Evolution of the Type C Package

During the revision cycle for the IAEA Regulations ST-1 for the Safe Transport of Radioactive Material it was suggested that additional performance criteria be added to the packages for shipment of plutonium by air. These additional requirements were initially based on the U.S. Nuclear Regulatory

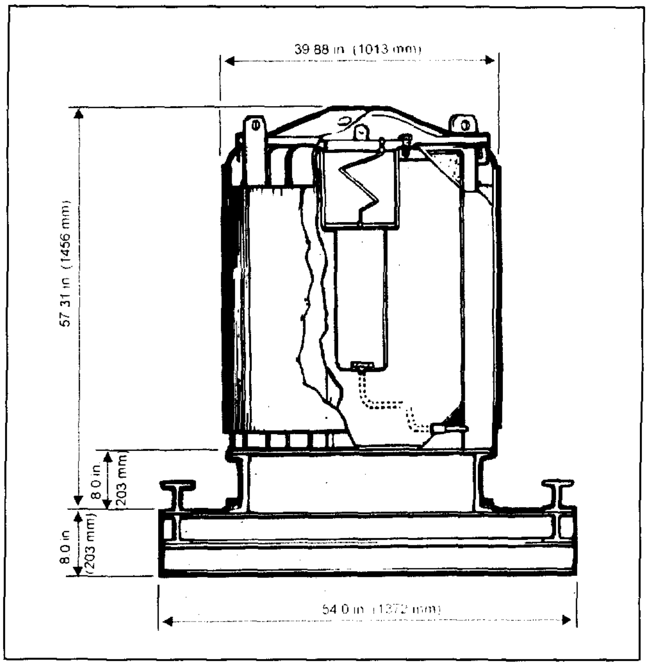

Figure 1. F-168 transport package

Commission (USNRC) 10 CFR 71.64 and 10 CFR 71.74 requirements for shipment of plutonium. Through discussions based on the hazards of various radionuclides, it was then determined that these additional requirements for air transport of plutonium should be extended to all other radionuclides. Subsequent meetings developed the Type C performance criteria.

At the final technical committee meeting for the ST-1 Regulations held in Vienna, it was felt by most member states that the new Type C package requirements would only affect a handful of shipments and mostly plutonium shipments.

Following the creation of the Type C package category the fuel cycle industry indicated that the material that they were shipping was so nondispersible that it would not require the additional safety requirements prescribed for Type C packages. The proposed regulations were modified to allow higher activities to be shipped in the current package design if the contents met the requirements for low-dispersable radioactive material (LDRM).

Cobalt 60 Transport Packages

Figure 1 shows a typical transport package. The MDS Nordion F-168 package design is commonly used for shipments of up to 7.4 PBq of Cobalt 60. The contents are normally special form radioactive material sealed sources, with activities of approximately 370 TBq. The sources meet the ISO 2919 performance classification, E65646, and are secured in a cavity. The cavity is approximately 160 mm in diameter and 500 mm in height. Shielding consists of approximately 270 mm of lead.

The main shield is surrounded by fins that dissipate heat during the normal conditions of transport and also provide impact protection during the Type B(U) mechanical tests. The fins are surrounded by a fireshield that protects the shielding and contents during the Type B(U) thermal test.

This package design has been in use for many years. MDS Nordion has shipped approximately 70,000 sealed sources and over 500 million curies (20,000 PBq) of Cobalt 60 have been shipped safely throughout the world. There have been no incidents resulting in the loss of shielding or containment in over forty years.

Building a Type C Package

The useful life of a Cobalt 60 source can exceed twenty years and the large installed base of Cobalt 60 sources makes it necessary to maintain existing or greater package cavity dimensions. Lead is the preferred material for shielding because of its relatively low cost, ease of installation, and other operational properties. The gamma processing industry operations are best suited to package capacities of 200 kCi or greater. These constraints fix the external dimensions of the shield. The design of the impact and thermal protection is the remaining challenge.

The most significant challenges related to the design of a Type C package are the requirements to survive the impact and enhanced thermal tests. Many approaches to the design of impact limiters have been successfully applied to Type B(U) packages. For this case study, the concept of extending the fins was explored. However, the arguments presented are equally applicable to other impact limiter designs.

The Type C impact test requires the dissipation of about

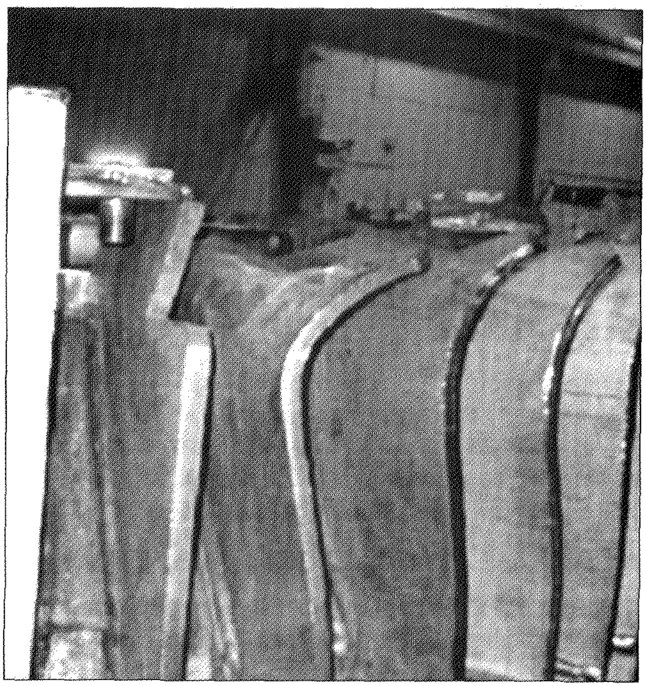

Figure 2. Typical fin deformation

fifty times more energy than the Type B(U) mechanical test. Normally, the plastic deformation of the metal impact limiters is calculated to establish the amount of impact protection required. For this example, a highly simplified approach is used. An average compressive strength of the cushion is assumed and the size of the cushion required to absorb the Type C impact energy is calculated.

Typically, metal fins are used as impact protection in these kinds of package designs. Fins are about 100 mm in length. Under drop test conditions, the fins deform as shown in Figure 2. Let us assume that the deformation is half the fin height, or 50 mm.

The energy absorbed in the cushion is equal to the product of its average compressive strength and the crushed volume. For a typical 5500 kg package, the 9m drop test requires the absorption about 500,000 Nm of energy. In an upright drop orientation, the area of a typical crush front is about 0.75 m^2. Thus, if the observed crush is 50 mm, the average compressive strength of the impact protection must be about 13 MPa.

Since fifty times more impact energy must be absorbed, modifications to the fins are required. Let us assume that improved materials, thicker fins, and other improvements in geometry enable the average compressive strength to be increased by a factor of seven to 90 MPa. Unfortunately, this also increases the inertial load to the package by a factor of seven, resulting in higher inertial loads during the accident conditions of transport.

Since we have increased the required energy absorption by a factor of fifty, and increased the crush strength by a factor of seven, the new crush depth will be 50 mm*50/7 = 350 mm. Allowing 50 mm for bottom out, yields a fin height of 400 mm.

Applying similar calculations to the remaining drop orientations would likely increase the required height of the fin. However, for this example, let us assume 400 mm of impact protection is required in all orientations.

Given a cavity 166 mm in diameter and 500 mm high, 270 mm of shielding and 400 mm of fin, the resulting external package dimensions would be 1,500 mm diameter x 1,840 mm. These dimensions are incompatible with many existing irradiator facilities and handling techniques. They also add 1,000 kg, or about 20 percent, to the weight of the package.

In addition to these structural modifications, changes must also be made to the thermal protection as the enhanced fire test is twice as long as the Type B(U) fire test. Insulation cannot be installed between the impact protection and the radiation shield because of the heat generated by the contents. 7.4 PBq of Cobalt 60 generates in excess of 3,000 W. Too much insulation would cause the shielding around the cavity to melt due to the heat of the contents. This limits placement of insulation to the outside of the impact protection. There is a delicate balance to be maintained. The high heat output of the sources combined with the enhanced fire test duration makes the design of the thermal protection a significant challenge. It is not clear if this could be achieved, or if a successful design could be licensed.

In order to resolve this problem, alternative materials could be used for shielding. Tungsten and depleted uranium are obvious candidates. Unfortunately their costs and characteristics make them impractical for this package design. These materials would decrease the external dimensions of the package and therefore decrease the amount of energy that needs to be absorbed during the impact test. However, the corresponding decrease in weight would be far less than the fifty-fold increase in impact energy.

It is estimated that the cost of designing a new Type C package for 7.4 PBq of Cobalt 60, the manufacture of prototypes, full scale testing, licensing and the manufacture of a fleet of packages would be approximately $2 million. As a relatively small number of packages are transported by air, the return associated with this investment would not merit the cost.

Other Options

MDS Nordion is committed to servicing the gamma processing industry. Since designing a Type C package for Cobalt 60 is not practical, other means must be considered to service the sterilization industry. These include qualifying the Cobalt 60 as LDRM, shipping Type C quantities by air using multiple Type B(U) packages and obtaining special arrangements for transport.

LDRM for Cobalt 60

Although it is possible to manufacture a source that would meet the test requirements for low dispersible radioactive material, section 605 (a) of the IAEA TS-R-1 regulations[1] limits the radiation level at 3m from the unshielded radioactive material, to 10 mSv/h. Assuming a typical activity of 370 TBq, the radiation level at 3 meters would be 15 Sv/h, which greatly exceeds the 10 mSv/h limit. Therefore, the high radiation level from the sealed source makes it impossible to certify it as low dispersible radioactive material. Hence, this option is not applicable.

Multiple Type B(U)-85 Packages

Shipment by air of Cobalt 60 in quantities not exceeding 1,200 TBq (32400 Ci), can be performed using a Type B(U)-85 package transporting three to four sealed irradiator sources. For the typical 7.4 PBq shipment, six Type B(U)-85 packages would be required. Although six F-168 packages can be transported in a Boeing 747, a typical plane would load less than six and would necessitate separating the shipment into two or more planes.

Neglecting the cost of purchasing five additional packages the average cost of shipping a single F-168 by air is $30,000. Hence, shipping six F-168 containers by air would represent an additional $150,000 per single shipment. For the average of ten shipments per year, the annual increase in cost is almost $1.5 million.

From a practical perspective, this option would not affect the risk associated with the shipment. The risk of an activity is determined by multiplying the consequence by the probability of the event happening. Assuming that all six Type B(U) packages are transported on the same plane the probability of an accident has not changed. Since the total activity has been divided into six smaller quantities per package, the potential consequence of an accident has changed marginally. Therefore, the increased shipment cost has not decreased the risk associated with the air transport of 7.4 PBq of Cobalt 60.

Special Arrangements under the IAEA and IATA Regulations

For shipments that do not satisfy all the applicable requirements of the IAEA regulations a special arrangement certificate can be obtained. A similar provision for exemption from the regulations is found in the Section 1.2.5 of the IATA regulations.[3] An exemption to the regulations is only granted in cases of extreme urgency or when other forms of transport are inappropriate or full compliance with the prescribed requirements is contrary to the public interest. The exemption must be granted by the states concerned including points of origin, transit, overflight, and destination.

Special arrangement certificates typically have been issued by competent authorities for the return of spent sources or other radioactive materials, which, if left in the current environment, would present a greater hazard to the environment and public health. Although the return of spent sources would qualify, it is unlikely that a special arrangement certificate would be issued to allow for a commercial shipment of new sources. In addition, a special arrangement certificate requires approval from all competent authorities affected by the transport.

It is foreseeable for a competent authority without an interest in the shipment to disallow transit or overflight. Furthermore, significant delays can be expected if multiple special arrangement certificates are required in multiple jurisdictions.

Logistics Issues with Marine and Road Transport

In recent years, MDS Nordion has made approximately ten shipments annually by air. By removing the air transport route, shipments outside Canada and the United States must now be done by marine transport. This becomes challenging as very few shipping lines accept radioactive material. The transport of large Type B(U) packages represent less than 1 percent of a shipping line business and incurs a large regulatory and insurance burden. Some shipping lines do not accept Class 7 goods.

Many airlines routinely transport radioactive material. The short half lives of many medical isotopes require them to be shipped by air. Volumes are also high. As a result, air carriers are familiar with the transport of Class 7 goods and have developed the infrastructure to support them.

In addition to the shipping line restrictions, regulatory approval may be required for Type B(U)-85 packages that transit through various ports and countries enroute to the final destination. This regulatory burden further hinders the efficient transport of packages.

Very few shipping lines will transport radioactive material, consequently there are countries that are therefore not serviced by any shipping lines. Consider the following examples:

1. There are currently no shipping lines that will allow the transport of radioactive material into a Mexican port. In addition, Mexico will not allow U.S. road carriers into Mexico and the United States will not allow Mexican carriers into the United States. As a result, the transport packages have to be transferred from a U.S. trailer to a Mexican trailer at the border or the trailer has to be hitched to a Mexican tractor at the border. Air transport easily resolves this issue.
2. There are no shipping lines that will transport Class 7 goods into the Mediterranean Sea. Therefore transport of Cobalt 60 to countries such as Italy is through other European ports and by road across Europe.
3. Today there is only one shipping line and one vessel that will transport radioactive material between South America and North America. This vessel transits from South America to North America every month. Typically the vessel is in port for less than forty-eight hours. Therefore the logistic issues involved with the delivery to the port are critical. Often, in addition to the regular shipment notification required by the regulations,[1] some countries also require the Canadian B(U) Certificate to be endorsed by a national competent authority, or require special permission to transit through a port. Air shipments would allow these countries to be bypassed.
4. Marine shipments may also be at risk due to commercial changes. In a similar example, a shipping line that accepted radioactive materials for direct transport between South America and North America was purchased by another shipping line that did not accept radioactive material. As a result of the acquisition, it became impossible to directly ship between South America and North America. The only means of transporting Class 7 goods was by first shipping the Cobalt 60 to Europe and then back to Canada. This has not only added to the cost of the shipment but has also increased the transit time considerably. In addition, since the transport package is now transiting through Europe, an ADR5 approval of the 1985

type B(U) package certificate was required.

5. In certain countries where marine transport is possible the road infrastructure is not adequate to allow the transport by road of Cobalt 60 from the port to the irradiator facility. Shipment weights often exceed the capacity of the roads. This makes delivery and retrieval of Cobalt 60 from certain locations extremely challenging.

Conclusion

Since the implementation of the Type C requirement in the IATA and ICAO regulations on July 1, 2001, MDS Nordion has not been required to ship to areas where air transport is the only shipping route available. MDS Nordion has received requests for shipment to certain areas where marine transport is not possible because shipping lines do transport radioactive material to this area. MDS Nordion has been investigating with freight forwarders other possible shipping routes using a creative approach of marine and road transport. The logistic difficulties involved and the increased in handling, storage, and transit time will result in increase cost, shipment duration, and radiation exposure to workers. The longer routes also increase the probability of an accident.

The cost of changing any regulations should be outweighed by the benefit gained from this change. The costs associated with the design and manufacture of a Type C package are prohibitive. The alternatives of multiple Type B(U) packages or special arrangements are also costly or impractical.

Operational experience has shown that shipment of Cobalt 60 by air is safe. The reduction in risk associated with the change in the air transport regulations has not been clearly shown. Consequently, costs and other practical considerations outweigh any benefits associated with this change in regulations.

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Waste Package and Material Testing for the Proposed Yucca Mountain High-Level Waste Repository

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Introduction

Over the repository lifetime, the waste package containment barriers will perform various functions that will change with time. During the operational period, the barriers will function as vessels for handling, emplacement, and waste retrieval (if necessary). During the years following repository closure, the containment barriers will be relied upon to provide substantially complete containment, through 10,000 years and beyond. Following the substantially complete containment phase, the barriers and the waste package internal structures help minimize release of radionuclides by aqueous- and gaseous-phase transport. These requirements have led to a defense-in-depth design philosophy. A multi-barrier design will result in a lower breach rate distributed over a longer period of time, thereby ensuring the regulatory requirements are met.

The design of the engineered barrier system (EBS) has evolved. The initial waste package design was a thin walled package, 3/8 inch of stainless steel 304, that had very limited capacity (3 PWR and 4 BWR assemblies) and performance characteristics, (300 to 1,000 years). This design required over 35,000 waste packages compared to today's design of just over 10,000 waste packages. The waste package designs are now based on a defense-in-depth/multi-barrier philosophy and have a capacity similar to the standard storage and rail transported spent nuclear fuel casks.

Concurrent with the development of the design of the waste packages, a comprehensive waste package materials testing program has been undertaken to support the selection of containment barrier materials and to develop predictive models for the long-term behavior of these materials under expected repository conditions. The testing program includes both long-term and short-term tests and the results from these tests combined with the data published in the open literature are being used to develop models for predicting performance of the waste packages.

