Fall 2005 | Winter 2006 | Spring 2006 | Summer 2006 | Volume XXXIV, Number 3

JNMM Journal of Nuclear Materials Management

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INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT
Published by the Institute of Nuclear Materials Management

JNMM (ISSN 0893-6188) is published four times a year by the Institute of Nuclear Materials Management Inc., a not-for-profit membership organization with the purpose of advancing and promoting efficient management of nuclear materials.

SUBSCRIPTION RATES: Annual (United States, Canada, and Mexico) $100.00; annual (other countries) $135.00 (shipped via air mail printed matter); single copy regular issues (United States and other countries) $25.00; single copy of the proceedings of the Annual Meeting (United States and other countries) $175.00. Mail subscription requests to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, IL 60062 U.S.A. Make checks payable to INMM.

ADVERTISING, distribution, and delivery inquiries should be directed to *JNMM*, 60 Revere Drive, Suite 500, Northbrook, IL 60062 U.S.A., or contact Jill Hronek at 847/480-9573; fax, 847/480-9282; or E-mail, inmm@inmm.org. Allow eight weeks for a change of address to be implemented.

JNMM Journal of Nuclear Materials Management

Spring 2006, Volume XXXIV, No. 3

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INMM
INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

On to Tennessee

By Cathy D. Key
INMM President

47th INMM Annual Meeting — July 10–14, 2006

Once again, as a reminder, our 2006 INMM Annual Meeting will be held July 16–20, 2006, in Nashville, Tennessee, U.S.A., at the Nashville Convention Center & Renaissance Hotel. During the week of March 6, the Technical Program Committee met in Seattle, Washington, U.S.A., to pull together the annual meeting program.

This year it seems that we are going to have a *record-breaking* number of abstracts/presentations for our annual meeting. Now I would like to think that it is because our annual meeting is being held in my home state of Tennessee, *but…* I believe that this is a refection on the times and the importance in our role of assuring excellence in the field of nuclear material management.

Once again, I wish to thank the members of the Technical Program Committee (chaired by Mr. Charles Peitri) for the outstanding job they have done in pulling together this year's meeting.

46th Annual Meeting — 2005 — Charles Curtis Opening Plenary Speaker

I wish to update everyone on the "progress to date" on the challenge that Mr. Charles Curtis bestowed upon us as a professional organization. (Note: Please refer to the winter 2006 *JNMM* "President's Letter" for background information.)

During our Executive Committee Meeting March 8 and 9, 2006, we hosted Ms. Joan Rohlfing of the Nuclear Threat Initiative (NTI) and Ms. Joyce Connery of the National Nuclear Security Administration NA-25 (NA-25). Our goal was to discuss the proposal put forth by the Fellows Committee in November 2005 concerning the challenge issued to the INMM during the opening plenary session at the annual meeting in 2005.

The INMM Fellows presented the proposal and the business plan. There was extensive lively discussion as we worked toward determining our next steps. We had a meeting facilitator who greatly assisted in allowing us to move forward on important issues. As it stands, additional decisions will be made by the Fellows in determining a specific group of INMM personnel (specifically fellows) to work closely with NTI and NA25 on this issue.

It was determined that an additional next step should be to hold a *stakeholders* meeting this fall to discuss the proposal and obtain buy-in from the stakeholders.

Additional details will be worked through the fellows and will be communicated through them to the Executive Committee. In turn, the Executive Committee will keep our membership informed of next steps. I wish to thank NTI, NA25, and the Executive Committee for working diligently during this meeting. Our progress was commendable and we look forward to additional steps forward on this matter.

INMM President Cathy D. Key may be reached by e-mail at cathykey@key-co.com.

GNEP — A Big Boost for INMM?

By Dennis Mangan
Technical Editor

On February 6, 2006, the U.S. Department of Energy, as part of President Bush's Advanced Energy Initiative, announced the launching of the Global Nuclear Energy Partnership (GNEP). As the press release notes, "This new initiative is a comprehensive strategy to enable the expansion of emissions-free nuclear energy worldwide by demonstrating and deploying new technologies to recycle nuclear fuel, minimize waste, and improve our ability to keep nuclear technologies and materials out of the hands of terrorists." The release goes on to state, "As the United States' economy and economies around the world continue to grow, the need for abundant energy resources will also grow. Nuclear energy is safe, environmentally clean, reliable, and affordable. Through GNEP, the United States will work with other nations possessing advanced nuclear technologies to develop new proliferation-resistant recycling technologies in order to produce more energy, reduce waste and minimize proliferation concerns."

This GNEP initiative appears to be no small effort. It is my understanding that there is $250 millions in the U.S. Department of Energy's 2007 budget, with significant increases planned for FY2008 and beyond. When one reads the words in the press release, words like "reduce waste," "proliferation resistant recycling," and "work with other nations," it's not hard to see our six technical divisions and our international scope allowing INMM to be a unique forum for the exchange of information among professionals in many of the envisioned program elements of GNEP. I'm aware of INMM members as well as some of our sustaining members who are planning activities in GNEP. However, will this be "a boost" for INMM? It's not clear to me that it's a given. Whenever big initiatives and programs are announced, it seems that experts pop up everywhere, *experts* who don't do the appropriate homework. These experts could come from the professional ranks, from stated capabilities of various organizations, or from other professional societies. We have a strong base — let us hope "the boost" is as it should be.

This issue of the *Journal* has four technical contributions. The first, *Physical and Economic Limitations for Distributed Nuclear Sensing,* by William Priedhorsky of Los Alamos National Laboratory, New Mexico, USA, a peer-reviewed article, provides a good background of distributed sensor networks and the pros and cons. Priedhorsky, in my opinion, addressed key issues (limitations of sensing, cost of sensing, and limits of technologies) of *things* to be sensed by remote sensing, and the limitations of approaches.

The other three papers were provided by Ed Johnson and Pierre Saverot, chair and associate technical editor, respectively, of our Waste Management Technical Division. These papers were presented at the Spent Fuel Management Seminar XXIII held in Washington, DC, January 11–13, 2006. These papers were judged by Johnson and Saverot as timely articles suitable for publication in the *JNMM.*

Michael Cappiello, also of Los Alamos National Laboratory in the USA, authored *Overview of AFCI Transmutation Engineering Activities.* This paper discusses some of the ongoing activities that will feed directly into the new GNEP initiative I discussabove. It is an interesting paper and addresses some of the complex problems that are being addressed. *Seal Performance of Metal Cask Under Drop Accident,* authored by Hirofumi Takeda and colleagues from the Central Research Institute of Electric Power Industry in Japan, discusses simulating drop accidents in a storage facility. Two drop tests of a metal casks are discussed, with positive results provided. The final paper, *Proliferation-Resistance of Advanced Nuclear Fuel Cycles,* by Kemal Pasamehmetoglu of the Idaho National Laboratory in the USA, likewise addresses a key issue associated with GNEP, namely proliferation resistance. His early discussions in the paper are certainly interesting and will resonate with many of you who worry about proliferation resistance. I personally found interesting his premise, *"After all, proliferation resistance is more like a direction for a journey than a destination. The immediate goal is to take steps in the right direction. Along the road further choices and trade-offs will likely be required."*

Should you have any questions or comments, as usual, you are welcome to contact me.

JNMM *Technical Editor Dennis Mangan may be reached by e-mail at dennismangan@comcast.net.*

Physical and Economic Limitations for Distributed Nuclear Sensing

William C. Priedhorsky
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Abstract

Remote sensing technologies make possible the detection of activities and communications from great distances. However, many objects and activities cannot be monitored at a distance. To obtain global situational awareness of the associated processes, one must deploy networks of *in situ* sensors. The spacing of these networks, and the cost of the individual sensors, drive the cost of coverage per square kilometer. We examine some of the fundamental and practical limits to these costs. There are limits on the miniaturization of certain sensors, and it will be expensive to cover large areas to detect, for example, nuclear sources. These costs can be minimized by deploying smaller sensors in greater numbers, by more discriminating sensors, and by exploring alternative signatures. In some cases, considerable improvement in sensitivity for moving sources can be obtained by following up a tentative detection with a fixed detector with a mobile, more discriminating detector.

Introduction

Tremendous value has been derived from the deployment of remote sensing technologies. They make possible the detection of activities and communications from great distances, based on platforms in the atmosphere and space. Most channels of information that can propagate through the atmosphere have been exploited; these include imagery and spectral imagery in the optical and infrared bands, radio communications and other signals from the MHz to the GHz regimes. However, for other information channels, sensing at a distance is exceedingly difficult or impossible. These channels are important for a wide range of processes that must be monitored to satisfy national security requirements. Examples of include nuclear material near the Earth's surface, acoustic and seismic signals, magnetic and gravimetric signatures, trace chemical emissions, biological materials, and weak RF signals in complex, noisy environments. To obtain global situational awareness of the associated processes, one must deploy networks of *in situ* sensors.

Where is progress to be made? In other words, what are the difficulties in surveillance and situational awareness where the advent of low cost, cheap, numerous, intelligent, and self-organizing sensors can have the greatest impact, yielding solutions that cannot be obtained by observing from a distance? Distributed sensor technology is on the way (Culler, Estrin, and Srivastava 2004) – how best can it be used?

It is clear that sensor nets have value for at least two applications: 1. persistent monitoring, and 2. sensing signals that are not detectable at a large distance. We can draw on the example of space astrophysics, where it is recognized that, because of the cost of space experiments, things should be done from space only if they cannot be done from the ground. Similarly, things should be monitored by expensive deployed nets only if they cannot be monitored by remote systems that cover large areas at once.

In this work, we are not addressing issues of data integration and connectivity (*e.g.,* Kahn *et al.* 1999; Hester *et al.* 2002), but rather concentrate on the physical and economic limits of measurement.

Alternatives to Sensor Nets

Remote sensing can cover huge areas in a single exposure, but certain signals cannot propagate through the atmosphere or large distances, and persistent imaging is not yet a reality. Transient reconnaissance, in which a sensor is flown or carried within range of a target, is a well-established technique. For transient exposures, the sensor can be brought within a range of 10^3 km with low Earth satellites, 10-100 km with manned or unmanned aircraft (the longer ranges are associated with large slant ranges), and <1 km with miniature unmanned vehicles.

The challenge lies in obtaining the geometric advantage of height and the temporal advantage of persistence at the same time. As Newton noted, the apple doesn't hover, but instead falls to the ground. A satellite platform can hover at geosynchronous altitude, but at enormous range. To form an image with one-meter resolution at 1 µm wavelength from a geosynchronous satellite at 40,000 km altitude requires an aperture, real or interferometric, of at least fifty meters, bigger than any telescope yet flown. In low Earth orbit, one can fly above a target at ranges as little as 300-400 km, but at 7 km s^{-1} the target passes out of sight in only a few minutes, and is not seen again for one or more likely many ninety-minute orbits.

Powered heavier-than-air flight offers persistence over a target, but is limited by the endurance of human pilots. Even an unmanned aerial vehicle (UAV), freed from the human endurance limitations of a manned aircraft, is limited by its fuel supply. The Global Hawk UAV, (GlobalSecurity.org 2004) was planned to be capable of twenty-eight hours of endurance while carrying 1,350 kg of payload at an altitude of 20 km above mean sea level. Solar-powered aircraft offer a solution to the fuel problem. However, despite successful flights at altitudes approaching 30 km, no solar aircraft has yet flown through the night, due to limitations on energy storage (Smith 2001; Baer-Riedhart 2002)

No energy is required to keep a lighter-than-air vehicle at altitude, although energy must be expended to hold position against ubiquitous winds. Several groups are working on airships that would fly above the air lanes, at altitudes greater than 20 km. (Wilson 2004, Schaefer *et al.* 2002). However, definitive demonstrations of this new generation of airships is still pending, at least in the public arena.

In summary, space and atmospheric platforms offer opportunities for remote sensing. They are limited in their persistence, but there are hopes of overcoming this limitation. More fundamentally, there are certain measurands that can never be measured at a distance, because they cannot propagate through large masses of air, or because they are buried in a sea of clutter and/or background at long range.