Waste Package Design

The design of a waste package is based on the waste forms that it will contain. Allocation of a waste form to a waste package of a particular design is based on the characteristics of the waste, not on its origin or current state of ownership. Additionally, the waste package has been developed to fulfill the following design requirements:

- Restrict the transport of radionuclides
- Provide criticality protection during and after the waste package is loaded with waste
- Manage the decay heat for the potential repository
- Provide unique identification of the waste package and its contents
- Enhance safety of personnel, equipment, and the environment
- Prevent adverse reactions involving the waste form
- Withstand loading, transportation, emplacement, and retrieval
- Withstand the emplacement drift environment
- Provide physical and chemical stability for the waste form
- Promote heat transfer between the waste form and the outside environment
- Facilitate decontamination of its outer surface

Due to the list of performance needs the design of the waste package has evolved into a multi-barrier component with specialty materials and with each component, in general, performing more than one function. As can be seen in Figures 1 and 2, the spent nuclear fuel (SNF) basket provides structural support for the fuel assemblies. This support is maintained during the preclosure time period as well as the postclosure, (10,000 years and beyond), performance time period. The SNF basket must also provide thermal heat

Table 1. Waste Package Design Options

Commericial Waste Package Types	Thermal Capacity (Min) watts	Thermal Capacity (Max) watts	Criticality Range (Min)	Criticality Range (Max)	~Percentage of Waste Packages	~Percentage of MTHM by Waste Package
21 PWR-absorber plates	0	850	0**	1.13	~55%	~38%
21 PWR-control rod	0	850	0	1.45	~1%	~1%
12 PWR absorber plates base-South Texas long WP	0	1,500	0	1.13	~2%	~2%
44 BWR-absorber plates	0 -	400	0**	1.37	~3.2%	~25%
24 BWR-thick absorber plates	0	520	0	1.54	<1%	~1%
Defense high level waste short and long	0	1,200	0	1.0	~7%	29%
Navy short and long	TBD	TBD	TBD	TBD	<2%	3%
2-MCO/2-DHLW Long	0	>1,200	0	1.0	<1%	~1%

*** k (infinity) is used as an indicator that additional neutron absorber is needed in addition to burnup credit. k (infinity) values bound k(effective). k(effective) is unique to the geometry of the storage, transportation, and disposal device and takes into consideration the specific geometry, burnup credit, and additional neutron absorber. The specific "k (effective)" for each waste package design will be sufficiently below 1.0 that no criticality is probable.*

removal in a thermally stressing environment. The thermal characteristics of the repository rock act similar to a thermos bottle holding in the heat, and this has focused the designs to be thermally efficient in a wide range of thermal environments. In addition, the waste package, along with the surrounding EBS, must ensure postclosure nuclear criticality control over the regulatory time period.

In addition to the numerous performance based requirements, the fact that there is a large variability in the characteristics of SNF, several waste package (WP) designs have been developed to accommodate all of the SNF earmarked for disposal in the proposed repository. There are logical common design features that have been implemented in the family of basic WP designs. There are four basic families of WP designs, which are listed in Table 1. These are designs for commercial SNF, defense HLW, Navy waste, and DOE SNF/waste glass co-disposed waste.

As is shown in Table 1 and the figures, the designs are all similar in that the outer and structural shell are made of the same material, the internal basket configuration uses a basket design style that accommodates the different waste forms, i.e., the BWR basket accommodates BWR size assemblies as does the PWR basket design.

A review of the projected waste streams provides a basis for the different waste package design concepts. The major determinants that were used to decide the number and size of waste package designs are: BWR assemblies; PWR assemblies; DOE waste forms; need for additional neutron absorbing material for criticality control; and the thermal output of the SNF assembly. Included in the determination of the size of the waste package was the proposed repository thermal loading.

Engineering Evaluations

The waste package design philosophy is rooted in engineering evaluations of thermal performance, structural performance, criticality, and radiation shielding issues. To create an acceptable WP design, it is essential to identify the major parameters that influence the performance and to quantify the important design parameters. A number of significant engineering evaluations and methods that are important for defining the behavior of the waste packages in the repository environment have been developed. These include:

- **Disposal criticality:** includes probabilistic analyses, burnup credit for principal isotopes, material performance, and repository environments.
- **Thermal:** Includes waste package, near field, and far field temperature evaluations to evaluate the thermal pulse that is caused by decay heat SNF. The design requirements are to accommodate a

wide range of repository thermal designs. Therefore, a number of additional thermal enhancements have been considered over the past few years, these include convective cooling of the emplaced waste package and storing the fuel on the surface until the waste will meet the required lower thermal output.

- **Structural:** To investigate the loading conditions from the initial WP handling in the surface facility, loading of the WP, transportation of WP to the emplacement drift, and then emplacement and WP performance through time. Drift stability and rock fall have potential for adversely affecting the performance of the waste package during emplacement. Since Alloy 22 is on the outside of the waste package, damage from rock-fall drift collapse may result in a reduction in performance of the barrier. However, with the addition of a drip shield, to preclude accumulation of water and minerals on the surface of the waste package and at the same time precluding rocks from damaging the barrier, the probability of loss of performance can be minimized. Figure 4 depicts a proposed drift emplacement configuration with the drip shield.

Table 1 shows that the basic commercial SNF waste package designs and the basic defense high-level waste (DHLW) WP designs will accommodate all of the existing and projected SNF and DHLW. Table 1 also shows the thermal output that each WP design will accommodate, as well as when additional neutron absorber is needed, and an estimate of the percentage of waste package types.

Basic Waste Container Designs

Figures 1 and 2 show the uncanistered fuel (UCF) disposal container. The UCF container design is a right cylinder with two barriers and an internal basket to support the spent fuel. The waste package internals include a basket grid, structural supports, and thermal shunts. As is shown in Figure 3, the center region, inside the defense high-level waste package, is allocated to the canister that will hold the DOE waste forms.

Waste Package Materials Testing

The waste package materials and waste-form testing programs are intended to provide information in support of the materials selection process, engineered barrier system development, and total system performance assessment activities. In general the testing program consists of the following:

Container materials testing:

- Long-term corrosion
- Humid air corrosion
- Crack growth
- Electrochemical potential
- Microbiologically-influenced corrosion

Of these the long-term corrosion test program is the cornerstone of the overall material-testing program being conducted in support of the Yucca Mountain Project.

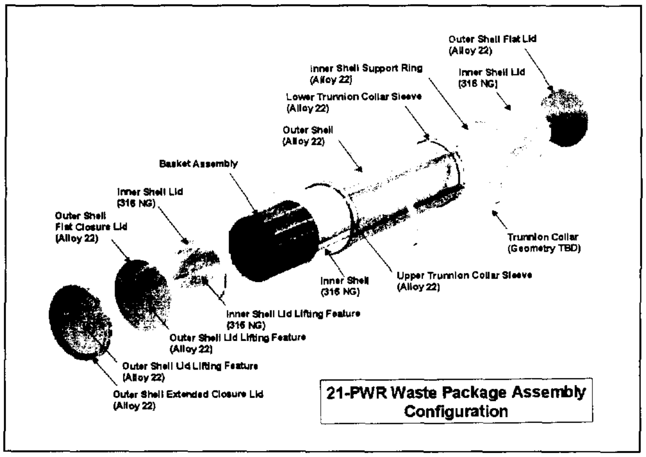

Figure 1. 21-PWR waste package assembly configuration

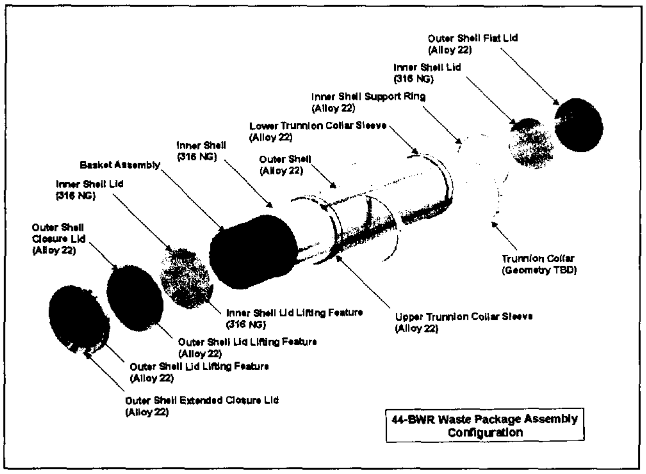

Figure 2. 44-BWR waste package assembly configuration

Comprehensive Corrosion Tests on Waste Package Materials

Long-term corrosion tests are being conducted on WP material specimens exposed to relevant repository environments. When completed, corrosion tests will have run for at least a period of five years, and some tests may continue for much longer periods of time beyond the license application period and into the repository construction period. The tests are comprehensive in the sense that many forms of corrosion can be tested. A planned interval test approach is being used, in which large numbers of specimens are initially exposed to the test environment and then periodic withdrawals of specimens are made and the specimens characterized. Thus, the time-dependence of the corrosion phenomena can be determined.

The strategy used for the waste package materials test program is shown on page 34.

Test Environments

The test environments are construed to be of the bounding type and were selected so that there would be a large difference in behavior for the different materials. Formulas have been developed for formulating the test environments. The formulas were based on previous experience on making up simulated J-13 well water (near the Yucca Mountain repository location) from various ionic salts. The characteristics of the four bounding water environments have been estimated as follows:

1. The base case water with the low concentration of ions will have a pH of 8.5 and contain 1,700 ppm total dissolved solids. For the purpose of comparison, this water is estimated to contain 67 mg/liter chloride ion.
2. The base case water concentrated 100-fold. This water will have a high concentration of ions, a pH of 10, and contain 146,000 ppm total dissolved solids. This water is estimated to contain 6,700 ppm chloride ion. This bounding environment represents what would happen with infiltrating ground water descending toward the repository, encountering the thermal zone, evaporating and concentrating dissolved salts.
3. The concentrated water acidified with sulfuric acid to a target pH of around 2.7. This water is estimated to have a total dissolved solids content of 146,000 ppm and contain 24,250 mg/liter of chloride ion. This bounding case represents the condition where microbial activity from certain species have produced acidic metabolic products. It also represents a bulk test condition simulating the case of a localized, sequestered water chemistry, such as that produced in a creviced geometry.
4. The concentrated water alkalized with calcium hydroxide to a target pH of 12. This water is estimated to have a total dissolved solids content of 132,000 ppm and contain 20,900 mg/liter of chloride ion. This bounding case represents water conditioned by prolonged contact with cementitous materials used to line the drift wall or used in the invert material underneath the waste package emplacement.

The four proposed bounding environments provide a range of pH (acid, neutral, and alkaline) and a range of ionic strength (dilute and concentrated).

Two test temperatures were selected for the long-term tests, 60°C and 90°C. These temperatures are representative of the environmental conditions and cover the range where high corrosion rates and the effects of localized corrosion and stress corrosion cracking for the corrosion resistant alloys may occur.

Test Specimens

Some 13,000 specimens were procured in FY96 in the three configurations. The materials are being tested in three categories:

Corrosion Allowance Materials:

Wrought carbon steel (AISI 1018)	UNS K01800
Centrifugally cast carbon steel	UNS J02501
2.25 Cr - 1 Mo alloy steel	UNS K21590

Intermediate Corrosion Resistant Alloys:

Alloy 400 (Monel 400)	UNS N04400
70-30 Cu-Ni (CDA 715)	UNS C71500

Corrosion Resistant Alloys

Alloy C-22 (Hastelloy C-22, Inconel 622)	UNS N06022
Alloy 825 (Incoloy 825)	UNS N08825
Alloy G-3 (Hastelloy G-3)	UNS N06985
Alloy 625 (Inconel 625)	UNS N06625
Alloy C-4 (Hastelloy C-4)	UNS N06455
Titanium Grade 12	UNS R53400
Titanium Grade 16 (Ti-0.05 Pd)	None to date

Other Testing Programs

The long-term comprehensive corrosion-testing program is a cornerstone for much of the testing effort for waste package materials. Several other short-term activities interface with the long-term test. For example, the electrochemical tests predict the relative susceptibilities of the candidate materials to localized corrosion; the long-term corrosion test validates whether these predictions are true for the longer term. These tests are important for modeling efforts. Parts of the long-term comprehensive corrosion test have counterparts in the shorter-term stress corrosion-tests and galvanic corrosion tests. The saturated steam condition existing in the top half of the test vessels represents a condition approaching 100 percent relative humidity, and thus is an extension of data points obtained at lower humidities.

Summary

Through the application of scientific and engineering methods, the engineered barrier system continues to adapt to meet the performance requirements established by government regulatory agencies, and the Yucca Mountain Project. Continuing research and development of the waste package design will help reduce the environmental impact of the proposed geologic nuclear waste repository at Yucca Mountain, and ensure the success of the project for thousands of years.

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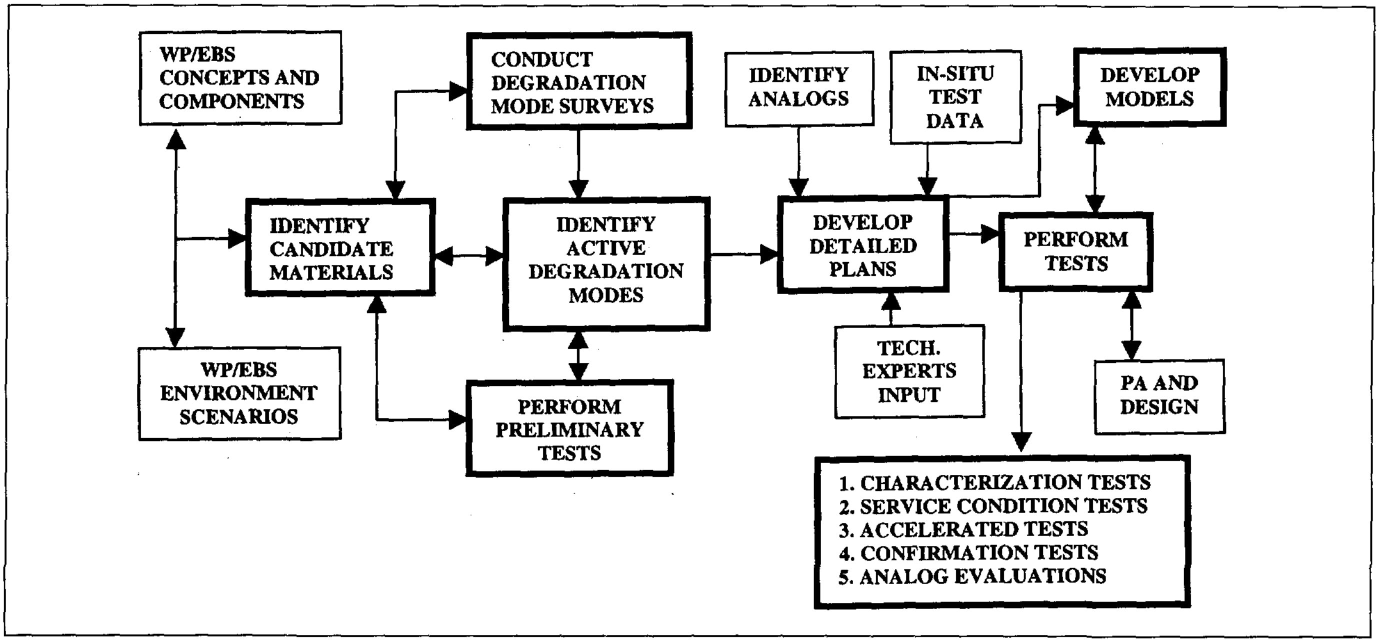

Diagram A

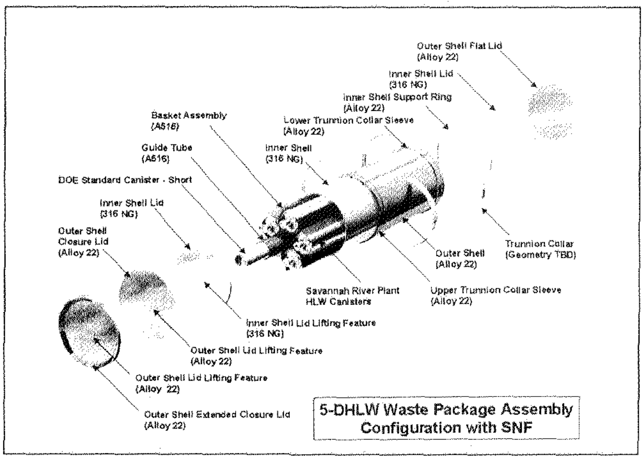

Figure 3. 5-DHLW waste package assembly configuration with SNF

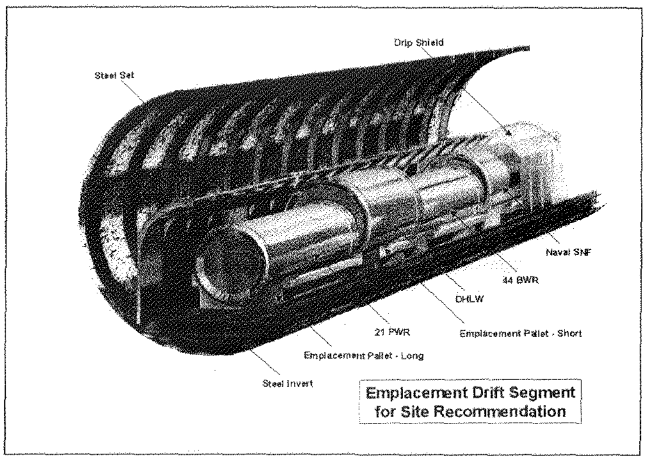

Figure 4. Emplacement drift segment for site recommendation

The Role of Partitioning and Transmutation in Future Nuclear Fuel Cycles

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Nuclear power will continue to contribute in a significant manner to the supply of energy in the United States for a number of decades to come. Whether the level of that contribution remains at or near the current level of about 100 GWe or increases to a greater percentage of the national electrical energy supply remains to be seen. The nature of the future nuclear enterprise is difficult to foresee, depending as it does on externalities such as consumer demand, environmental issues, public acceptance, economics, and national policy. In anticipation of the continuation of nuclear electric power generation, and particularly in the continued generation of spent nuclear fuel at a rate at least equal to the current rate of more than 2,000 metric tons per year, the U.S. Department of Energy in 1999 launched a program aimed at developing the technologies for partitioning and transmutation of the transuranic elements and long-lived fission products present in spent light water reactor fuel.