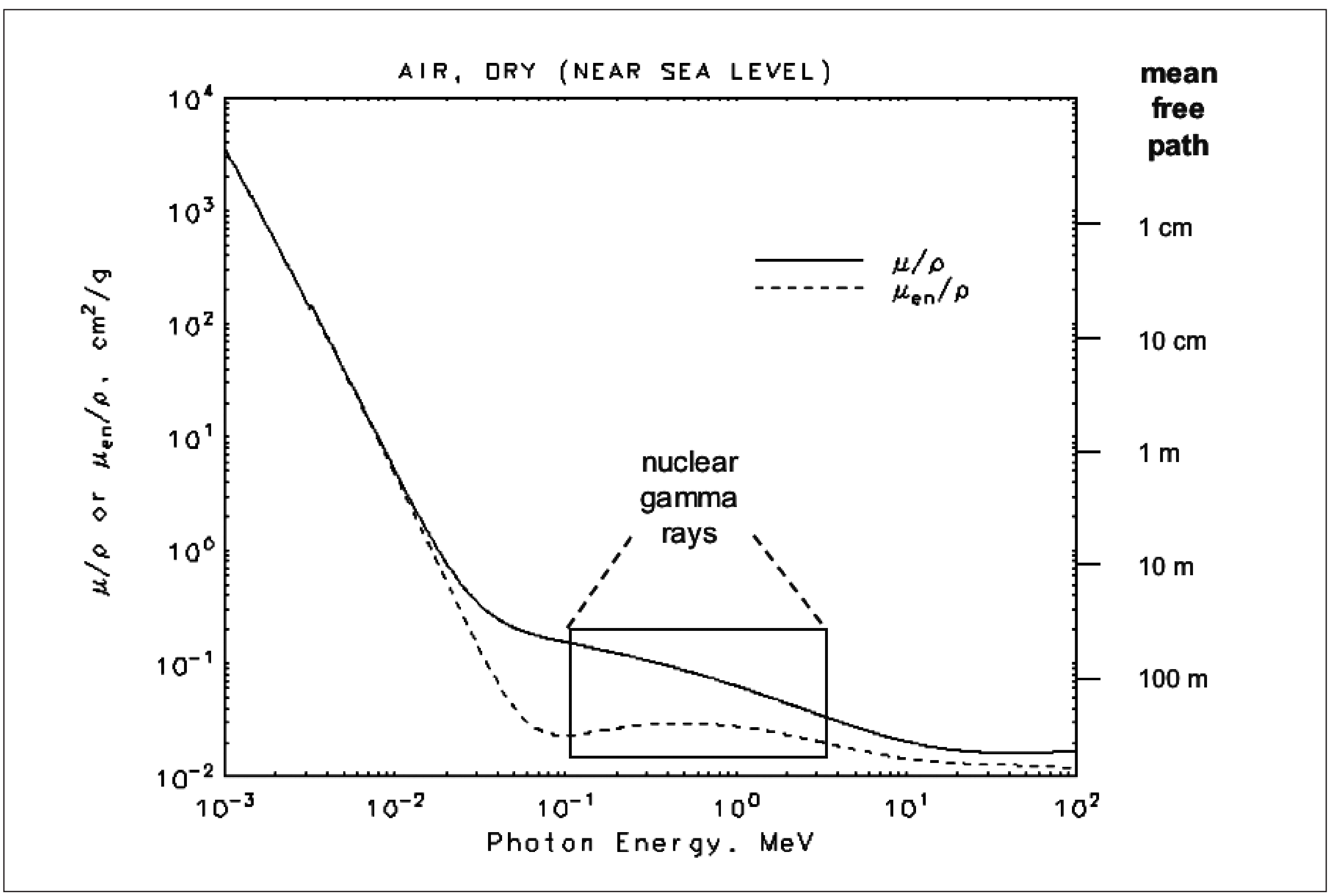
Unique Capabilities of Distributed Sensors

Signals that Cannot Travel a Great Distance

There are a number of measurands of interest that cannot be detected at long range, or can be sensed only with great difficulty. These short-range measurands include:

- Temperature
- Humidity
- Pressure
- Wind
- Acceleration
- Vibration
- Radio emissions in noisy environments
- Sound
- Gases (chemicals)
- Nuclear radiations (e.g., gammas, neutrons, alphas)
- Millimeter wave radio signals
- Biologicals

Figure 1. A fundamental (but usually not the practical) limit to the range of gamma-ray detection is set by atmospheric absorption. More usually, the detection range is set by background or clutter. (Hubbell and Seltzer 1996)



The increase in measurement difficulty at long range can be enormous. For example, local measurements of surface temperature require a simple thermistor that can be easily miniaturized, while long-range range measurements of temperature require precisely calibrated infrared spectrometry, and careful correction for the intervening atmosphere. A dime store thermometer to do the former costs ~$1, and a microsensor far less, while a low-cost satellite for long range thermometry, like the U. S. Department of Energy's Multispectral Thermal Imager (Bell and Weber 2001), costs in excess of $100 million, for a cost differential greater than 10^8:1. In some cases, the preference for local measurement is not only economical, but absolute.