The incentives for partitioning and transmutation are numerous, including utilizing the energy potential of the fissionable materials present in spent LWR fuel, eliminating a future source of plutonium for weapons uses by proliferant groups, and easing the problems of future high-level waste disposal by reducing waste volume and radiotoxicity. The transuranic content of spent LWR fuel at present generation rates is sufficient to fuel 20 percent of the current commercial reactor complement in the United States and the waste remaining after extraction of the actinides and long-lived technetium and iodine fission products would have a level of radiotoxicity 1,000 times less than that of the untreated spent fuel.

Studies done in support of the proposed Yucca Mountain geologic repository performance analysis have shown that ^{99}Tc and ^{129}I dominate the radiation dose to nearby residents at time periods up to 50,000 years after repository closure. Thereafter, the dose is largely from the transuranic elements plutonium and neptunium. These analytical results, together with a general notion that a reduction in the radiotoxicity of wastes to be emplaced in the repository should be of benefit, led to an initial goal of eliminating 99.5 percent of the transuranics and at least 95 percent of the technetium and iodine from wastes intended for repository disposal.

The efficient elimination of the selected nuclides at these levels of transmutation was the subject of an intense study in 1999, leading to a report to the Congress describing a roadmap for development of the necessary technologies. The system envisioned at that time consisted of a single tier arrangement directed toward the treatment of the inventory of commercial spent nuclear fuel projected to exist in the United States in 2010, assuming no new orders and no plant life extension (about 87,000 metric tons). The commercial fuel was to be processed to separate the transuranic elements and the long-lived fission products for subsequent transmutation in an accelerator-driven subcritical reactor device. The duration of the period for partitioning and transmutation of the commercial spent fuel was chosen to be ninety years, with approximately 1,450 metric tons of commercial LWR fuel to be processed each year for sixty years. This processing was to separate the transuranics from the LWR spent fuel and send them without further separation to accelerator-driven reactors for transmutation. The system involved the construction of eight plants having some thirty gigawatts (thermal) of reactor capacity, including sixty-four 840 MWt reactors driven by a total of sixteen linear accelerators delivering 45 mA proton current at 1.0GeV to spallation targets that produce about thirty neutrons per incident proton. Each

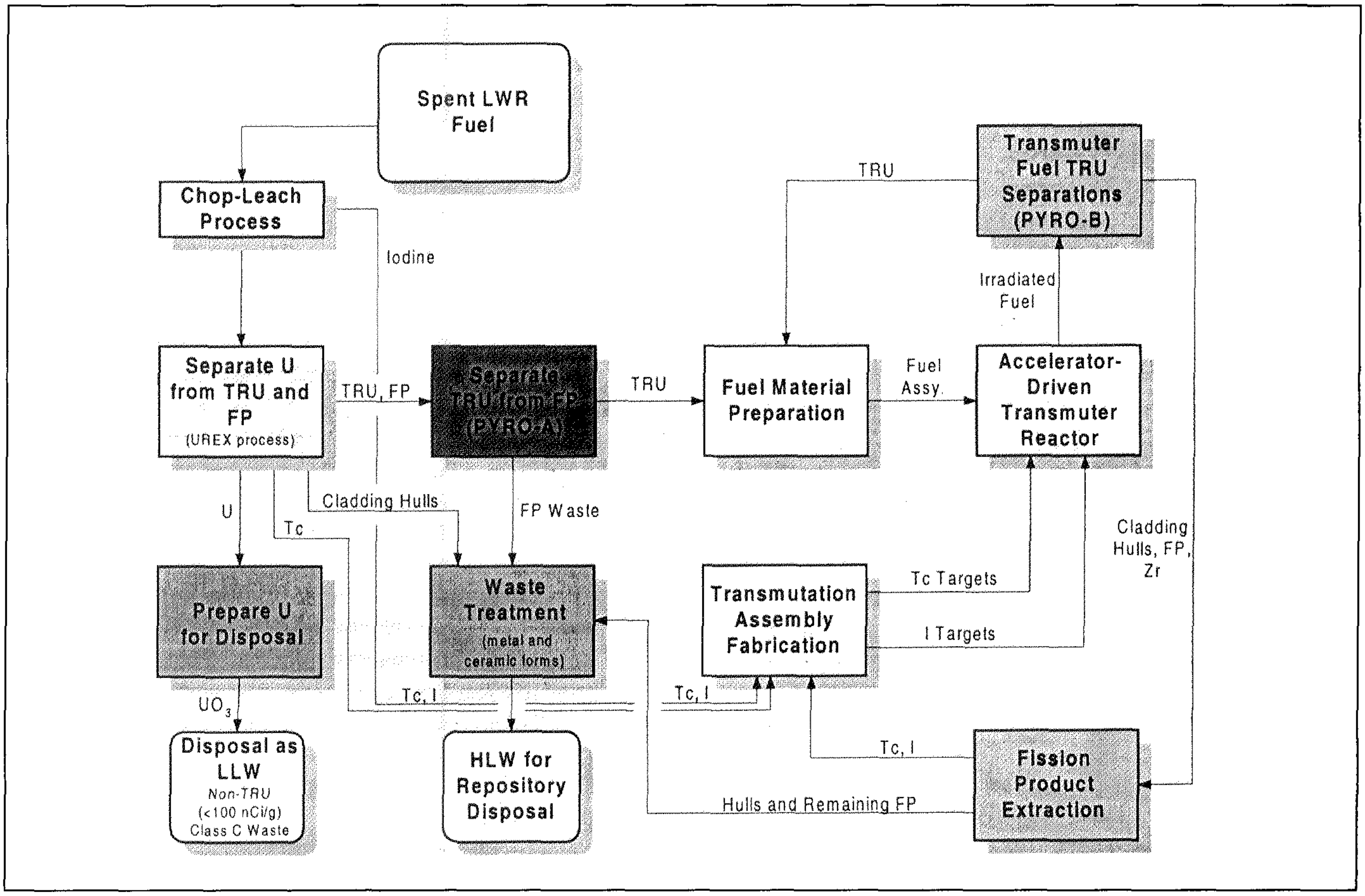

Figure 1. Hybrid processing system chosen for the U.S. single-tier transmutation system

plant was intended to generate electricity for delivery to the commercial grid, for the purpose of offsetting in part the costs of construction of the system. This required the development of a highly reliable LINAC accelerator that could meet the continuous operation requirements of a commercial generating plant.

The chemical separations scheme chosen for this single-tier system was a hybrid hydrometallurgical and pyrometallurgical process as shown in Figure 1. An aqueous solvent extraction system was selected for the processing of LWR spent fuel because such processes are used commercially in Europe and Asia for the purpose of LWR spent fuel treatment and are capable of dealing with the high throughput requirements of the U.S. system. The commonly used PUREX process was modified for U.S. use to avoid the separation of plutonium; the modified process, named UREX, extracts pure uranium, in addition to product streams of iodine and technetium. The uranium, with a ^{235}U enrichment level near that of natural uranium, is sent to disposal or long-term storage. The transuranic elements and other fission products are including in the UREX liquid raffinate, which is calcined to dryness. The resulting oxide powder is sent to a pyrochemical process known as PYRO-A, where the transuranics are separated from the fission products. The fission products go to high-level waste form production, in which the active metal fission products are incorporated in a composite ceramic waste form and the noble metal fission products, together with LWR fuel cladding hulls, are immobilized in a zirconium-based metallic waste form. The transuranics are fabricated into non-fertile (i.e., non-uranium bearing) fuel elements for the accelerator-driven transmuter reactor. After reaching goal burnup, these fuel elements are discharged and processed by another pyrochemical process that has been designated PYRO-B. The PYRO-B process recovers unburned transuranics and newly generated iodine and technetium for recycle to the transmuter. Other fission products are incorporated in the same types of waste forms produced in the course of LWR fuel processing.

Partitioning and transmutation obviously raises a major policy issue: that of reprocessing. Although the process proposed for the single-tier system does not require the separation of plutonium, it is clearly only a matter of a minor change to the process to accomplish pure plutonium extraction. Current policy on reprocessing remains that as stated in previous administrations: that the United States will not separate plutonium for recycle in civil power reactors. Clearly, if the benefits of partitioning and transmutation are to be realized, it will be necessary to reformulate the policy. Because no process that involved the chemical separation of any constituents of spent nuclear fuel can be made immune to modifications that would permit the separation of plutonium, a new national policy should deal with the realities of proliferation resistance. The recovery of plutonium, for example, requires access to actual weapons, stored plutonium, or spent fuel. The weapons states presently restrict access to nuclear weapons to the best of their abilities, and stored plutonium also receives careful protection. No such controls are applied to spent fuel, with reliance placed instead upon self-protection from fission product decay radiation. After several half-lives of the most active fission products have passed, this protection is substantially degraded and a potential proliferator can gain access to the plutonium in the spent fuel by means of well-known chemical processes. This argues for more rigid controls to be placed on spent fuel, and could be an incentive for removal and destruction of the spent fuel plutonium content. A new and more timely national policy might be that spent fuel would be treated as an asset under rigorous inventory control and sent to a processing plant for transuranic separation following a limited cooling period. The recovered fissile materials must then be immediately incorporated into recycle fuel, without offsite transport of the separated materials and without an increase in the national inventory of separated plutonium. Chemical processing and fuel fabrication would be of necessity carried out under a full IAEA safeguards regime.

Such a new national policy would address the real issues of nuclear proliferation through the diversion of plutonium from spent fuel. It would also permit the harmonization of U.S. policy with that of other countries engaged in nuclear electric power generation. Under such a policy, a multi-tier system would be practical, with the current fleet of commercial LWRs comprising the zeroth tier. Plutonium and neptunium recovered from spent fuel discharged from these reactors could be recycled into plutonium-burning Tier 1 reactors that could be MOX-burning LWRs, gas-cooled reactors such as the PBMR or GT-MHR, or dedicated fast reactors. The minor actinides (Am and Cm) recovered from the LWR spent fuel, together with minor actinides and higher isotopes of plutonium recovered from the processing of spent Tier 1 reactor fuel, would be directed to a Tier 2 fast spectrum reactor that could be a critical reactor or an accelerator-driven reactor. These multi-tier concepts would require a separations technology featuring the separation of plutonium from the LWR component. Tier 1 and Tier 2 fuels are assumed to be non-fertile, with significant fissile content upon reaching limiting burnup levels prior to recycle. Under these conditions, the processing system most likely to be used would be an aqueous system similar to UREX for the LWR spent fuel, with an additional step for Pu/Np extraction. Pyrochemical processes for the Tier 1 and Tier 2 fuels would be most practical, because the higher fissile content and the higher alpha activity of these fuels would preclude the use of contemporary aqueous processes due to criticality concerns and solvent degradation. As the deployment of fast reactors proceeds, it may become advantageous at some point to convert a fertile fuel, utilizing stored uranium recovered from LWR spent fuel. These reactors could then perhaps evolve to a new sustainable system involving breeding.

Development of the technologies for a U.S. partitioning and transmutation system is underway and excellent progress is being made. Such a system points the way to a sustainable nuclear power enterprise that will supply the nation's electricity needs for centuries to come. Under the current schedule, far-reaching decisions as to the nature and scope of a deployable system will be made within the next decade. A pilot-scale demonstration of the system could follow thereafter.

Proliferation Resistance: New Visibility and Myths

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Abstract

The recent rebirth of interest in nuclear power has ignited discussions of the role of intrinsic proliferation resistance in increasing acceptance of nuclear power options. This paper reviews some of the proposed measures and argues that they need to be evaluated in an environment that considers the role of safeguards in preventing proliferation. Approaches that do not consider both technical and institutional measures have the potential to damage the credibility of the nuclear community.

Introduction

On April 20, 1977, President Jimmy Carter announced that the United States would forego reprocessing of civilian nuclear spent fuel because this practice constituted an unacceptable proliferation threat. Further, he called upon the other nations of the world to follow the U.S. example.[1] In effect, a once-through fuel cycle using uranium-based fuels was judged to be more proliferation resistant than one based on plutonium (Pu) recycle. Over the last twenty-four years, this determination together with concerns about safety have had a chilling effect on nuclear power throughout much of the world. Proliferation concerns of course are not new. Indeed, finding a way to enjoy the benefits of nuclear power while avoiding increasing the number of states armed with nuclear weapons challenged some of the best minds of the 20th century.

The key to nonproliferation that has been consistently identified is restriction on the availability and use of nuclear material. Historically, two approaches have been pursued. The first, which has been called intrinsic proliferation resistance,[2] is to design into a fuel cycle technical features that complicate the task of producing and separating nuclear material. The second, extrinsic proliferation resistance, is the use of active, institutional measures such as domestic materials control and accounting and international safeguards and export control to prevent diversion of material from a civil fuel cycle to a weapons program. The balance of this paper further explores these two forms of proliferation resistance and points out that they are both necessary but that neither is sufficient unto itself. Further, it discusses the need for care in the design of new intrinsic measures to avoid needlessly complicating extrinsic measures.

The Search for Intrinsic Proliferation Resistance

The goal of intrinsic proliferation resistance is to place hurdles in the path of those wishing to produce nuclear materials for weapons use by making fuel-cycle materials less attractive to proliferators. Historically, this has meant a state diverting nuclear material from a civil nuclear power program to a clandestine military program.[2] However, similar measures would complicate the problems faced by a terrorist organization. The following hurdles may be considered: fissile materials in the fuel cycle are kept as dilute as possible, opportunities for further transmutation are limited, the processes of concentration are made difficult through the use of highly refractory matrices, and plutonium stockpiles that have accumulated in the current fuel cycle are reduced through transmutation. The intention is for these complications to help to deter would-be proliferators.

The DOE Energy database for 1977 to 2001 has 231 articles on proliferation resistance, and among these no broad consensus has developed on what proliferation resistance means. Even with these uncertainties, a large number of these papers propose new technologies to enhance the proliferation resistance of the nuclear fuel cycle. Creative approaches to increase intrinsic proliferation resistance are not in short supply. These concepts of proliferation resistance fall into three broad categories: (1) reducing (or slowing the expansion of) total fissile inventories, (2) increasing the work required to access or separate fissile material, and (3) minimizing the weapons value of available Pu by achieving higher burnup, which results in less favorable isotopic compositions. Examples of the suggested approaches include the following:

- The Integral Fast Reactor (IFR) concept is based on the use of a liquid-metal-cooled fast neutron reactor using metallic fuel (probably U-Pu-Zr). Pu would be recycled within the process using pyrochemical (molten salt) technology. Once started, proliferation resistance would be conferred by never producing a separated Pu stream, never discharging waste with significant levels of Pu, having very efficient destruction of actinides due to the fast neutron spectrum, and having the recycled Pu still contain some fission products.[3,4]

- Alternative reprocessing strategies for production of fuels for thermal reactors, such as using a variety of technologies that produce a product material mixed with uranium and some fission products. As with the IFR, no pure Pu stream is produced, and the fission products, as well as the minor actinides, complicate recovery of Pu for weapons purposes. Examples include Coprocessing,[5,6] AIROX,[7] and DUPIC.[8]
- Replacement of U in mixed oxide (MOX) fuels with a nonfertile matrix (one that will not capture neutrons to produce fissionable products such as ^{239}Pu and ^{233}U). Candidates include Al_2O_3, MgO, CaO, $MgAl_2O_4$, CeO_2, and ZrO_2.[9]
- Reactor fuels designed to achieve very high burnups that will produce Pu that is thought to be less attractive because of its high ^{240}Pu concentration.[10]

While each of these address one or more of the proliferation resistance categories described above, they all have the potential to complicate the materials accountancy aspect of nuclear safeguards and/or result in a product stream that is arguably more attractive to a potential proliferator than conventional spent pressurized water reactor (PWR) fuel. For example, it will be more difficult to accurately account for the quantity of material consumed in IFR and other separations approaches that do not yield a pure Pu stream. Also in the case of DUPIC, nonfertile MOX reactors and high-burnup fuels result in elemental Pu concentrations that are higher than those of spent PWR fuel, making the material more attractive for at least part of the fuel cycle. Objectively weighing these trade-offs and evaluating whether they increase or decrease proliferation resistance would be required before any option were implemented. Moreover, the proliferation resistance of these approaches may depend on other nuclear capabilities (isotope production processing, etc.) within a given country.

The Proliferation Resistance Threshold

At this juncture it is useful to ask the question, "What degree of intrinsic proliferation is necessary to deter a proliferator?" This question cannot be answered with any precision, but it is possible to examine at least two benchmarks against which intrinsic barriers might be compared: enrichment of natural U to highly enriched U (>20 percent ^{235}U) and production of Pu from natural U.