Physical Limitations

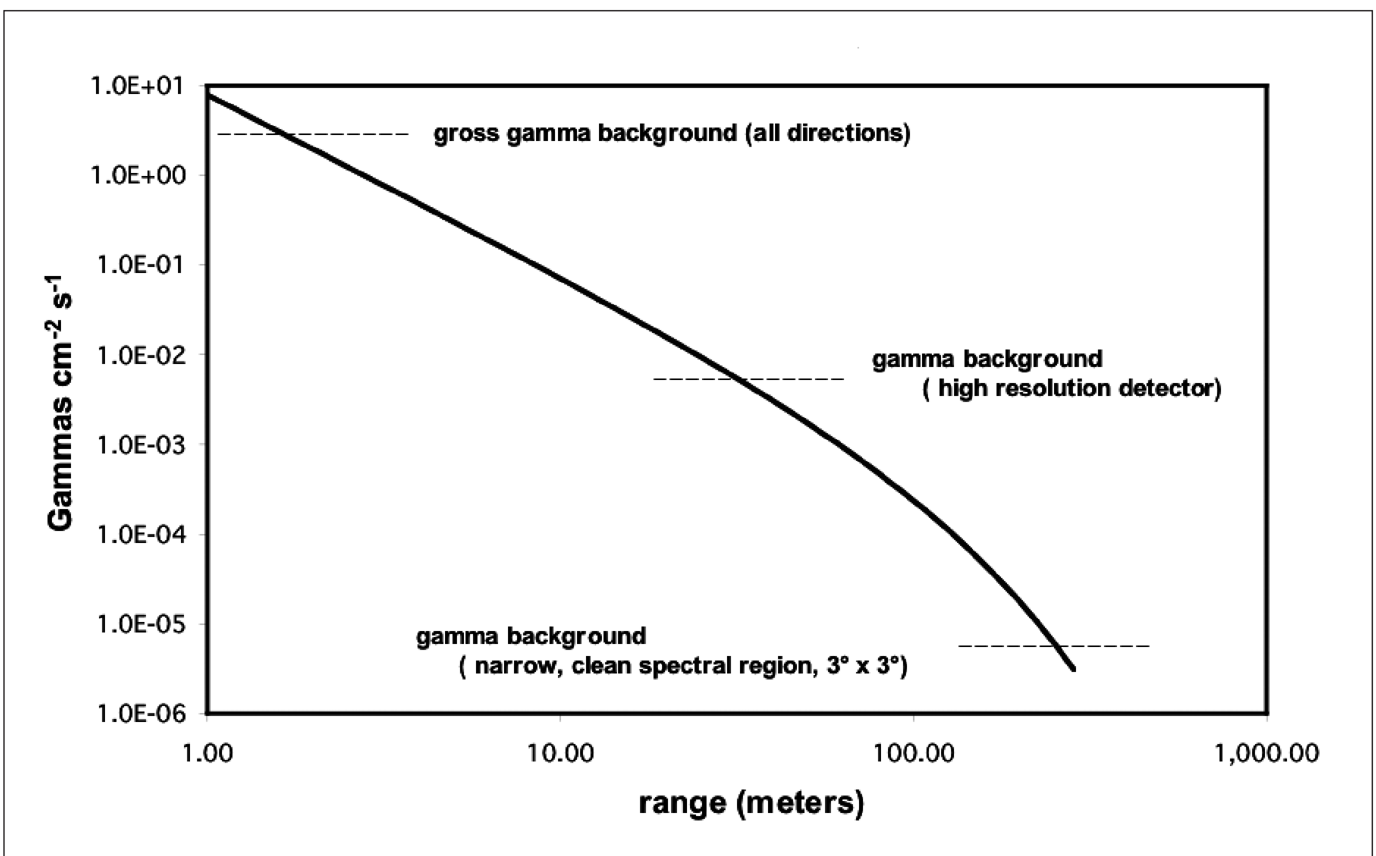
Obviously, acoustic signals and particles do not propagate into a vacuum, and therefore cannot be sensed from space. These are prime candidates from distributed sensor networks (Maroti *et al.* 2004). Only certain regions of the electromagnetic radiation, principally the optical, infrared, and radio bands, can propagate the full thickness of the atmosphere. Other regions of the spectrum are completely absorbed. For instance, no radiation of wavelength shorter than 0.3 µm can pass through the atmosphere, and nothing between 30 µm and 600 µm can reach space from sea level (Cox 2000).

Nuclear radiations are strongly attenuated with distance. Figure 1, for example, shows the mean free path of gamma-ray photons in air. Photons in the energy range produced by radionuclides, 0.l - ~3 MeV, have a mean free path of no more than a few hundred meters, making their detection at ranges of kilometers an impossibility. If they are to be sensed at all, they must be sensed locally.

Even before signals are absorbed, they can fall below the statistical variations in ambient backgrounds. This is particularly important, for example, in the case of nuclear signals. In the gamma-ray region, the background is of order a few photons cm^{-2} s^{-1}, integrated across the gamma-ray band, in a typical outdoor urban environment (Tsutsumi *et al.* 2001, Latner *et al.* 2002). Of course, these backgrounds can vary dramatically from location to location.

Figure 2 shows how the signal from a weak gamma ray source quickly falls below background. We assume a source of 400 keV gammas that radiates 106 s^{-1} into 4≠ steradians (1 Mbq), and consider how it competes with a typical gamma-ray background.

Figure 2. The signal from a weak gamma-ray source falls below background quickly as distance increases. Detection range is typically limited by background rather than atmospheric attentuation.



This source is comparable to a sphere of plutonium, with a mass equivalent to the International Atomic Energy Agency (IAEA) significant quantity (8 kg), shielded by 2.5 cm of iron. The mean free path before scattering at this energy is about 80 meters at sea level. At a few meters, the unscattered flux has fallen to a few gammas cm^{-2} s^{-1}, and is about as bright as the background. If most of the background can be rejected by exploiting the high spectral resolution of a detector like high-purity germanium, the signal can compete with background out to a few tens of meters. If an even more complex imaging detector, like a Compton camera (Herzo *et al.* 1975), rejects all background events outside a 3° x 3° angular region around the source, the signal can compete with background until the exponential absorption of the atmosphere comes into play. But for simpler detectors, background can be more important than absorption.

A signal need not be greater than background to be detected, if the background can be well characterized. In this case, the detection limit is set by statistical fluctuations in the background, which make it impossible to subtract the background completely. This yields a detection limit:

$$S_{min} = 4\pi\ N\ R^2\ B^{1/2}\ A_{det}^{\ -1/2}\ \varepsilon^{-1/2}\ \tau^{-1/2}\ ,\ (1)$$

where S_{min} is the minimum detectable source strength (gamma s^{-1}), N is the required statistical significance (typically 4 or 5 sigma), R is the range, B is the environmental gamma rate (γ cm^{-2} s^{-1}), A_{det} is the detector area, ε is the detector efficiency, and τ is the exposure time.