Because of a number of inherent intrinsic barriers, separation of significant amounts of fissile nuclear material is not an easy process. It is complicated by the low concentrations of fissile materials in nature. ^{235}U constitutes only 0.7 percent of natural U, and U ores contain generally at most only a few percent U of all isotopes. Production of highly enriched uranium (HEU) then requires the isotopic enrichment of ^{235}U. Enrichment to weapons-grade material is an expensive and tedious process, which must select for the desired isotope against other isotopes using physical properties, particularly mass, that at best differ by only 1.25 percent.

Pu, of course, is essentially nonexistent in nature. It is produced by the transmutation of ^{238}U in an intense neutron field. For practical purposes, this process requires a nuclear reactor, which relies on the fissioning of ^{235}U to produce sufficient neutrons to be captured by the more common isotope, ^{238}U. Even then, the concentration of the product is only on the order of 0.012 percent Pu for production reactors and 1-2 percent in commercial spent fuel. The Pu must then be concentrated from an intensely radioactive (45 Curies/kg fuel), chemically toxic mixture that generates significant quantities of heat.[11]

Despite these challenges, seven nations have tested nuclear weapons. The originators of nuclear weapons, the United States, along with its British and Canadian allies, did so in an attempt to influence the course of the most destructive war in human history. At the end of World War II, Canada decided that its future national security no longer required that it have a military nuclear program. The United Kingdom, on the other hand, moved forward to obtain its own nuclear stockpile in order to secure its international position. The Union of Soviet Socialist Republics and the People's Republic of China developed nuclear weapons programs to counter the power of the Western Alliance. France felt that it needed weapons to enhance its position within the Alliance and as a final guarantee of national security in the event of a Warsaw Pact-NATO confrontation. India and Pakistan made similar judgments in light of severe regional rivalries. Although it did not test, South Africa developed nuclear weapons in an effort to prop up a regime that was considered anathema to most of the world but later destroyed its stockpile when it was clear that the days of that regime were numbered. Based on post-Gulf War inspections, it is clear that Iraq pursued a large, complex, and expensive weapons program in an effort to become a regional hegemon.

If the reports in the popular and scholarly literature[12,13,14] are to be given credence, each of these programs required the expenditure of considerable amounts of national wealth and in some cases heroic levels of activity. While one can argue about the correctness of their perceptions of the advantages of possessing nuclear weapons, it is abundantly clear that these states believed that they needed nuclear weapons and were prepared to take the steps necessary to obtain them.

While many of the proposed intrinsic proliferation resistance measures would seriously complicate and possibly delay a weapons development program based on the diversion of fuel from a civil fuel cycle, it is hard to argue that they would provide an insurmountable barrier given the levels of motivation that these states felt. Intrinsic proliferation resistance measures could, however, increase the probability that a state's activities would come to the notice of the international community, if the state used the commercial fuel cycle as a proliferation pathway.

Extrinsic Approaches to Nonproliferation

Faced with the obvious examples of states going to great lengths to overcome the naturally occurring intrinsic barriers to produce nuclear materials, the world community turned to institutional approaches to limit the use of nuclear materials for weapons by verifying the state's compliance with their treaty obligations. This resulted in the current multi-faceted international nonproliferation regime that includes a network of treaties, agreements, national laws, export controls, and multilateral inspections. This section focuses on two measures at the heart of the current international safeguards regime: materials accountancy and containment/surveillance. These measures, when applied in the context of international safeguards, are aimed at assuring that nations that have pledged not to develop nuclear weapons will not try to subvert their guarantee through the diversion of nuclear material from civil programs. The potential for additional formal openness and possibly wide-area environmental monitoring under the IAEA's strengthened safeguards protocol may further improve safeguards[15] but are not discussed in this paper.

It is well known that the quality of nuclear materials safeguards depends fundamentally on the nature of the facilities and materials being monitored. Care in selecting the time and place for these measures can significantly improve the level of confidence in their results. Examples of these lessons include the following:

- Nuclear materials in the form of items (well-characterized material sealed in containers) require less effort to control than material in bulk processes (reprocessing, MOX fuel fabrication, etc.)
- Nuclear material should be in a chemical and physical form that facilitates measurement. This puts an emphasis on the homogeneity of the material, the nature of the matrix, the location in the process stream, etc.
- Surveillance works best when it is applied to areas where there is limited extraneous activity.
- Determining bulk quantities of SNM by weighing usually has higher precision and accuracy than volume measurements. However, both approaches will require either destructive or nondestructive assay to determine what weight-percent of SNM is in the compound or solution.
- Experience shows that lower-intrusive measures will enhance the host state's acceptance of the safeguards regime. Examples of this include the use of remote/unattended monitoring and the substitution of quicker, cheaper nondestructive assay techniques for destructive assay approaches.

Comparison of these points with the current once-through fuel cycle reveals its favorable qualities. All bulk handling is limited to less attractive low-enriched or natural U, and all Pu is generated in items (fuel rods). Fuel rods are generally stored in low-activity areas that make surveillance more effective. Problems do arise with the difficulty of directly measuring the fissile material content of spent fuel. This makes direct determination of a materials balance at reactors impossible. However, the item nature of the material and the ease of surveillance compensate. The greatest weakness of the approach is that spent-fuel Pu may require some form of monitoring for tens of thousands of years, whether spent fuel is stored or disposed of. In addition, over long time scales, the attractiveness of Pu in spent fuel increases with time because of the decay of short-lived, highly radioactive fission products; uncertainty in the safeguards regime also increases because it depends on the stability of nations and agreements (which arguably have "half lives" on the order of hundreds of years and dozens of years, respectively).

In contrast, a fuel cycle based on Pu recycle, for example, has a greater short-term risk because of the bulk-handling nature of reprocessing and MOX fuel fabrication; the presence of difficult-to-measure materials, including solutions whose volumes must be determined; the need in the current processes to separate Pu; and the relative ease of separating Pu from unirradiated MOX by chemical means. The intended proliferation benefit of Pu recycle is long-term reduction in total separated and spent-fuel Pu inventories.[16]

A proper comparison of these two cycles obviously must find a way to handle the matter of long-term, lower risk verses short-term, higher risk of proliferation. This tradeoff requires at least two conditions: (1) nuclear power using fertile fuels is terminated, and (2) the Pu recycle continues through many recycling "generations." If the first assumption is not correct, then a secular equilibrium of spent fuel will persist for as long as civilization uses nuclear power.[17] If the second assumption is not correct, then there will only be an order of magnitude reduction in total Pu, at best.[9] This still would leave a substantial quantity of Pu in spent fuel, in similar concentrations to that of the original spent fuel.

Discussion

Well-intentioned efforts to promote intrinsic proliferation resistance of advanced fuel cycles can result in misleading or overly optimistic statements of the benefits of intrinsic measures. The long-term credibility of the nuclear community depends on avoiding these overstatements.

Several discussions on proliferation compare the growing quantities of spent fuel with current stockpiles of weapons-grade Pu. Associated statements or implications are that proliferation concern grows linearly with this growing stockpile of civil Pu. Arguably proliferation concern does grow with the amount of available Pu, but there is clearly not a linear relationship. For example, IAEA and most state accounting verification requirements provide for statistical sampling verification measures. Using DOE orders as a model, statistical sampling may result in an upper limit of ninety-one items sampled during a physical inventory (assuming no anomalies are detected). This value is approached asymptotically as the number of spent fuel items grows.[18]

Similarly pragmatic considerations apply to analyses on a country-by-country basis on what constitutes proliferation concern. A stable government with a mature and effective state system of accountancy arguably presents a smaller proliferation concern than a state with nuclear power that either has an unstable government or an ineffective state system of accountancy and control. This may hold even if the former has orders of magnitude more Pu in more attractive forms than the latter. (This comment does not apply to the IAEA's consideration of proliferation risk but may be a pragmatic analysis done by individual states in assessing their national security interest and commerce in nuclear technologies.)

Recycle is argued to be an effective means to reduce long-term proliferation risk of spent fuel.[9] For reasons stated above, a single-step recycle only improves proliferation risk of that material if a country has very small throughput of spent fuel. In these cases it is more cost-effective and more proliferation resistant for another country with more advanced nuclear capabilities to take custody of the spent fuel and either dispose of or reprocess it.[17, 19] Reprocessing may have merit from other considerations, but it is difficult to envision how reprocessing alone addresses proliferation resistance on a long-term, global scale.

Another argument made is that higher burn-up fuels are fundamentally more proliferation resistant that other fuels.[9] While it is assumed that all or most weapons in the world's stockpile are made of "weapons grade" Pu (~^{240}Pu/^{239}Pu < 10 percent), high burnup Pu can be used to create fission devices.[20] IAEA (and U.S. domestic) safeguards criteria, which treat all Pu as the same (except for >80 percent ^{238}Pu), reflects this international consensus.

Summary

The historical record of states being willing to take extreme measures to develop nuclear weapons when they judge them to be necessary to achieve their national security goals creates a high bar that any form of proliferation resistance must surmount. It further argues that approaches like those currently employed that are based on both intrinsic and extrinsic measures are more likely to be successful than approaches that overemphasize one at the expense of the other. As new intrinsic measures based on new reactor designs and novel processing systems are proposed, it is important that these systems be compatible with appropriate extrinsic measures. It also implies that the safeguards community must become involved in the development of these new intrinsic measures at the earliest possible time to either properly tailor existing complementary extrinsic measures or to develop new ones.

The reverse is also true. Increases in the intrinsic proliferation resistance of the fuel cycle may permit increases in the efficacy and efficiency of safeguards. Whether the inverse (improvements in safeguards relaxing the need for intrinsically proliferation-resistant fuel cycles) is true would be an interesting topic for further analysis. To quote from a recent DOE-sponsored study of research and development opportunities in proliferation resistance:

> It would appear that the intrinsic barriers in some systems could be strengthened by successful completion of R&D, but the ongoing need to preserve the strength of extrinsic barriers has been strongly reinforced in the analysis of the Task Force to date. In addition, as an important matter, the application of extrinsic barriers to specific reactor and fuel cycle systems can be made more effective if proliferation resistance assessments, including trade-off studies between intrinsic and extrinsic measures, become an integral part of the overall design and engineering process.

None of the intrinsic proliferation resistance strategies proposed to date have been developed in sufficient detail to allow the kinds of analyses that have been applied to the current fuel cycles. However, when such studies are done, it is hoped that both intrinsic and extrinsic proliferation resistance will be given equal weight in the total system.

It is likely that global environmental considerations and increasing energy requirements will eventually result in the growth of nuclear energy. Anticipating this growth in the use of nuclear energy, discussions on proliferation resistance and proliferation resistant fuel cycles have become increasingly visible. However, the role of proliferation resistance should be defined, kept in perspective, and evaluated carefully. Proliferation resistance does not justify the use of nuclear energy. Rather, proliferation resistance is a factor that should be considered in evaluating a long-term, stable energy strategy. Moreover, overzealous use of the term "proliferation resistance" runs the risk of damaging the credibility of the nuclear community, particularly when there is no common or accepted definition of the phrase.

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The Need for Nuclear Energy—
Four Years After the Harvard Speech
America's Energy Challenge—
The Nuclear Answer

■

U.S. Senator Pete V. Domenici
New Mexico U.S.A.

George Bush Presidential Conference Center
Texas A&M University
November 19, 2001

■

Earlier this year, blackouts in California were front-page news. There was serious discussion about our energy crisis. The situation eased in the last few months thanks to mild weather and increased conservation. The economic slowdown after the terrorist actions will also depress energy needs for awhile. But while the urgency of an energy crisis has abated somewhat, the basic facts haven't changed. Our nation and the world are facing immense shortfalls in energy, both in the short term and even more so in the long term.

In October 1997, I gave a speech at Harvard that anticipated the severity of the energy problems for both this nation and the world. In that speech, I called for a national dialogue on nuclear power. I'd like to contrast that with another speech given that same month by President Clinton as he laid out his strategy for negotiations at Kyoto.

He talked about renewables, conservation, and his deep concerns about emission of greenhouse gases—but he never said one word in that speech about nuclear. By ignoring nuclear energy, he dismissed the largest source of clean electricity we have today, or will have for a long time.

Today we have a different administration. Thanks to the leadership of President Bush, we also now have a realistic energy policy that recognizes the need to increase all sources of energy. I am very pleased that nuclear energy figures prominently in his plan. (In passing, I should note that I won't take time here to discuss the unfortunate choices made by the Senate majority party to avoid committee debate on a legislative version of the president's energy plan.)

The Vice President's National Energy Policy stated that:

> *The Policy Development Group recommends that the President support the expansion of nuclear energy in the United States as a major component of our national energy policy.*

President Bush accepted that recommendation without hesitation. In his speech releasing and endorsing the National Energy Policy, he noted that:

> *"America should expand a clean and unlimited source of energy—nuclear power"*

and added:

> *"By renewing and expanding existing nuclear facilities, we can generate tens of thousands of megawatts of electricity, at a reasonable cost, without pumping a gram of greenhouse gas into the atmosphere."*

In contrast to President Clinton's speech, my Harvard speech certainly mentioned the "nuclear" word—considerably more than once. I discussed several concerns and challenges, with perhaps the most critical issue being the focus of anti-nuclear groups only on the risks involved with nuclear. They simply don't discuss its benefits, or discuss the solid technical solutions for the risks. Unfortunately, their actions do not help the public toward a balanced view of this complex issue.

This issue is hardly unique to nuclear energy. Energy production, by any technology, represents a trade-off between risks and benefits. The public must have information to fairly judge both sides of this equation for each energy source. With that kind of comparison, which you and your colleagues can help to frame, nuclear energy fares very well. From this debate, and from continued progress on many fronts, I believe that nuclear energy will play an increasing role in future domestic and global electrical supplies.

As you know, there's a long list of real benefits from nuclear energy, fundamental to its superb record in supplying clean, reliable, low cost electricity. In fact, its operating costs are among the lowest of any source, even 10 percent below coal.

The output of nuclear plants has risen dramatically since the 1980s. In 2000, our plants generated over 91 percent of their maximum output. Since the 1980s, our average unit output has increased by over 20 percent. That's equivalent to gaining over twenty new nuclear plants without building any.

Safety has been a vital focus, as evidenced by a constant decrease in the number of emergency shutdowns, or "scrams," in our domestic plants. In 2000, for the fourth year in a row, the number of unscheduled reactor shutdowns was zero.

Another example of the exemplary safety of well-run nuclear reactors is our nuclear navy. They now operate about ninety nuclear powered ships. Over the years, they've operated about 250 reactors. They've accumulated over twice the number of reactor-years as our civilian sector without any significant incidents. They are welcomed into over 150 major foreign ports in over fifty countries, only excluding New Zealand.

Some question the safety of nuclear plants in light of the recent terrorist attacks. I concur that it is appropriate that we carefully evaluate the safety of all major nodes of our critical infrastructures—chemical plants, electrical transmission systems, pipelines, oil tank farms, and nuclear plants, to name a few. But we need to remember that nuclear plants are probably the most hardened commercial structures in the world.

In addition, critics of nuclear energy need to remember that we and our allies control the fuel supplies for nuclear energy. That's in stark contrast to petroleum-based fuels where the fuels are largely controlled by sources outside the United States who will consider their own best interests ahead of ours.

In my view, it just doesn't make sense to conclude that any potential target that cannot be hardened against any and all acts of war should be abandoned, as some of the antinuclear groups might suggest for nuclear plants. With that line of reasoning, we should be abandoning airplanes and high buildings.

Instead, I think the president's leadership is taking us on precisely the correct course—to work diligently to root out the causes and sources of terrorism around the world. Only then can we return to enjoying the lifestyle that we value and that we want to preserve for our future generations.

Some have sought to limit nuclear energy by arguing that transportation of spent fuel is too dangerous. These arguments are being raised again in light of the terrorists' actions. Indeed, such transportation must be done with great care, but it's also something that we already do very well. There has never been a breach in a spent nuclear fuel container during almost 3,000 American shipments covering 1.6 million miles.

The environmental benefits of nuclear energy are immense. It is essentially emission free. We've avoided the emission of more than two billion tons since the 1970s. A recent Japanese study showed that nuclear was the lowest electricity source in overall carbon dioxide emissions except hydropower. The inescapable fact is that nuclear energy is making a vital contribution to our environmental health and security.

In fact, we could be doing much more with nuclear energy to promote the health of our environment. For example, France generates 76 percent of its electricity from nuclear. That helps France achieve spectacular results for minimal emissions of carbon dioxide. Their emission of CO_2 per dollar of GDP is almost three times lower than ours.

Since that speech at Harvard, many of you in this room participated in the national dialogue that followed. From that dialogue and many concrete actions, the nuclear industry of 2001 bears little resemblance to that of 1997.

In 1997, it was a real challenge to find a headline talking about the future of nuclear energy. There was little optimism for re-licensing, and any talk about a new plant would have been dismissed as lunacy.

Many factors contributed to this dramatic shift. I think that Harvard speech helped. Congressional initiatives helped and support in Congress is now much stronger. The president's strong support for nuclear energy is a key development. And initiatives, including some that I helped to encourage, to streamline the Nuclear Regulatory Commission also helped. Today there's real enthusiasm for expanded use of nuclear energy.

Today, six nuclear plants have been re-licensed to add up to twenty years to their service. These six studies took between seventeen and twenty-three months. That's in contrast to the old NRC that took eight years studying one application for an enrichment plant.

There are fourteen re-licensing applications pending at the NRC now. And there are twenty-six renewal applications expected in the next few years.

I've also been approached by several utilities who tell me to expect three applications for operating licenses of new plants by the end of 2002. Around the world, there are ninety-three new reactors planned by 2016, thirty-seven are under construction today. Eight are scheduled for operation in 2002.

Earlier this year, when I have introduced extensive legislation to support and encourage future nuclear energy development, I found many senators eager to help. Eighteen senators joined me in cosponsoring this bipartisan legislation—a most impressive number. Nuclear energy is included in several other energy bills as well.

For the current fiscal year, nuclear energy is well supported, including:

- $17.5 million for university support to ensure educational resources needed for nuclear power,
- $7 million for nuclear energy plant optimization to improve reliability and productivity of our 103 existing nuclear power plants,
- $32 million for nuclear energy research,
- $7 million to continue work on advanced reactors including Generation IV,
- $5 million for cost-shared programs with industry to support new licensing applications at the Nuclear Regulatory Commission,
- $18 million to continue the research on improved understanding of the health impacts of low doses of radiation,
- $5 million for continued joint work with Russia on high temperature, gas-cooled reactors,
- $10 million for our Nuclear Regulatory Commission to prepare to license new plants, and
- $50 million for research on reprocessing and transmutation to reduce quantities and toxicity of final waste forms.

In closing, I'd like to discuss two specific areas. One involves the largest remaining roadblock to rebirth of a new era for nuclear energy. The second involves my vision for the role of nuclear energy around the world.

Perhaps the most frustrating area of challenge for future use of nuclear energy involves our lack of credible strategies to deal with spent fuel. The barriers to progress in this area are entirely political, and not technical. This is one area that I fear could doom our nation's prospects for future use of nuclear energy if we don't make faster progress.

We continue to focus on Yucca Mountain as a permanent repository, despite the fact that it is not obvious that permanent disposal of spent fuel is in the best interests of all our citizens. (See Waste Package and Material Testing for the Proposed Yucca Mountain High-Level Waste Repository on page 31.) It's even less obvious to me that we should equate the terms "spent fuel" and "waste."

Depending on our future demands and options for electricity, we may need to recover the tremendous energy that remains in spent fuel. Furthermore, strong public opposition to disposal of spent fuel, with its long-term radiotoxicity, may preclude use of repositories that simply accept and permanently store spent fuel rods.

For these reasons, I favor centralized storage for a period of time in a carefully monitored, highly secure, fully retrievable, configuration. At a minimum, this type of storage could allow concentration of the spent fuel from its seventy-plus locations around the country into one or more centralized, tightly controlled storage areas.

Such a monitored storage facility can allow future generations to evaluate its own needs for energy and decide on appropriate reuse of spent fuel or final disposition. In a very real sense, this facility would represent a national nuclear fuel reserve for future generations.

Congress has worked very hard to make progress on the spent fuel issues. Last year, a bill passed both houses of Congress by large margins that created an "early receipt facility" in Nevada; it also created an office within the department to seriously evaluate strategies for spent fuel. The vote for passage was 253-167 in the House and 64-34 in the Senate—those are both impressive margins. Unfortunately, President Clinton vetoed this bill, and the veto override vote failed in the Senate by a single vote.

That office would have studied alternative management strategies for spent fuel, including both reprocessing and transmutation. We need to do the research today that can allow tomorrow's leaders to decide whether some forms of reprocessing and transmutation can lead to reduced risks and enhanced benefits from nuclear energy.

Transmutation, as part of an integrated national or international strategy for spent fuel, could dramatically alter the radiotoxicity of final waste products destined for a repository and allow recovery of much of the residual energy in spent fuel. This option might involve systems utilizing both existing or new reactors, plus accelerators, to develop a new fuel cycle. I've successfully championed a major research program for this effort, Advanced Accelerator Applications or AAA, which is funded at $50 million this year.

If this program is successful, we can recover the residual energy in spent fuel. We would also produce a final waste form that is no more toxic, after a few hundred years, than the original uranium ore. If we reach that goal, I think public concerns about waste will be dramatically reduced.

I was very pleased that the president endorsed these studies in the National Energy Policy which:

> *"recommends that, in the context of developing advanced nuclear fuel cycles and next generation technologies for nuclear energy, the United States should reexamine its policies to allow for research, development and deployment of fuel conditioning methods (such as pyroprocessing) that reduce waste streams and enhance proliferation resistance. In doing so, the United States will continue to discourage the accumulation of separated plutonium worldwide."*

In addition, the new policy also stated:

> *"The United States should also consider technologies, in collaboration with international partners*

> *with highly developed fuel cycles and a record of close cooperation, to develop reprocessing and fuel treatment technologies that are cleaner, more efficient, less waste-intensive, and more proliferation resistant."*

Before closing, I'd like to mention my vision for a major future role for nuclear energy. It involves the increasing globalization of the world's economies. I don't believe that the world can develop in the peace and harmony that we all want unless the large differences between the "have" and "have-not" nations are addressed.

The standards of living for billions of people lag the Western world by extremely large factors. Reliable sources of electricity underpin the economies of the developed world. They are one of the factors determining each nation's standard of living and are certainly one of the prerequisites for modernization in all developing nations. As you are well aware, there is now a vast gulf in energy usage per capita between Western nations, especially the United States, and the developing world.

I firmly believe that globalization offers immense benefits to the American people. We benefit from a network of global trading partners. These partners help create markets for our high technology products. But this will happen only if the rest of the world increases its standards of living to levels that closely match our own. And that won't happen unless they have access to clean, reliable, low cost sources of electrical power.

Nuclear energy, appropriately designed to avoid proliferation concerns and operate in absolute safety, can play a major role in energizing the rest of the world. It can be one of the solutions to providing global energy needs and helping to bring many of the poorer economies into the 21st century.

In closing, I want to commend Texas A&M University on a tremendous record of achievements in your first 125 years of existence. Your strong program in nuclear engineering is most impressive. Programs like yours are essential for training the next generation of young scientists and engineers who will be the ones evaluating, building, and operating the new nuclear plants that can continue to provide us with the benefits of nuclear technologies in the next millennium.

Strengthening Nuclear Security Against Post-September 11 Threats of Theft and Sabotage

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Abstract

The appalling events of September 11, 2001, require a major international initiative to strengthen security for nuclear materials and facilities worldwide, and to put stringent security standards in place. This paper recommends a range of specific steps to upgrade security at individual facilities and strengthen national and international standards, with the goal of building a world in which all weapons-usable nuclear material is secure and accounted for, and all nuclear facilities are secured from sabotage, with sufficient transparency that the international community can have confidence that this is the case.

Introduction

The attacks of September 11, 2001, make clear that the threat of large, well-organized global terrorist groups bent on causing mass destruction is not hypothetical but real. Attackers armed with box-cutters achieved horrifying destruction. There can be little doubt that if they had had access to nuclear weapons, they would have used them. Osama bin Laden has called the acquisition of weapons of mass destruction a "religious duty." Indeed, there is evidence that bin Laden's Al Qaeda organization has been seeking nuclear weapons and weapons-usable nuclear material—and that they had procured diagrams of U.S. nuclear power plants, possibly in preparation for an attack on such a facility.[1]

On September 11, the threat revealed itself to be bigger, smarter, better organized, and more deadly than the threats most of the world's security systems were designed to defend against. We must ensure that our defensive response is every bit as intelligent and capable as the attackers of September 11. Fragile modern industrial societies present a wide range of targets for attacks that could cause mass destruction or mass disruption, many of which would be far easier to attack than nuclear weapons, materials, or facilities. Nevertheless, given the horrifying consequences if a terrorist group did manage to acquire a nuclear explosive or destroy a nuclear power plant—or if nuclear weapons or fissile material to make them were to fall into the hands of a hostile state —every reasonable effort must be made to ensure that these materials and facilities are effectively secured.[2]

International Arms Control: Now More Than Ever

This paper focuses on steps to strengthen security for nuclear material and facilities. But for that effort to be fully effective, it will have to be built on a solid structure of arms control and nonproliferation measures binding states to norms and rules of behavior, and to cooperative approaches to security problems. Arms control and nonproliferation agreements bind bureaucracies into implementing good practices, add strength to the arguments of domestic advocates of improved controls, and give governments more authority in regulating facility operators and private enterprises. In the case of nuclear materials, the necessary regime would include a strengthened and adequately funded IAEA safeguards system, international requirements to protect nuclear material from theft and sabotage, a verified cutoff in the production of fissile material for weapons, international verification of the removal of large quantities of fissile material from military stockpiles, and other measures.[3] Politically, these efforts cannot be a one-way street: if the United States wishes to build international political support for new security measures that will involve constraints and inconveniences for non-nuclear-weapon states, it will have to re-engage on multilateral arms control, including supporting measures that impose some constraints and inconveniences on its own forces and facilities. As George Bush Sr. remarked on September 13, the terrorist attacks should "erase the concept that America can somehow go it alone in the fight against terrorism, or in anything else for that matter."[4]

The Threat of Nuclear Theft

Limited access to fissile materials—the essential ingredients of nuclear weapons—is the principal technical barrier to nuclear proliferation in the world today. As the U.S. Department of Energy has officially warned:

> *"Several kilograms of plutonium, or several times that amount of HEU [highly enriched uranium], is enough to make a bomb. With access to sufficient quantities of these materials, most nations and even some sub-national groups would be technically capable of producing a nuclear weapon..."*[5]

Acquisition of such material could shorten a proliferator's bomb program from years to months. The international community could be faced with a new threat with little warning. Reactor-grade plutonium poses nearly as great a proliferation threat as weapons-grade plutonium.[6]

Those seeking to acquire nuclear material will go wherever it is easiest to steal, and buy it from anyone willing to sell. Hence, vulnerable weapons-usable nuclear material anywhere is a threat to everyone everywhere. While security for nuclear material has traditionally been seen as solely a national responsibility, the international community has an overwhelming interest in seeing that all such material is secure and accounted for.

Global stockpiles of such material are large and widespread. A decade after the end of the Cold War, there are still some 30,000 nuclear weapons in the world (more than 95 percent of them in the U.S. and Russian arsenals). The world's stockpiles of separated plutonium and HEU, the essential ingredients of nuclear weapons, are estimated to include some 450 metric tons of military and civilian separated plutonium, and over 1,700 metric tons of HEU.[7] These stockpiles, both military and civilian, are overwhelmingly concentrated in the five nuclear weapon states acknowledged by the nuclear Non-Proliferation Treaty, but enough plutonium for many nuclear weapons also exists in India, Israel, Belgium, Germany, Japan, and Switzerland.[8] In addition, some twenty metric tons of civilian HEU exist in civilian nuclear research facilities in at least forty-three countries, sometimes in quantities large enough to make a bomb.[9] As we will see, levels of security and accounting for both the military and civilian material vary widely, with no binding universal standards in place. Some weapons-usable material is so poorly secured and accounted for that, even if it were stolen, no one might ever know.

This problem is most acute today in the former Soviet Union, where the collapse of the Soviet state left a security system designed for a closed society with closed borders, well-paid nuclear workers, and everyone under close surveillance by the KGB, facing a new world it was never designed to address.[10] Nuclear weapons, which are large and readily accountable objects, remain under high levels of security—though even there, scarce resources for maintaining security systems and paying nuclear guards raise grounds for concern. For nuclear material, the problem is more urgent. Many nuclear facilities in Russia have no detector at the door that would set off an alarm if someone were carrying out plutonium in a briefcase, and no security cameras where the plutonium is stored. Nuclear workers and guards protecting material worth millions of dollars are paid less than $200 a month. As a result, there have been a number of confirmed cases of theft of kilogram quantities of weapons-usable material in the former Soviet Union. Russian officials have confirmed that as recently as 1998 there was an insider conspiracy at one of Russia's largest nuclear weapons facilities to steal 18.5 kilograms of HEU—a theft that was stopped before the material actually left the gates.[11] These are the conditions that led a distinguished U.S. bipartisan panel to warn, as the Bush Administration took office in early 2001, that "the most urgent unmet national security threat to the United States today is the danger that weapons of mass destruction or weapons-usable material in Russia could be stolen and sold to terrorists or hostile nation states."[12]

The problem of insecure nuclear material, however, is by no means limited to the former Soviet Union. Indeed, in the United States itself, which probably has some of the toughest physical protection regulations in the world, there have been repeated scandals going back decades over inadequate security for weapons-usable nuclear material.[13] In some countries around the world, there are research facilities with fresh or lightly irradiated fuel that simply do not have the resources to sustain effective security for this material over the long haul. The problem was highlighted by the 19.9 percent enriched uranium seized in 1998 from criminals trying to sell it in Italy, which appears to have been stolen from a research reactor in the Congo.[14] Theft of insecure HEU and plutonium, in short, is not a hypothetical worry: it is an ongoing reality, not only from the former Soviet Union but from other states as well.

At the same time, thousands of people worldwide have critical knowledge related to the manufacture of nuclear weapons and their essential ingredients. In October 2000, an official of Russia's Security Council confirmed that the Taliban had unsuccessfully attempted to recruit a Russian nuclear expert—and that three of his colleagues had left his institute for countries unknown.[15]

The Threat of Nuclear Sabotage or Radiological Dispersal

A range of means is available by which terrorists might seek to disperse radioactive contamination—with the goal either of causing mass fatalities or simply provoking fear and economic disruption.

By far the most potentially devastating radiological attack (but also the most difficult to accomplish) would be to sabotage a nuclear power plant or spent fuel pool—both of which have huge concentrations of intensely radioactive material, and both for which scenarios exist for generating the nuclear or chemical energy needed for dispersing it widely.[16] Studies sponsored by the U.S. Nuclear Regulatory Commission have projected, in a worst case, over a 100,000 deaths from a beyond design-basis accident, as might be caused by successful sabotage.[17] Unlike many other hazardous industrial facilities, nuclear power plants in some countries are protected by containment vessels several feet thick, are equipped with redundant safety systems, and are protected by armed guards and other security systems. To cause a core meltdown and disperse a substantial fraction of the radioactive material into the atmosphere would require defeating a well-protected plant's security systems and destroying or disabling multiple safety systems simultaneously. Nevertheless, nuclear power plants have been the subject of some terrorist interest: threats or attempts to blow up or penetrate nuclear reactors have been reported in Argentina, Russia, Lithuania, Western Europe, South Africa, and South Korea.[18]

In the United States, the NRC requires that nuclear power plants have armed guard forces and a variety of barriers capable of protecting the plants from a small group of well-armed terrorists, possibly working with one insider at the plant; since 1994, the plants have also been required to be protected against truck bombs (though there is ongoing debate as to whether currently required protections are sufficient, as a 1984 Sandia National Laboratories study concluded that large truck bombs could potentially cause unacceptable damage to critical safety systems even if detonated outside the protected area of some plants).[19] Roughly half the U.S. commercial nuclear power plants have failed tests involving a threat of the kind specified in the regulations (typically involving only a few attackers, and an insider involved only in providing information)—where failure means that the test attackers would have been able to destroy critical safety systems.[20] After such tests, security upgrades are undertaken to correct identified deficiencies.

There appear to be wide variations in national practices with respect to security for nuclear material and facilities. A study of the physical protection practices that were described by experts to two 1997 conferences at Stanford and the IAEA showed great variation in practices from country to country: many countries did not even explicitly identify terrorism or sabotage among the threats their systems were designed to defend against.[21] In a small but more recent Stanford survey of country physical protection practices, six of seven respondents did not indicate having any special plans to deal with sabotage, such as a truck-bomb attack, that was intended to spread radioactive material beyond the protected area of a nuclear facility.[22] Significant variations from country to country in security practices for similar facilities were identified by nuclear experts asked by the IAEA to review facilities in ten countries. The experts reported: "Differences in culture, perceived threat, financial resources and technical resources, and national laws are some of the reasons for variations."[23] Overall, internationally required standards, accompanied by an effective and well-financed effort to assist countries in meeting them, could do much to reduce these differences in practices and improve national standards.

In addition to power plants, spent fuel storage and processing facilities are another target whose destruction could conceivably lead to catastrophic releases.[24] In the case of dry cask stores, while it is certainly possible to imagine scenarios in which one or more casks might be destroyed, the prospects for mobilizing large quantities of radionuclides into the atmosphere seem much more limited. Spent fuel transports are another potential target for sabotage. Anti-tank weapons could be used in attempts to penetrate the spent fuel casks and disperse some of the radioactivity.[25]

Other forms of nuclear terrorism have the potential to cause enormous fear and disruption, given the public fear of anything "radioactive," and could result in large economic and cleanup costs, but would not be likely to result in large numbers of fatalities. In particular, although there are many lurid press accounts of the possibility of radiological "dirty bombs," it would be difficult for terrorists to cause large numbers of fatalities by this means.[26]

Current International Cooperative Efforts to Improve Security, Strengthen Standards

In recent years, there have been substantial international cooperative efforts both to upgrade the security of specific facilities around the world and to put more effective security recommendations and standards in place—and a number of new steps have already been taken or proposed since the September 11 attacks.