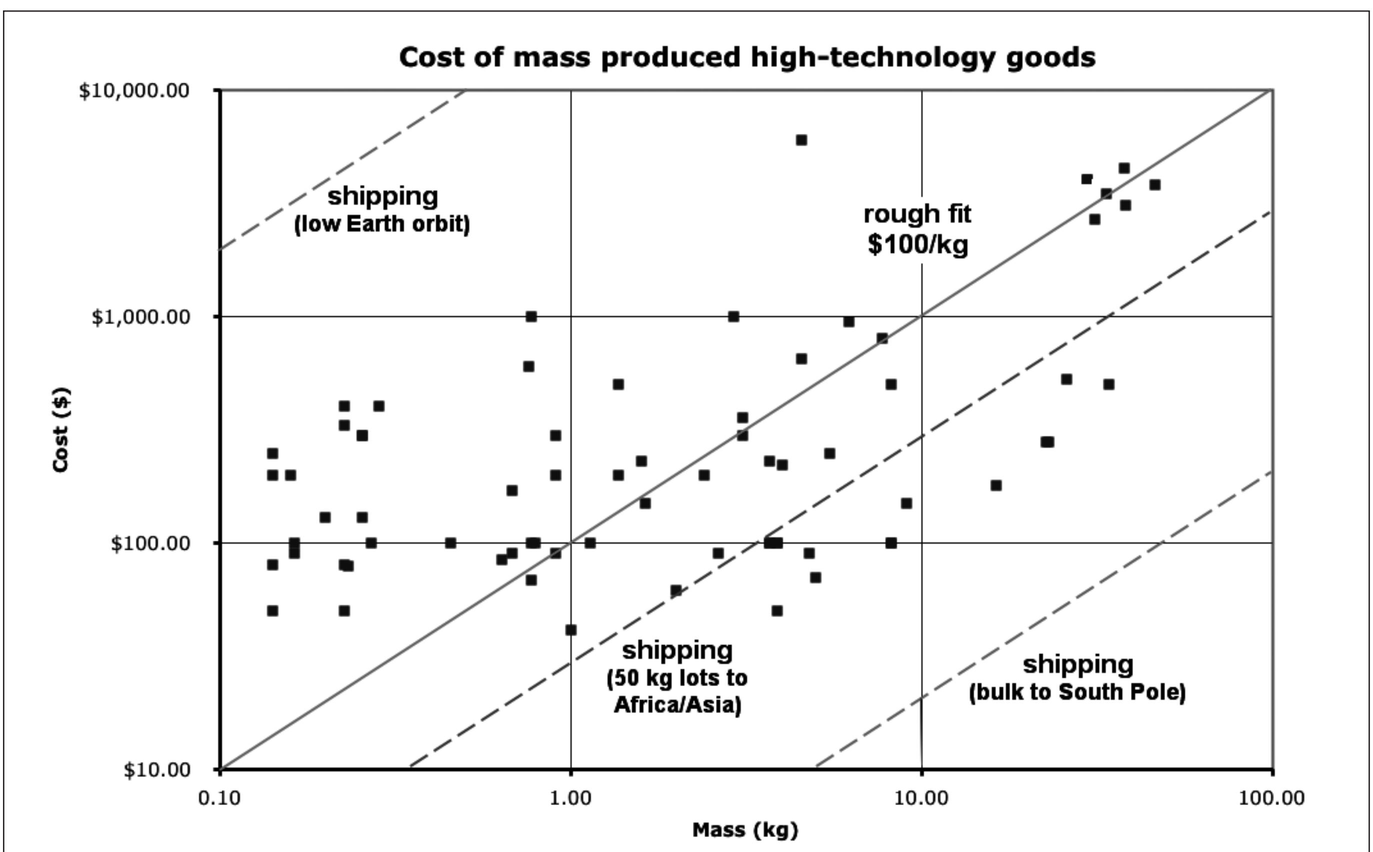
Sometimes, however, the background cannot be characterized, and presents an unpredictable competition to the signal. The signal must clearly exceed the background clutter to be detectable. Radio frequency (RF) signals often fall into this class. In the 50-200 MHz region, for example, the continuum noise leaving the Earth totals ~10^{-12} W M m^{-2} Hz^{-1} even in quiet parts of the spectrum (Fitzgerald *et al.* 1999), and more than two orders of magnitude greater where strong emitters exist, like in the FM broadcasting bands.

These scalings all argue for a small, nearby detector, even if it must be replicated in large numbers, instead of a distant, more capable detector.

Economic Limitations

Given that many sensing problems are best solved by distributed arrays of sensors, the cost of an individual sensor immediately comes to the fore. This is because sensors must be deployed in large numbers, and the individual sensor cost must be multiplied

Figure 3. An informal survey of the cost of high-technology, medium-volume items in normal commerce shows that many items tend to cost about $100 per kg, to within a factor of 10. These data allow a rough estimate of the deployed cost of large networks of sensors.



by a large factor. For example, to cover the District of Columbia (177 km^2) with sensors that have a ten-meter range would required a total of more than 500,000 sensors.

The cost of such a network will include installation, communication, and shipping as well as hardware. But it is useful to understand the lower limits set by hardware costs. Since the cost of multiple unit production runs differs from laboratory one-of-a-kind prototypes, we would like to estimate the cost of high-tech items produced in commercial quantities. These prices have little to do with the "one-off" prices of R&D prototypes that one faces in the laboratory. To estimate these costs, we scanned the Web for boutique high-tech items, with substantial electronic or optical components, that are produced in quantities of thousands. Examples of these items are shown in Figure 3, where their cost is plotted as a function of unit mass. To within a factor of a few, high-tech items in boutique production costs of order $100 per kg. These implies that our putative District of Columbia array, if each sensor weighs 0.5 kg, might cost ~$25 million. In this case, an array of sensors is about as expensive as a single spaceborne system.

Anyone who has ever ordered anything from the Web will know that one pays extra for shipping. Figure 4 shows these costs. The shipping cost to remote parts of the Earth was taken from the Web page of an international freight forwarder, and the bulk cost to the South Pole derived from the net cost of diesel fuel at the Pole ($2/liter). Even with considerable shipping costs, it is more costly to build high-tech items than to ship them. This is in contrast to space, where the delivery cost to low Earth orbit is about $10,000/pound (Lindroos 2001). Because this cost is so much greater than normal manufacturing costs, space systems are driven to high cost, with a large investment in reliability and longevity to match the delivery cost.

Within the range of the possible, some sensors are much more compact and cheaper than others. Micro miniaturization has been possible in cases like seismic, acoustic, and magnetic sensing, and simple measurements of temperature and pressure. At a larger, 1 cm^3 scale, one can package miniature CCD cameras and video, and electromagnetic sensors (Pister 2002). Sensitive nuclear and mass spectrometric sensors remain at a larger scale, of order 1 liter, while active assays or analytical processes such as radiography, DNA analysis by PCR, and active interrogation (the induction of fission by neutron or gamma bombardment) are more massive still, and may never be miniaturized.

Example: Nuclear Sensing

Nature of the Problem

To quantify the possibilities and economics of a distributed sensor net, we consider a particular case: the detection of a weak nuclear source over a wide area. In this case, the range of detection might be limited by atmospheric absorption, background statistics, and/or unpredictable backgrounds (clutter). Unfortunately, there has been no credible proposal for the remote detection of nuclear radiation. Ionized air molecules can drift in the wind, and be detected at ranges (tens of meters) greater than the original alpha radiation, but certainly not at kilometers or beyond (MacArthur *et al.* 1992; Koster *et al.* 1994). It has been suggested that the ionization plume created by an intense source, such as the stack of a nuclear power plant, can be detected by optical fluorescence, or by its radar reflection, but these signatures appear unlikely to be detectable (Peurrung 2002, 2004). To date, the only reliable way to detect a nuclear source remains direct detection of its nuclear radiation, and area coverage requires a distributed sensor network. The use of distributed sensor networks for direct nuclear detection has been discussed by Nemzek *et al.* (2004), Brennan *et al.* (2004), and references therein.

A Quantitative Example

Consider the problem of detecting and tracking a 100 microCurie Cs^{137} source (662 keV gammas emitted at a rate of 4.8 x 10^6 s^{-1}) somewhere in a 1 km^2 area. For simplicity, we consider a flat area with no obstacles. We assume 3" x 3" cylindrical NaI scintillator detectors. We will assume a realistic value for the gamma background (10^{-3} gammas keV^{-1} cm-2 s^{-1}; Latner *et. al.* 2002), but perhaps optimistically assume that the background is well known, and the source detected as a perturbation to the background. We require that the source be detected at a 4σ level of confidence every five seconds, and that it be within range of three detectors at any time in order to track its motion. We allow a false negative probability of 2.5 percent; *i. e.,* in any five-second interval, the source might be missed by any given detector with 2.5 percent probability.

In this case, each detector, with an efficiency of about 33 percent at this energy (Grosswendt and Waibel 1976), will be able to make a 4 σ detection in 5 s detection at a range of ten meters, with a mean signal of twenty-nine counts and background of nine counts. This is sufficient for a 4σ level detection, using a threshold set for a 2.5 percent false negative rate.

The 3" x 3" detector crystal will weigh 1.28 kg. If we allow as much mass again for electronics, communications, mechanical housing etc., the 9,500 detectors required for triply redundant coverage over one square kilometer will mass more than twenty-four metric tons. If we apply a canonical cost of $100 per kg (which is cheaper than sodium iodide crystals, but might be a target for higher production levels), the sensor hardware will cost a total of $2.5M. In this case, areal coverage with a distributed sensor net is a significant investment.

Smaller is Better

In this case, like many others, a cost savings can be had by reducing the size of the sensors and bringing them closer. More smaller detectors will outperform fewer large detectors. This is even more true if absorption is important, which is not the case in a few meters of air for penetrating gamma rays. However, the geometry must be such that the detectors can cover every possible source, without gaps or denied areas.

In the limit of Gaussian statistics, and when sensitivity is limited by statistical noise on the background (*e.g.,* not clutter-limited), the required detector size scales as the fourth power of the maximum detection range: $A_{det} \sim R^4$. This is because the minimum detectable signal scales as $A_{det}^{-1/2}$, while the signal falls as R^{-2}. Since the number of detectors required to cover a piece of ground scales as R^{-2}, and the mass of a detector typically scales with the area, the total mass of detectors on the ground scales as $R^2 \sim A_{det}^{1/2}$. Many smaller detectors require less mass.

To test this scaling, we consider smaller 2" x 2" sodium iodide detectors for the detection problem above. Despite the somewhat smaller photopeak efficiency (29 percent), this detector should be able to make a 4σ detection at a range of 7.7 meters in five seconds, with a mean of nineteen signal counts against 3.5 background. Since the detector mass is down by a factor of $(2/3)^3 = 0.30$, while the reduced range requires that their numbers must be increased by 69 percent , the total mass of the system is 50 percent of the previous system, for a hardware cost of $1.25 million. This is in rough accord with the scaling above, which predicts a mass 2/3 the original. The difference comes because we changed the detector thickness as well as area, and from the non-linear scaling of Poisson statistics in the low-count limit.