The United States has spent hundreds of millions of dollars on cooperative efforts with the states of the former Soviet Union to modernize MPC&A systems at dozens of nuclear sites. Other nations have contributed to this effort as well. Substantial international cooperation has also focused on improving capabilities to monitor, analyze, and interdict illicit trafficking in nuclear materials. The IAEA has established an International Physical Protection Advisory Service, which offers international expert peer reviews and coordinates donor state assistance for upgrading physical protection at the request of member states. Through that mechanism and others, significant physical protection upgrades have been accomplished in several countries outside the former Soviet Union as well. However, because of inadequate funds, IPPAS has been able to conduct peer reviews in only twelve such countries since it began in 1995.

Standards and recommendations have also been upgraded. A substantial revision of the IAEA's recommendations on physical protection was completed in 1999 (INFCIRC 225/Rev. 4). New initiatives have been undertaken to provide assistance to states in developing design-basis threats for their physical protection systems, and to expand international physical protection training. However, the only treaty in this area is the Convention on the Physical Protection of Nuclear Material, which calls for physical protection measures only for material in international transport (or storage incidental to such transport). Furthermore, its protection requirements are against theft of nuclear material, not against sabotage—and are extremely general.[27] The Convention includes no mechanisms for verification—not even voluntary reports on, or peer review of, physical protection practices.

In 1998, the United States proposed that the Convention be amended to (a) extend its coverage to civilian nuclear material in domestic storage, use, and transport; (b) require that at a minimum, states provide levels of protection comparable to those recommended in INFCIRC 225; and (c) require that states provide reports on their physical protection arrangements every five years, to be discussed at international conferences that would also take place every five years.[28] The IAEA Director General convened an experts' meeting, which recommended drafting an amendment to the Convention. Their pre-September 11 consensus report recommended extending the Convention's coverage to civilian nuclear material in domestic use, storage, and transport; adding a requirement to protect against sabotage of nuclear facilities as well as theft of nuclear material; and stating twelve general principles for physical protection in the Convention. These principles included, for example, a call for each party to the treaty to adopt a national regulatory framework to govern its physical protection practices. The report was welcomed by the September 2001 IAEA Board of Governors and General Conference meetings, and the twelve principles were approved.[29]

The experts' consensus recommendations did not include any specific standards for domestic physical protection. They did not include any requirement that states prepare a report to the IAEA or to other states on their physical protection arrangements and regulations; any mechanism for international peer review of such arrangements; or any reference to the much more detailed IAEA physical protection recommendations (INFCIRC 225/Rev.4), even that these be "taken into account." The experts' "principle" calling for a national regulatory framework also called for an independent national regulatory agency and national inspections to verify compliance with national requirements.[30] This is useful in itself, but some experts have relied on it to oppose international verification and international standards for physical security. In our view, in the aftermath of September 11, the experts' pre-September 11 consensus in these areas should be fundamentally reconsidered: while national sovereignty in the area of nuclear security is important, so is every state's interest in making sure that every other state is carrying out its responsibilities in these areas appropriately.

Several post-September 11 developments are worth noting. First, most major states heightened security for their own nuclear facilities and undertook reviews of their national requirements for protection of nuclear material and facilities from terrorist theft or attack.

For example, the U.S. NRC immediately recommended that all nuclear reactors go to their highest state of alert; national guard forces were called out to protect reactors in some areas; and the NRC has since been conducting a "top to bottom review" of its nuclear security requirements, a review that is leading to new orders to heighten security.[31] France has installed anti-aircraft missiles to protect its La Hague reprocessing facility; Japan has put armed guards in place at its nuclear facilities for the first time.[32]

Second, substantial steps have been taken to expand and accelerate U.S.-Russian cooperative efforts to upgrade security and accounting for nuclear materials. In December 2001, Congress allocated an additional $226 million to DOE nonproliferation programs in the emergency supplementary legislation (including $120 million for MPC&A and nuclear smuggling interdiction bringing that total to $293 million), along with related funds for the Department of State; President Bush, in an important December 11 speech at the Citadel, emphasized the crucial importance of keeping weapons of mass destruction out of terrorist hands, along with the vital role of cooperation with Russia in achieving that objective, and pledged to ask Congress for "an overall increase in funding to support this vital mission,"[33] and the Bush administration completed its review of threat reduction programs with Russia, endorsing most of the efforts and targeting some for expansion.[34] While the budget President Bush sent to Congress on February 4, 2002, represented a reduction in some categories from the substantial sums Congress had voted after September 11, it nonetheless offered substantially more for these efforts than any of the Clinton budgets. And with the new spirit of U.S.-Russian anti-terror partnership following the September 11 attacks, the chances have improved for accelerating implementation of these security upgrades.

Third, international security upgrade cooperation coordinated by the IAEA has also been expanded and accelerated since September 11, and a much larger expansion proposed. In late October, the private Nuclear Threat Initiative announced a $1.2 million three-year grant—which was soon matched by a new U.S. government contribution—to expand and accelerate the IAEA's physical protection review and upgrade program.[35] At the November 2001 IAEA Board of Governors meeting, the IAEA secretariat proposed a broad program of IAEA activities intended to help prevent nuclear terrorism—including efforts to upgrade security for nuclear material and facilities around the world—with an estimated price tag of $30-$50 million per year.[36] The member states are expected to indicate soon how much they are willing to pay for such a program.

At the same time, efforts to negotiate actual amendments to the Convention on Physical Protection have made little progress. Even if these talks succeed, any draft amendment produced by a working group must be formally reviewed by the Convention's parties, a majority of whom must agree to convene an amendment conference; then, two-thirds of the parties must ratify the amendment before it can enter into force.[37] Years are likely to elapse before that can happen.

The Vision: A World of Secure Materials and Facilities

In the aftermath of September 11, our goal must be of a world in which:

- Every nuclear weapon and all weapons-usable nuclear material worldwide is secure and accounted for, to stringent standards;
- All high-consequence nuclear facilities (and high-consequence material transports) are secure from both insider and outsider sabotage and attack;
- Effective measures are put in place to interdict nuclear smuggling;
- There is sufficient transparency to give the international community confidence these steps have been undertaken.

Of course, it is not possible to defend every facility against every imaginable threat. Society has other things to secure besides nuclear material and facilities, and other things to expend its resources on besides security. The debate over "how much security is enough?" is crucial, and has only just begun. While some security facts must be kept secret, this debate must be as transparent as possible, allowing a well-informed public to make judgments as to how much it believes should be spent to reduce the risks, and what remaining risks are acceptable. In the United States, for example, while some have complained that the NRC's physical protection regulations are not strong enough, at least the broad outlines of the requirements are openly published, making them available for public discussion and debate[38]—which is not the case in many other countries.

The stakes justify a significant investment in improving security worldwide. Given that states have been willing to spend billions of dollars on their efforts to produce fissile material—and given that a single bomb could threaten tens of thousands of lives—the level of effort devoted to securing and accounting for stocks of even a few kilograms of fissile material should be higher than that devoted to protecting large amounts of money. This is manifestly not the case at many facilities in many countries today. Indeed, a strong case can be made that the essential ingredients of nuclear weapons should be protected roughly as rigorously as nuclear weapons themselves are, as a committee of the U.S. National Academy of Sciences recommended in 1994.[39]As the DOE regulations on physical protection put it, "use of weapons of mass destruction by a terrorist(s) could have consequences so grave as to demand the highest reasonably attainable standard of security."[40] Safeguards and security today are a small contribution to nuclear costs: To take one example, even at the THORP reprocessing plant, one of the most sensitive civilian nuclear facilities in the world, capital cost was over $5 billion in current dollars, annual operating costs are nearly $500 million—but security costs for all the plutonium operations for THORP and other facilities at the Sellafield site are estimated by BNFL at $15 million per year.[41] Thus substantial security increases could be implemented for costs that are low by comparison to what states are accustomed to spending for military security, or when judged as a proportion of the costs of nuclear-generated electricity.

Priority One: Implementing Security Upgrades

Below, we provide a range of specific suggestions for action in the wake of the September 11 attacks, grouped into two main categories—first, direct steps to implement security upgrades at specific facilities and to interdict nuclear smuggling, and, second, steps to strengthen national and international security standards.

- Every nation state with weapons-usable nuclear materials or high-consequence nuclear facilities should urgently assess its security arrangements and regulations in light of the magnitude of the threat demonstrated on September 11, and upgrade them where necessary. If technical assistance is needed to perform security reviews, the state should request that the IAEA IPPAS program organize a peer review —and if the state does not have adequate resources to carry out needed upgrades, it should request that the IAEA organize assistance.
- Working with Russia, the United States should launch a new initiative to control and secure weapons of mass destruction in both their countries and worldwide. The September 11 attacks have created a security moment as unique as the collapse of the Soviet Union, justifying a new initiative on the scale of the

Nunn-Lugar initiative launched at that time—a new "Alliance Against Catastrophic Terrorism," which could be led jointly by the United States and Russia.[42] As recommended in the Baker-Cutler report of January 2001, the United States should (a) work with Russia to develop a strategic plan "to secure and/or neutralize in the next eight to ten years all nuclear weapons-usable material located in Russia, and to prevent the outflow from Russia of scientific expertise that could be used for nuclear or other weapons of mass destruction"; (b) appoint a senior official to manage the many programs involved; and (c) appropriate the funds needed to implement this effort as rapidly as possible—significantly more than even the expanded Bush requests since September 11.

- In particular, as part of such an initiative, the United States and Russia should drastically accelerate their joint cooperation to improve MPC&A. Other states should substantially increase their contributions to this effort as well. This would include: (a) substantially increased funding (to a U.S. budget in the range of $300 million for fiscal year 2003, for example); (b) joint U.S.-Russian development of a strategic plan to complete the needed upgrades as rapidly as the job can be accomplished, and to put the initial "rapid upgrades" in place within, for example, two to three years; (c) high-level Russian commitment to sustain effective security and accounting after U.S. and international assistance phases out in the future, with a working group established to work out specific measures and commitments for sustainability; (d) agreement on a drastically expanded and accelerated effort to consolidate nuclear material in fewer buildings and facilities, including providing comprehensive incentives to facility managers to give up their material; (e) agreement on a "rapid accounting" initiative, in which all nuclear weapons and weapons-usable materials would be identified, tagged, and sealed very rapidly, with the more laborious process of actual measurement of the nuclear material following behind;[43] (f) rapid agreement on measures to sweep aside the disputes over access and assurances to ensure that U.S.-funded upgrades at sensitive facilities are implemented appropriately; and (g) a greatly increased focus on achieving security that can be and will be sustained after initial upgrades are complete, including strengthened MPC&A regulation and a wide range of other measures related to resources, organizations, and incentives to sustain MPC&A.[44] The scope of these efforts should be expanded to include physical protection assistance needed to prevent catastrophic sabotage.
- As additional elements of such an initiative, the United States and Russia should also accelerate their other cooperative programs designed to secure, monitor, and reduce stockpiles of nuclear weapons, plutonium, and HEU; downsize nuclear complexes and re-employ nuclear weapons and materials experts; interdict nuclear smuggling; and control sensitive nuclear exports. Here, too, other states should substantially expand their contributions. This would include, for example, measures to accelerate the blend-down of highly enriched uranium, and to place excess weapons plutonium under international verification and transform it into forms no more usable in nuclear weapons than commercial spent fuel.[45]
- The United States and other major nuclear states should provide substantial funding—at least several tens of millions of dollars for the coming year—to finance MPC&A upgrades and assistance for sustaining high levels of security in other countries around the world—focused both on securing nuclear material and on preventing sabotage. The package the IAEA proposed to the Board of Governors is an excellent start.
- States that in the past have had no armed guards at their nuclear facilities should reconsider, and develop appropriate approaches to deploying armed security personnel at each nuclear facility with weapons-usable nuclear material or whose sabotage could cause a major catastrophe.
- The United States and other major nuclear states should finance a drastic increase in physical protection training around the world, as recommended in the final report of the IAEA-convened experts group. This training should include not only technical training, but discussion of the crucial role of such security in preventing the spread of nuclear weapons and stopping nuclear terrorism. Effective training is crucial to improving security and assuring that improvements are sustained over time.[46]
- The budget and personnel available to the IAEA's physical protection program should be drastically increased—going well beyond the U.S. private and government grants to the IAEA mentioned above—making it possible, for example, to carry out a much larger number of missions to help member states improve security measures, and to provide more effective follow-up to such missions.
- International cooperative efforts to reduce the number of sites around the world where HEU and separated plutonium are stored should be drastically expanded. Small, potentially insecure facilities using HEU or plutonium should be provided with targeted incentives to give up this material, which could include assistance with other research that did not require it, offers to purchase the material, help in decommissioning research reactors and critical assemblies, help in managing

spent fuel and other wastes, and funding for conversion to low-enriched uranium. In particular, the budgets available for converting HEU-fueled research reactors to LEU, taking back fresh and spent research reactor fuel to the country of origin, and developing new higher-density fuels should be substantially increased, so that these efforts can be accelerated—including particularly Russian take-back of Soviet-supplied HEU from vulnerable sites around the world.

- Every state with weapons-usable nuclear materials should review, and strengthen as necessary, the accuracy and effectiveness of its state system of accounting and control—as control and accounting systems are an important part of preventing and detecting insider theft. Non-nuclear-weapon states party to the NPT already have state control and accounting systems reviewed by the IAEA, as it implements safeguards. The nuclear weapon states should each undertake a self-audit, identifying the quantities and locations of all of its weapons-usable nuclear material, and matching these to historical production and use (comparable to the audit the United States undertook as part of its Openness Initiative).[47]
- Firms in the nuclear industry should drop their opposition to more stringent security standards; this opposition is "penny wise and pound foolish." While increased security measures will cost money, successful theft of nuclear material for a nuclear weapons program, or successful catastrophic sabotage of a nuclear power plant, would be a gigantic disaster for the nuclear industry in all countries, wherever it occurred.[48]
- The nuclear industry should establish a cooperative industry organization focused on improving security standards worldwide through peer review and assistance, comparable to the role the World Association of Nuclear Operators (WANO) has played in improving nuclear safety.
- All relevant states and the IAEA should undertake dramatically increased efforts to interdict nuclear smuggling and control sensitive nuclear exports, including: (a) far-reaching sharing of intelligence and law-enforcement information; (b) ensuring that every relevant state has at least a small unit of the national police trained and equipped to deal with nuclear smuggling, and other law-enforcement and border-control units are trained to contact them as appropriate; (c) ensuring that every relevant country has a unit of its national intelligence service focused on, trained to deal with, and cooperating with other states on, the nuclear smuggling and illicit export threats; (d) providing equipment and training for detection at key border crossings, airports, ports, and at potential key nodes within countries as well (e.g., major highways near nuclear facilities, train stations in Moscow); and (e) substantially improving international nuclear forensics capabilities to examine seized samples and determine their origin.
- The United States, the countries of the European Union, Japan, and other states should increase their assistance for measures to assist the states of the former Soviet Union in re-employing weapons of mass destruction experts in non-weapons jobs, downsizing the WMD complexes, and strengthening controls on exports and transfers of sensitive technologies.

Priority Two: Strengthening National and International Standards

In addition to immediate upgrades, strengthened standards are needed if security is to be improved consistently worldwide and sustained over the long haul.

National Standards and Regulations

- Every state with weapons-usable nuclear material or high-consequence nuclear facilities should move urgently to put in place effective national security standards (including clear regulations, strong and independent regulators, appropriate inspection programs, and effective enforcement) reflecting the threat as perceived after September 11.
- Every state with weapons-usable nuclear material or high-consequence nuclear facilities should incorporate design basis threats into its regulations. These threats should take into account the global reach of terrorist organizations such as that which struck on September 11. At a minimum, it is difficult to argue that there is any country with major nuclear facilities where an attack by a small group of well-armed, well-trained terrorists, using at least a truck bomb and having the assistance of one insider, is not a plausible threat against which security systems should be prepared to defend.
- National standards and regulations should include regular, realistic, independent testing of the performance of security systems in defeating intelligent, well-trained insider and outsider efforts to overcome them. The IAEA's physical protection advisory service should be expanded to include helping countries to carry out such tests and establish such domestic testing programs.[49]
- Every relevant country should put in place strong legal and regulatory frameworks to deal with the problem of theft and illicit trafficking in nuclear material.

International Recommendations and Agreements

- Every state with weapons-usable nuclear material or high-consequence nuclear facilities that has not already done so should sign and ratify the Convention on the Physical Protection of Nuclear Material.

- Every state with weapons-usable nuclear material or high-consequence nuclear facilities should voluntarily commit to provide security for its facilities comparable to or better than that recommended in INFCIRC 225/Rev. 4. Major wealthy nuclear states such as the United States, France, the United Kingdom, Japan, and Germany should join in making a politically binding commitment that they will provide the levels of security recommended in INFCIRC 225/Rev. 4 (or some other stringent standard on which they can all agree—perhaps a performance-based one) for all their nuclear material and facilities, military and civilian; that they will report to the IAEA on their regulations and procedures; that they will allow managed peer review of physical protection at selected facilities; and that they will encourage other states to make comparable commitments (including requiring that foreign facilities that they supply or contract with demonstrate that they are meeting the agreed standard). The United States, in particular, should extract itself from the embarrassing position of opposing its own previous proposal to create an obligation to meet INFCIRC 225 standards by investing the resources necessary to bring its own facilities up to these standards and working to convince other states to do likewise.[50]
- A new review of INFCIRC 225 should be initiated, to make whatever modifications are necessary given the new understanding of the threat in the aftermath of September 11.[51]
- The Convention on Physical Protection of Nuclear Material should be amended as rapidly as practicable, to expand its coverage to domestic material and make the other improvements recommended by the experts' group.
- At the same time, in the aftermath of September 11, some of the experts' group's conclusions should be reversed. Parties to the convention should work to build support for an amendment that would include obligations to: (a) provide levels of security against both theft and sabotage at least comparable to those now recommended in INFCIRC 225/Rev.4 (with some provision for raising standards in the future without going through the time-consuming treaty amendment process); (b) provide some carefully managed and appropriately confidential form of international peer review; and (c) report to the IAEA on national legislation and regulations adopted pursuant to the Convention.
- Every nuclear supplier state should undertake steps to examine whether security in its recipient states is adequate, and if not, work with the recipient states to ensure that effective and sustainable security measures and regulations are put in place, including providing assistance where needed. The Nuclear Suppliers' Group should adopt more stringent requirements prohibiting exports to countries that do not provide levels of security comparable to those called for in INFCIRC 225/Rev. 4. Either peer reviews by the supplier state or international peer reviews organized by the IAEA could be used to confirm that such requirements were being met.
- Major nuclear states should adopt a policy that their governments and firms will not enter into contracts with nuclear facilities that fail to provide effective security and accounting for their nuclear material—making this part of the "price of admission" for doing business in the major nuclear markets.

Transparency

- Every state with weapons-usable nuclear material or high-consequence nuclear facilities should take care to keep confidential details of its physical protection arrangements that would be useful to terrorists seeking to overcome them.
- At the same time, sufficient information should be made available to enable informed public debate and build public and international confidence that sufficient steps are being taken.
- In particular, the IAEA's member states should support the IAEA's efforts to seek information on each country's physical protection practices. No international agreement requires submitting such information to the IAEA (even on a confidential basis), and countries have been very reluctant to provide the information unless they needed advice and asked for IPPAS peer review or financial help. As a result, no one knows where the worst problems are. As IAEA Director General Mohamed ElBaradei has said, "the most immediate task is to achieve a more complete picture of nuclear security worldwide, to enable a rapid response to the most urgent needs, and to develop a coherent plan for longer term action."[52] To help resolve that problem, every state with weapons-usable nuclear material or high-consequence nuclear facilities should voluntarily report to the IAEA on the steps it has taken to strengthen security and put in place effective national regulations. Major nuclear states should take the lead in taking particularly stringent measures and being among the first to report them to the IAEA.
- Voluntary peer reviews of physical protection arrangements, such as have been organized in recent years by IAEA assistance programs, should become, over time, a regular, normal part of doing business in major nuclear facilities—just as safety peer reviews have become. Toward that end, major nuclear states such as the United States, France, Japan, Britain, and

Germany should not only provide greater funding for such peer reviews but should invite peer reviews at selected facilities of their own. A new industry-led international organization comparable to WANO could eventually provide effective physical protection peer reviews.
- New cooperation should be established between the IAEA's safeguards inspectors and its physical protection experts. The IAEA's safeguards inspectors should be instructed to provide relevant information observed during their inspections to the physical protection office (while keeping the information safeguards-confidential). The IAEA's inspectors should be provided limited physical protection awareness training to facilitate this.
- Using information from all available sources, the IAEA physical protection office should work to establish a confidential data base on the state of physical protection for nuclear materials and high-consequence nuclear facilities around the world, with a view toward identifying the facilities most in need of security upgrades.

Rethinking the Design Basis Threat

The September 11 attacks require a fundamental rethinking of the threats that nuclear security systems must be designed to address. The September 11 threat consisted of nineteen well-trained attackers operating in four independent but coordinated teams; who were both suicidal and bent on causing mass destruction; who came from an organization with access to heavy weapons, explosives, and extensive combat training and experience; who attacked without warning; and who appear to have planned, trained, and collected intelligence for the attack for more than a year. Even without the addition of the use of large civilian aircraft fully loaded with jet fuel, this is a threat far larger and more capable than most nuclear security systems (at least civilian facilities) are designed to cope with. Countries around the world will have to rethink what threats are plausible and must be defended against, asking questions such as these:

- What, if anything, should be done to protect nuclear facilities from attack by aircraft? An IAEA spokesman has acknowledged that current nuclear power plants were never designed to withstand attack by "a large jumbo jet full of fuel," and some national regulatory authorities have acknowledged that their security requirements did not foresee such threats.[53] Can it now be assumed that large civilian airliners will become sufficiently difficult to hijack that the threat of a fully-fueled airliner attack on a power plant can be safely ignored? Or should we consider deploying anti-aircraft defenses at such facilities? [54] What about smaller planes, such as middle-sized jets that operate from unregulated airports and might be packed with explosives?
- How many people attacking on the ground, with what training, attack vehicles, and weaponry, should design basis threats now include? What would be the cost of providing effective protection against threats on the scale of September 11?
- Should facilities be protected against attackers arriving and departing by unconventional means designed to overcome delays at the perimeter, such as helicopters, or by boat?

While this reconsideration has only just begun, a few things do seem clear already. First, high-consequence nuclear facilities should be designed to survive truck bomb attacks. Second, it is unsafe to rely on the assumption that there will be prior warning before an attack. Third, terrorists are clearly willing to commit suicide attacks by crashing aircraft or trucks on their targets.

Impact on the Future of Nuclear Energy

After September 11, the possibility of terrorist attack will inevitably be one factor that utilities, publics, and governments weigh when considering nuclear energy in comparison to other energy sources. Beyond that, September 11 has implications for specific nuclear energy choices:

- The desirability of reactors with "inherent safety" features, designed so that no plausible set of circumstances can lead to a core melt and large-scale dispersal of radioactivity, appears even higher than before.
- However, proposals that such reactors can be built with no containment vessels—a key part of the projected favorable economics of the ESKOM pebble bed system, for example—are likely to be as dead as the race to build ever-taller office buildings.
- The concept of underground nuclear reactors should be explored again, to see if such systems can provide energy at reasonable cost.
- Most controversially, perhaps, we believe that there should be a phased-in moratorium on current approaches to reprocessing and recycling plutonium. Whatever safeguards and security measures are put in place, a world in which tens of metric tons of plutonium are being separated, processed, fabricated, and shipped to dozens of locations around the world every year is a world that poses significant risks above and beyond those of a world in which that is not occurring. Nuclear power's future will be best assured by making it as cheap, as safe, as secure, as proliferation-resistant, as simple, and as uncontroversial as possible—and current reprocessing and recycling technologies point in the wrong direction on every count. [55]

Conclusions: Preparing for a New World

The events of September 11 created a new world—a world in which we know for certain that there are highly capable terrorist groups with global reach bent on mass destruction. At the same time, the aftermath of September 11 is demonstrating that we are living in a world where far-reaching international cooperation toward common objectives could be a reality.

This new world calls for new approaches for securing much of the fragile infrastructure of modern industrial societies—including nuclear materials and facilities. A major new international initiative is needed to improve security for nuclear materials and facilities worldwide. The first priority must be to upgrade security for the least secure nuclear material and high-consequence nuclear facilities, in the former Soviet Union, the United States and worldwide; strengthened international standards will likely take longer to achieve (though the momentum from September 11 should not be lost).

These steps will cost money. Many of them have been blocked or slowed in recent years because of lack of political priority, bureaucratic obstacles, penny-pinching budgets, reluctance to make commitments that would cost money in the future, and the like. In the aftermath of September 11, governments and industry should work together to sweep these obstacles aside and take the steps needed to ensure that nuclear materials and facilities do not become the tools of terrorists. The costs and risks of failing to act are far higher than the costs of acting now.

Endnotes

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3. For outlines of such an international regime to improve controls over nuclear weapons and materials worldwide, see, for example, Committee on International Security and Arms Control, Management and Disposition of Excess Weapons Plutonium (Washington, DC: National Academy Press, 1994), esp. pp. 101-102 and 123-139; David Albright, Frans Berkhout, and William Walker, Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities, and Policies (Oxford, UK: Oxford University Press for the Stockholm International Peace Research Institute, 1997), esp. Chapter 15; and William Walker and Frans Berkhout, Fissile Material Stocks: Characteristics, Measures, and Policy Options (Geneva, Switzerland: United Nations Institute for Disarmament Research, 1999).
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9. Albright, Berkhout and Walker, Plutonium and Highly Enriched Uranium, 1996, op. cit., p.398. This estimate includes fresh, in-core, and irradiated HEU. Inclusion of irradiated HEU is appropriate in this context because at many research reactors the fuel was only lightly irradiated, has been cooling for many years, and is in fuel elements of modest size, meaning that the fuel elements are not sufficiently radioactive to be self-protecting against theft—especially by terrorists for whom death is part of the plan, such as those of September 11.
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the Atom, April 2000, available at http://ksgnotes1.harvard.edu/BCSIA/Library.nsf/pubs/Nextwave).

11. See discussion and references in Bunn, The Next Wave, op. cit.
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37. Convention on the Physical Protection of Nuclear Material, Art. 20.
38. The text of these regulations is in 10 Code of Federal Regulations Part 73. Some U.S. Department of Energy and Department of Defense rules for protecting their nuclear materials are public, but key provisions specifying specific protection standards are not.
39. See Management and Disposition of Excess Weapons Plutonium, op. cit. For a more detailed discussion of what such a standard might entail, see George Bunn, "U.S. Standards for Protecting Weapons-Usable Fissile Material Compared to International Standards," *Nonproliferation Review* (Fall 1998).
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41. Capital cost is reported in BNFL, The Economic and Commercial Justification for THORP (Risley, UK: BNFL, 1993), p. 22; estimates for operating costs for a plant identical to THORP were provided by BNFL in OECD/NEA, The Economics of the Nuclear Fuel Cycle, 1994, p. 113. The $15 million/yr figure is from BNFL input to the BNFL National Stakeholder Dialogue Waste Working Group, Interim Report (London, UK: The Environmental Council, February 28, 2000), Appendix 3 (available at http://www.the-environment-council.org.uk/Dialogue/bnfl_national_dialogue.htm). Total security costs at the Sellafield site since 1985 are estimated at $375 million, converted at a 2000 average exchange rate of 1.5.
42. See, for example, Graham Allison and Andrei Kokoshin, "A US-Russian Alliance Against Megaterrorism," Boston Globe, November 16, 2001.
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47. See Albright, Berkhout, and Walker, Plutonium and Highly Enriched Uranium 1996, op. cit., and Walker and Berkhout, Fissile Material Stocks, op. cit.
48. See note 42.
49. In the U.S., which already has NRC performance-testing programs in place, the program should not be turned over to the reactor operators whose performance is being tested.
50. The U.S. has been opposing its own proposal—both because the proposal was unpopular with other countries in the talks, and because the Department of Energy argued that bringing U.S. facilities up to INFCIRC 225/Rev. 4 standards would be excessively costly and have little benefit. See, for example, Marshal D. Koehn and Joseph D. Rivers, "DOE's Involvement in Negotiations on the Question of Whether to Revise the Convention on the Physical Protection of Nuclear Material," Proceedings of the 42nd Annual Meeting of the Institute for Nuclear Materials Management. U.S. regulations are generally performance-based (rather than the rule-based approach that is still emphasized in INFCIRC 225), and generally offer even higher levels of security than called for by INFCIRC 225. DOE regulations, however, have a different categorization approach that provides for much lower levels of security than called for in INFCIRC 225/Rev. 4 for mixed materials containing less than 10% by weight plutonium or U-235, such as mixed-oxide fuel. As noted earlier, however, there are strong arguments for changing these regulations. Particularly in the aftermath of September 11, the United States would be better off taking the lead in building toward strong global standards than undermining progress toward that end to save money in its own complex.
51. It would be useful to shift increasingly to a more performance-based and less rule-based approach. In addition, among many other modifications that should be considered, it would be desirable to add a recommendation that barriers be put in place to protect against truck bombs.
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Member News Highlights

As I mentioned in the last issue, INMM is a completely member-driven organization. For this reason, we appreciate the many hours that members put in to specific areas of this organization in order to make it both active and effective. These hours are unpaid and reflect the dedication of these members to the cause of promoting the safe and appropriate management of nuclear material.

In light of this, it is always difficult for us to see a member who has been active decide to step down, but we understand the need to do so. After many years as the chair of the Packaging and Transportation Technical Division, Billy Cole resigned from that role on March 15. While we are sorry to see him leave this post, we envy his reasons for doing so: retirement and the desire to spend his time engaged in less stressful activities, such as riding his Harley. We wish him all the best and hope to see him often at future INMM meetings.

Another long-time member of INMM, John Immele, was recently named deputy director for national security at Los Alamos National Laboratory. Immele had been the program director for nuclear materials management in the threat reduction directorate, and previously headed Los Alamos' nuclear weapons program. Immele's background spans a wide range of scientific leadership efforts in the area of nuclear materials management at both Los Alamos and Lawrence Livermore National Laboratory, with extensive experience in nuclear and non-nuclear national security areas. He has served in the Washington, D.C. Office of Nonproliferation and National Security, and with the newly formed National Nuclear Security Administration Planning Office. When you see John, congratulate him on this outstanding recognition of his skills in strategic thinking and analysis.

We continue to welcome new members from all over the world and look forward to the contributions that each of these individuals will make to the goals of INMM. Since the last issue of the *JNMM*, 32 new members have been added. We welcome each of them. When you receive your copy of the 2002 Membership Directory, I am confident you will again be impressed with the wealth of experience and knowledge that is represented by our members. If you want to be included in our 2003 Membership Directory, be sure to join or renew before December.

As always, if you have any news about an INMM member, be sure to keep your colleagues informed by contacting either me at scott.vance@shawpittman.com or our *JNMM* Managing Editor Patricia Sullivan at psullivan@inmm.org. Please include photographs when possible.

Submitted by Scott Vance
INMM Membership Committee Chair

Author Submission Guidelines

The *Journal of Nuclear Materials Management* is the official journal of the Institute of Nuclear Materials Management. It is a peer-reviewed, multidisciplinary journal that publishes articles on new developments, innovations, and trends in safeguards and management of nuclear materials. Specific areas of interest include physical protection, material control and accounting, waste management, transportation, nuclear nonproliferation/international safeguards, and arms control and verification. *JNMM* also publishes book reviews, letters to the editor, and editorials.

Submission of Manuscripts: *JNMM* reviews papers for publication with the understanding that the work was not previously published and is not being reviewed for publication elsewhere. Papers may be of any length.

Papers should be submitted in *triplicate*, **including a copy on computer diskette**. Files should be sent as Word or ASCII text files only. Graphic elements must be sent in TIFF format in separate electronic files. Submissions should be directed to:

Dennis Mangan
Technical Editor
Journal of Nuclear Materials Management
60 Revere Drive, Suite 500
Northbrook, IL 60062 USA

Papers are acknowledged upon receipt and are submitted promptly for review and evaluation. Generally, the author(s) is notified within 60 days of submission of the original paper whether the paper is accepted, rejected, or subject to revision.

Format: All papers must include:

- Author(s)' complete name, telephone and fax numbers, and E-mail address
- Name and address of the organization where the work was performed
- Abstract
- Camera-ready tables, figures, and photographs in TIFF format only
- Numbered references in the following format:
  1. Jones, F.T. and L.K. Chang. 1980. Article Title. *Journal* 47(No. 2):112–118.
  2. Jones, F.T. 1976. *Title of Book*, New York: McMillan Publishing.
- Author(s) biography

Peer Review: Each paper is reviewed by two or more associate editors. Papers are evaluated according to their relevance and significance to nuclear materials safeguards, degree to which they advance knowledge, quality of presentation, soundness of methodology, and appropriateness of conclusions.

Author Review: Accepted manuscripts become the permanent property of INMM and may not be published elsewhere without permission from the managing editor. Authors are responsible for all statements made in their work.

Reprints: Reprints may be ordered at the request and expense of the author. Contact Patricia Sullivan at psullivan@inmm.org or 847/480-9573 to request a reprint.

Nuclear Industry Experts Join Management and Board of ATI Nuklear AG

Advanced Technology Industries, Inc. announced that it has completed the formation of ATI Nuklear AG (AG), a wholly owned subsidiary of Advanced Technology Industries, Inc. AG has been formed to consolidate all of ATI's nuclear waste remediation technologies and services. The focus of the company is on nuclear waste remediation throughout Europe, Russia, and the countries of the former Soviet Union. AG is actively engaged in numerous projects and nuclear waste remediation applications.

Several noted nuclear industry experts have recently been appointed to the management team and board of directors of the AG.

Dr. Juergen P. Lempert has joined AG as its chief executive officer. Professor Alexander Kaul and Dr. Norbert Eickelpasch have joined the AG board. Kaul will serve as chairman. Joining them on the board will be Hans-Joachim Skrobanek, president of ATI. Additionally, James G. Burritt has joined as senior vice president of AG.

Lempert, a noted nuclear industry expert with more than twenty-nine years of industry experience in the nuclear remediation field, will be responsible for overseeing all of the AG's daily operations, strategic planning, and product development programs. He has previously held positions with Deutsche Gesellschaft zum Bau und Betrieb von Endlagern fur Abfallstoffe mbh and Brown Boveri Reaktor GmbH.

For more information, contact avdiinfo@look.ca.