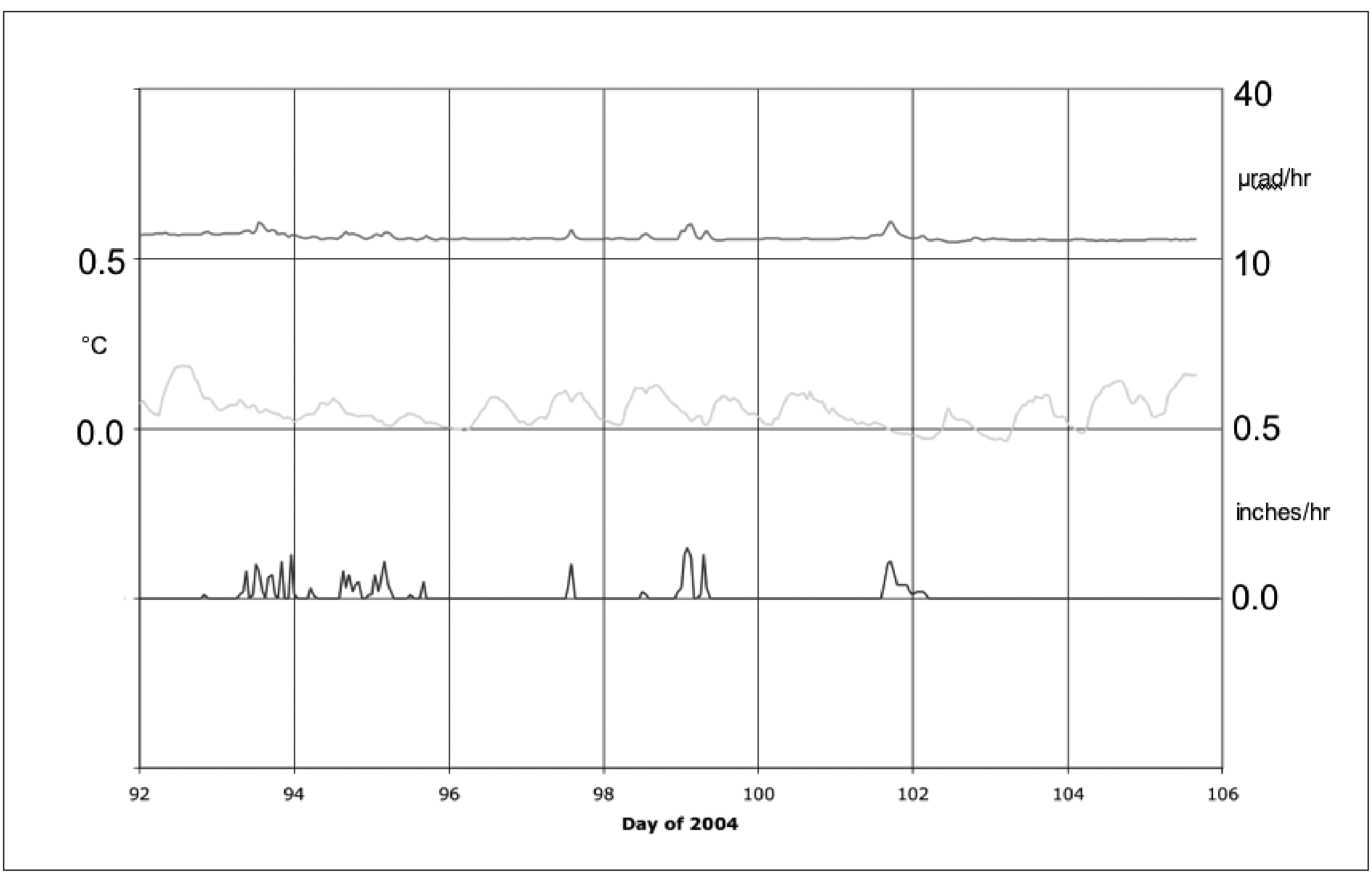
Better is Better

Another way to reduce the mass of the network is to employ better, more selective detectors. The calculations above were based on sodium iodide detectors, with a 6 percent energy resolution. In order to accept all the counts from the instrumentally-broadened 662-keV line, one must accept about 40 keV bandwidth of continuum background. But in the Gaussian limit (eqn. 1), the detector area and the background per unit area weigh in with the same power. A detector with ten times better spectral resolution has the same sensitivity as one ten times larger. In the clutter limit, where backgrounds are *not* predictable, reduction of background is even more important. One can afford to spend ten times more for a detector that has ten times better spectral resolution.

Alternate Channels

In order to avoid costs of this sort that are associated with direct detection, one should be on the lookout for less costly, indirect means of making a measurement. For example, as Pister points out (2002), one might monitor the activity levels in a building by simple light sensors in a few locations, and thereby infer progress in a project conducted in the building.

Figure 4. Sometimes an indirect measurement may be the way to bypass an otherwise unaffordable sensing problem. In this case, one can track the level of background radioactivity by sensing precipitation.



Another example of indirect, less costly detection is shown in Figure 4. Here, the problem is to track variations in the background radiation level, which requires an ionization detector. But at a lower cost, trends in the radiation background (upper curve) can be predicted by a simple measurement of rainfall (lower curve), which is often associated with temperature drops (middle curve). The measurements were taken at Los Alamos High School in April 2004 using the Los Alamos National Laboratory NET distributed environmental sensors.

The Advantage of Mobile Sensors

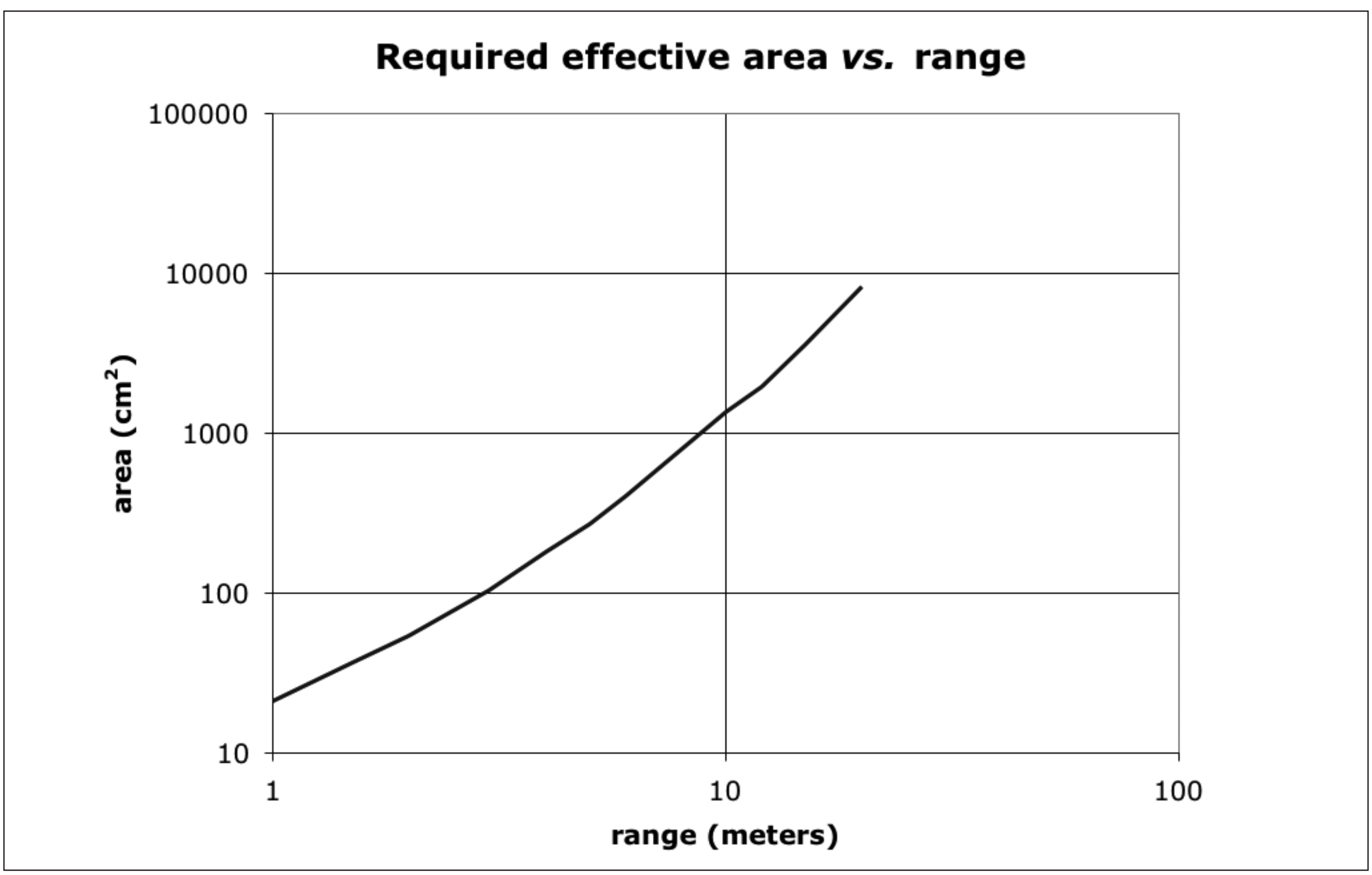
Given the importance of proximity, we should consider other means to reduce detection distance. Rather than lay out an array of sensors and wait for the source to get close, one might make the sensor mobile, and bring it to the source.