24 Years, $4 Billion and Secretary of Energy Recommends Yucca Mountain Site to Bush

As required by the Nuclear Waste Policy Act, on January 10, 2002, Secretary of Energy Spencer Abraham notified Nevada Governor Kenny Guinn and the Nevada state legislature of his intention to recommend to President Bush that the Yucca Mountain site is scientifically sound and suitable for development as the nation's long-term geological repository for nuclear waste.

DOE statements characterized the Yucca Mountain site as one that will help ensure America's national security and secure disposal of nuclear waste, provide for a cleaner environment, and support energy security.

Also in January, the Department of Energy issued a statement welcoming a report of the Nuclear Waste Technical Review Board (NWTRB) about the ongoing scientific study of Yucca Mountain that provided valuable independent confirmation of a critical conclusion reached after twenty-four years and $4 billion of research. The Board stated, and DOE agrees, that "no individual technical or scientific factor has been identified that would automatically eliminate Yucca Mountain from consideration as the site of a permanent repository" for the country's nuclear waste.

In addition, the Department also agrees with the Board's recommendation that the Department "continue a vigorous, well-integrated scientific investigation to increase its fundamental understanding of the potential behavior of the repository system."

The Department said Secretary Abraham welcomed the Board's report. "The Department welcomes the Board's statement that 'no individual technical or scientific factor has been identified that would automatically eliminate Yucca Mountain from consideration.' Moreover, the Department fully agrees, and believes that such a course of research, as contemplated by both the Board and the Secretary, will increase confidence in long-term projections of repository performance," Under Secretary of Energy Robert Card said.

"The Secretary is committed to ensuring the safety of citizens of Nevada and of the nation, a timely recommendation on a repository, and an ongoing course of research that would last so long as the repository is in its operating and monitoring period — as much as 100-300 years after its opening," Card said. "The Secretary looks forward to working with the Board in developing and conducting a course of research for the future."

The Department also agrees with another of the Board's findings that, "[e]liminating all uncertainty associated with estimates of repository performance would never be possible at any repository site." The Department is committed to reducing uncertainties with estimates of performance thousands of years in the future, and will continue to prove its commitment through aggressively seeking and utilizing resources for important research, Card explained.

In addition, the DOE notes that the Board did not disagree with the Department that a repository at the site would be safe throughout its operating and monitoring period, hundreds of years into the future. In fact, Card said, no legitimate scientific organization disagrees on this issue.

The Board also recognized in its report that it is a matter of policy on whether to proceed. If the president decides to recommend the site, the state of Nevada will have the opportunity to disapprove the recommendation, meaning that Congress would ultimately have the responsibility for designating a site for development. Proper exercise of this responsibility, along with the power of the Congress to fund the important research recommended by the Board, NRC, and the Department, will ensure that this project is conducted in the safest manner possible.

"The Board's review of the twenty-four years of scientific study at Yucca Mountain is important, as is the decision on whether or not to address the country's nuclear waste problem at this time, given the impacts to national security, environmental protection, and continued clean-up of nuclear waste," Card said. He noted also that spent nuclear fuel and high level radioactive waste is currently scattered across 131 sites in thirty-nine states.

New Canberra Inc. Formed

The formation of the new Canberra Inc., headquartered in Meriden, Connecticut U.S.A., was announced in January. Canberra Inc., is a wholly owned subsidiary of COGEMA, Inc., which in turn is a part of the recently formed AREVA Group.

The new Canberra is composed of two main groups — Canberra Industries Inc., based in Meriden, and Canberra-Eurisys S.A., based in Montigny, France. Both organizations are responsible for manufacturing and engineering specific product lines as well as sales and service for all product lines in specific geographical areas.

Canberra Industries Inc. includes elements of the former Aptec-NRC, which was merged into Canberra in June 2001. In total, Canberra Industries operates five production facilities in the United States, two in the United Kingdom, one in Canada, and one in Belgium.

Canberra Eurisys, S.A., consists principally of the former Eurisys-Mesures. It operates four production facilities in France and wholly owned sales, service, and application facilities in France, Belgium, and Germany.

The AREVA Group was formed last year by the combination of CEA-Industrie, COGEMA, Framatome ANP, and FCI. The AREVA Group is a world leader in nuclear power, present in every aspect of the nuclear power cycle, from mining to facility decommissioning, including both reactor and fuel fabrication. In 2001, AREVA Group revenues exceeded $9 billion.

"Combining the strongest companies in the nuclear measurements field under the well established Canberra name demonstrates our commitment to the nuclear measurements business," said Christian Petit, Canberra Inc., chief executive officer. "Now backed by AREVA, Canberra is the only company in nuclear measurements with a 100 percent focus on the nuclear industry. We are well positioned to continue to expand our position in all facets of the radiation measurement field."

For more information on Canberra Inc., access http://www.canberra.com.

ORTEC Gets Patent for Improved Dead-Time Correction Technique

Advanced Measurement Technology Inc. announced in January that ORTEC received a patent for an improved dead-time correction technique enhancement that provides valuable improvements to accuracy in gamma-ray spectrometry.

ORTEC Spectroscopy products have been granted a patent for the implementation of Zero Dead Time (ZDT) loss-free counting correction.

ORTEC DSPECplus is the first instrument to use a completely digital zero dead-time method for loss-free counting that is fully automatic and also gives the uncertainty for each channel in the corrected spectrum. The innovative technology in this method allows ZDT to be used in any spectroscopy system by operators of any experience level.

All gamma-ray spectroscopy systems suffer from dead-time related data losses at high-data rates. The traditional methods, which extend the acquisition time to allow for lost data, are inaccurate when the sample has varying data rates. The more recent dynamic methods, which correct the data in real time, and thus solve the problem of varying count rates, are unable to calculate the uncertainty on the corrected spectral data.

The patented ZDT method for the first time enables the spectroscopy system to dynamically correct the spectral data for losses while maintaining a variance spectrum from which the uncertainty in the corrected spectrum is easily and accurately obtained.

For more information, access http://www.ortec-online.com.

Meet the Member: Yvonne Ferris

Name: Yvonne Ferris
INMM Member Since: 1972
Technical Division Affiliation: International Safeguards, Materials Control and Accountability, Nonproliferation and Arms Control, and Waste Management

In 1956, a woman in the nuclear materials management industry was an uncommon sight. But Yvonne Ferris began her career that year at Rocky Flats in materials control and accountability and quality control. She remained there for the next twenty-one years, until a two-year stint at the International Atomic Energy Agency in Vienna. After her work at the IAEA, Ferris returned to Rocky Flats. In 1991, she was detailed to Washington D.C., and in 1992, she retired from Rocky Flats. She then joined the Science Application International Corp. (SAIC) as a senior technical analyst where she stayed until she joined GEM Technology in 1995.

"When I first started at Rocky Flats, women were fired if they became pregnant. Women were not permitted to go in the hot areas. Women were not permitted to travel because they could not share a room with anyone else in the party. Men never shared a room, you understand, but that was beside the point," she said. But Ferris had supervisors who challenged these rules and her career flourished. "I was permitted to go into the hot areas. (How can one calibrate a tank filled with plutonium nitrate from one's desk?) And I traveled as much as anyone else. As in any discipline, if one is professional, fair, dedicated, and courteous, one is welcomed on the team," she said.

Today, Ferris is a senior safeguards scientist at U.S. Department of Energy headquarters in Germantown, Maryland. She assists, oversees, and audits all phases of domestic and international safeguards. Her work includes measurement methodology, measurement equipment, statistics, accounting, chemistry, physics, electronics, and materials control, she said.

Ferris joined the Institute of Nuclear Materials Management in 1972, and since that time has held a variety of leadership positions. She is an INMM past president, serving in that role in 1985-86. She also has served as a member of the Executive Committee; program chair; vice chair of the Institute; nominations committee chair; and as vice chair of the N-15 Committee. Currently, Ferris serves as the Awards Committee chair.

Recognizing the best and brightest in the nuclear materials management profession is something that Ferris enjoys tremendously. She and the Awards Committee work diligently to honor professionals who give so much to the industry and to the INMM. "I enjoy the Awards Committee because it allows me and my fellow committee members to give something back to the members and the global contributors who have given so much to the safeguards community," she said.

The awards "provide a means of recognition for outstanding service in the safeguards disciplines or to the Institute of Nuclear Materials Management," Ferris said. Nominating someone for an award is very simple: "One writes a nomination letter to the Awards Committee and describes the individual's accomplishments and contributions to the industry or the Institute, depending on the award. This needs to be fairly detailed as we get many nominations and must be able to judge which is the more deserving candidate," she said. The committee also asks for letters from several of the individual's peers supporting the nomination for the award. (For more information on the INMM Awards programs, access the INMM Web site at www.inmm.org.)

Ferris today lives in Bethesda, Maryland. She was born in East St. Louis, Illinois — in the same hospital as tennis champion Jimmy Connors, she noted.

Outside of nuclear materials management and her INMM work, Ferris travels extensively. "I like the paths less traveled," she said. "My most memorable trips are Kenya, Antarctica, and the Panama Canal. I look forward to taking the train across the Australian outback, traveling on the Trans-Siberia railway, and hiking through Banff and Lake Louise. I have so many places I'd like to visit, I'll have to live to be 110 to get them all in."

How are we doing?

Meet the Member is a new feature the *JNMM* has introduced in recent issues and we'd like your feedback. Do you enjoy reading about other INMM members? Do you know someone INMM members should know better?

Send your suggestions, feedback, and ideas to *JNMM* Managing Editor Patricia Sullivan at psullivan@inmm.org.

Book Review

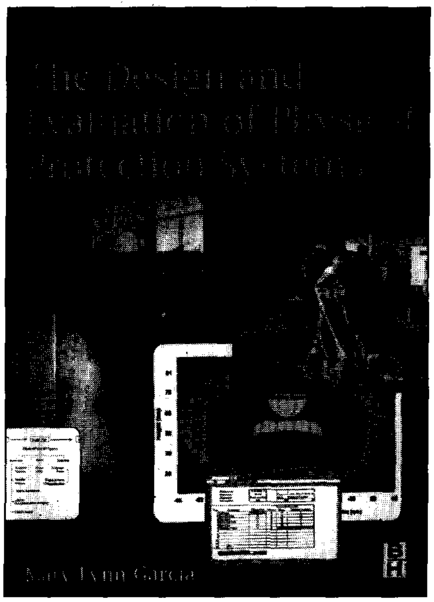
Editor's Note: *This book review is the first in what we hope will again become a regular feature of* JNMM. *Thanks to Book Review Editor Walter Kane and Reviewer Joseph Indusi for their efforts here. Please forward your recommendations for books for this section to Managing Editor Patricia Sullivan at psullivan@inmm.org.*

The Design and Evaluation of Physical Protection Systems
By Mary Lynn Garcia
Butterworth and Heinemann, 2001
ISBN 0-7506-7367-2
Reviewed by Joseph P. Indusi

The Design and Evaluation of Physical Protection Systems, by Mary Lynn Garcia, is a significant contribution to the field of physical protection systems. It fills the need for a systematic exposition of physical protection systems design and evaluation. It provides a textbook for teaching an introductory course or can be used for self study to gain an understanding of the elements of physical protection systems. The book also provides sufficient background and detail to serve as a reference manual for many physical protection components.

The material is divided into three main parts: Determining System Objectives, Designing the Physical Protection System, and Analysis and Evaluation. The bulk of the material is in the second section on physical protection system design. It covers the elements of detection, delay and response, and the implementation of these elements through chapters on exterior and interior intrusion detection, alarm assessment, alarm communication and display, entry control, access delay, and response.

The first area discusses a number of important issues including the facility operations, regulatory requirements, legal issues, and safety considerations. This is followed by a discussion of the threat definition and includes tables for qualitatively ranking the potential threats from potential adversaries. There is also a discussion of design basis threats for a given type of facility. The last section covers target identification and those areas of the facility to be protected. It introduces the use of logic diagrams for large facilities where there are multiple targets and complex relationships among the subsystems of the targets or vital areas of the facility. This material is relevant to a single facility and provides the proper background for proceeding to the design stage.



As stated earlier, the majority of the book is devoted to the second part on physical protection system design. The chapters are very well written and provide sufficient detail to serve as a reference manual and beginning point for more in-depth study of a particular subject. This material is based in large part on many years of development and testing of physical security systems and components carried out at Sandia National Laboratories. Many of the topics covered here involve computer systems and other electronic components and over time there will be significant advances in these technologies. However, this book will continue to provide useful information in these areas.

The third part of the book covers analysis and evaluation and is based on the analysis of adversary paths. Key to the analysis is evaluating the probability that the adversary sequence of actions or path will be interrupted by the elements of the physical protection systems. The next section discusses quantitative analytical computer models and focuses on the EASI (Estimate of Adversary Sequence Interruption) model that traces its beginnings back to the 1970s. An appendix provides an example of EASI using a Microsoft Excel application. The last section deals with the concept of risk assessment, which is a function of the probability of an adversary attack, the probability of adversary interruption, and the consequences of a successful attack. These are related by the equation:

$$R = \text{Risk} = P_A * [1-P_I] * C$$

where PA is the probability of attack, P_I is the probability of interruption, and C is the consequence value which ranges from 0 to 1. While the probability of attack, P_A, can only be estimated, it is instructive to understand the concept of risk and to evaluate the risk, R, under different assumptions on the probability of attack.

In summary, this book represents a significant contribution to the field of physical protection systems and provides a useful reference for those involved in physical security system design and operation.

Joseph P. Indusi is chair of the Nonproliferation and National Security Department of Brookhaven National Laboratory in Upton, New York, U.S.A.

Calendar

April 18-20, 2002
12th Annual International Arms Control Confernece, Albuquerque, New Mexico, U.S.A. Sponsored by Sandia National Laboratories. Contact: Evangeline Clemena, conference coordinator, Sandia National Laboratories, P.O. Box 5800, MS 1203, Albuquerque, NM 87185-1203; E-mail, edcleme@sandia.gov.

April 30-May 1, 2002
North America Young Generation in Nuclear, The Ritz-Carlton at Tiburon, Naples, FL. U.S.A. Sponsored by the Nuclear Energy Institute. Contact: Sonja Simmons, Nuclear Energy Institute, 1776 I St. NW, Suite 400, Washington, DC 20002; phone, 202/739-8042; fax, 202/785-4019; E-mail, sss@nei.org.

May 1-3, 2002
Nuclear Energy Assembly, The Ritz-Carlton at Tiburon, Naples, FL, U.S.A. Sponsored by the Nuclear Energy Institute. Contact: Lisa Steward, Nuclear Energy Institute, 1776 I St. NW, Suite 400, Washington, DC 20002; phone, 202/739-8006; fax, 202/293-3056; E-mail, lis@nei.org.

June 23-27, 2002
43rd INMM Annual Meeting, Renaissance Orlando Resort, Orlando, Florida, U.S.A. Sponsor: Institute of Nuclear Materials Management. Contact: INMM, 60 Revere Drive, Suite 500, Northbrook, IL 60062; phone, 847/480-9573; fax, 847/480-9282; E-mail, inmm@inmm.org; Web site, http://www.inmm.org.

October 14-18, 2002
Safe Decommissioning for Nuclear Activities: Assuring the Safe Termination of Practices Involving Radioactive Materials, Pro Arte Hotel Berlin, Berlin, Germany. Sponsor: International Atomic Energy Agency. Contact: IAEA, IAEA-CN-93, Vienna International Centre, Wagramer Strassse 5, P.O. Box 100, A-1400 Vienna, Austria; E-mail, official.mail@iaea.org; Web site, http://www.iaea.org.

October 16-18, 2002
Americas Nuclear Energy Symposium (ANES 2002), The Biltmore Hotel, Miami, Florida, U.S.A. Sponsors: The U.S. Department of Energy and the American Nuclear Society. Contact: Caroline Raffington; phone, 305/348-5016; E-mail, anes2002@hcet.fiu.edu; Web site, http://www.anes2002.org.

November 4-8, 2002
International Symposium on Nuclear Power Plant Life Management, Budapest, Hungary. Sponsors: International Atomic Energy Agency. Hosts: the government of Hungary through the Hungarian Nuclear Society. Contact: K. Morrison, Conference Service Section, Division of Conference and Document Services, IAEA, Vienna International Centre, Wagramer Strassse 5, P.O. Box 100, A-1400 Vienna, Austria; E-mail, K.Morrison@iaea.org; Web site, http://www.iaea.org.

December 2-6, 2002
International Conference on Safety Culture in Nuclear Installations, Rio de Janeiro, Brazil. Sponsor: International Atomic Energy Agency. Host: the government of Brazil in cooperation with Eletrobras Termonuclear S.A. - Eletronuclear and Industrias Nucleares Brasileiras. Contact: Hildegard Schmid, Conference Service Section, MTCD, International Atomic Energy Agency, IAEA-CN-97, P.O. Box 100, Wagramer Strasse 5, A-1400 Vienna, Austria; phone, (+43) 1-2600-21316; fax, (+43) 1-26007; E-mail, Hildegard.Schmid@iaea.org; Web site, http://www.iaea.org.

January 15-17, 2003
INMM Spent Fuel Management Seminar XX, the Loews L'Enfant Plaza Hotel, Washington, D.C. U.S.A. Sponsor: Institute of Nuclear Materials Management. Contact: INMM, 60 Revere Drive, Suite 500, Northbrook, IL 60062; phone, 847/480-9573; fax, 847/480-9282; E-mail, inmm@inmm.org.

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