The following example demonstrates the power of mobility. We consider another problem in nuclear sensing – the detection and confirmation of a weak, moving gamma-ray source that emits at a single energy in the 400-500 keV region. Our source emits 7 x 10^5 gammas s^{-1} into 4≠ sr, and travels at 30 mph (13.4 m s^{-1}) past a fixed point. We again make the optimistic assumption that we are limited by statistical variations in the background. Our strategy is to obtain an initial preliminary detection from a large fixed detector, then follow up with a high-sensitivity detection at short range with a high spectral resolution detector.

In this part of the spectrum, we assume a background of 2 x 10^{-3} gammas keV^{-1} cm^{-2} s^{-1}, which has been recorded in typical interior and exterior urban settings (Tsutsumi *et al.* 2001, Latner *et al.* 2002). The monoenergetic signal must compete with continuum background, summed over a bandwidth determined by the spectral resolution of the detector (assumed to be 7.7% FWHM at this energy, typical of sodium iodide). We assume that the source is unshielded, and that it moves past the fixed detector in a straight line. In Figure 5, we show how the detector area must increase with distance to obtain a signal-to-noise of 4 during the passage of the source. The required A_{det} is obtained from equation (1) for S_{min} = 7 x 10^5 s^{-1} and τ = R/v. This required area scales strongly with range (as R^3, rather than the R^4 for a non-moving source discussed in IV.C, because the exposure time increases as the range increases). If we consider ranges appropriate to a detector placed at the side of a roadway, say six meters, we need a detector of significant size, approximately 400 cm^2 effective area (or about twice as large in geometric area), and weighing about 15 kg.

Once this preliminary, crude, and perhaps confused detection is made (confused due to the modest spectral resolution), it

Figure 5. Size of a screening detector to detect a 7 × 10^5 gamma s^{-1} source moving past at 30 mph (13.4 m s^{-1}). This detector is the first in a two-step detection strategy, and is followed by a much smaller mobile detector to confirm the detection with high confidence.



can be confirmed with high confidence using a tiny mobile detector. We assume a high-resolution scintillation detector, like lanthanum bromide (Shah *et al.* 2003; 3.2 percent FWHM spectral resolution), with an effective area of 1 cm^2 and a mass of a few grams. If by some means this detector can move to within three meters of the source (by wheels, wings, teleportation, or whatever robotic means), and hold position for 30 seconds, it would detect an average of eighteen signal counts against a mean background of 0.77 counts, for a detection confidence better than 10^{-7} (better than 5σ), with better spectral resolution and less confusion than the original, much larger detector.

We conclude that, by bringing a sensor to the immediate vicinity of a suspect object, we can detect and characterize a radiation source far better than by lying in wait with a network of massive sensors. Robotic mobility is the key, and is a complex topic beyond the scope of this study.

Conclusions

Distributed sensor networks are needed to detect certain signatures, for example chemical, nuclear, and biological signals, that do not propagate far enough to be sensed by remote techniques. Even so, there are limits on the miniaturization of certain sensors, and it will be expensive to cover large areas to detect, for example, nuclear sources. These costs can be minimized by deploying smaller sensors in greater numbers, by more discriminating sensors, and by exploring alternative signatures. If it is possible to make sensors mobile, bringing Muhammad to the mountain rather than the mountain to Muhammad, much smaller, cheaper sensors can be employed.

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Acknowledgment

These thoughts were focused by the workshop on Intelligent Sensor Systems for Remote Monitoring. The workshop was only possible thanks to the leadership of Paul Rockett and David Spears of the U.S. Department of Energy/National Nuclear Security Administration/Nonproliferation Research and Engineering (NA-22), and Jacob Trombka of NASA. Support for the workshop came from NA-22. I would like to acknowledge my gratitude to Christine Shannon for pulling together the workshop logistics, and Karl Pitt, chair of our session, for thought-provoking discussions.

This work was supported by the U. S. Department of Energy/National Nuclear Security Agency, and is derived from an invited talk at the NNSA/NASA Workshop on Intelligent Sensor Systems for Remote Monitoring, Warrenton, Virginia, April 27–29, 2004. This work has been approved for public release as LA-UR-04-5907.

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Overview of AFCI Transmutation Engineering Activities

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Introduction

The Advanced Fuel Cycle Initiative (AFCI) is a key part of the U.S. Department of Energy's Office of Nuclear Energy, Science, and Technology (DOE-NE) research and development program that is addressing the challenges of the 2005 Energy Policy Act. The DOE-NE effort also includes the Nuclear Power 2010 Program, the Generation IV Nuclear Energy Systems Initiative, the Nuclear Hydrogen Initiative, and the Nuclear Energy Research Initiative. Working together these programs will develop and demonstrate technologies to:

- Support the expansion of nuclear energy in the United States
- Effectively manage radioactive waste
- Reduce the threat of nuclear material misuse
- Enhance national security

AFCI Program

The goal of the AFCI program is to develop technologies that will meet the needs for economic and sustained nuclear energy options while satisfying requirements for a controlled, proliferation-resistant nuclear materials management system. In keeping with this goal, the strategic elements of the AFCI program are to develop:

- Separations technology needed by industry to deploy a proliferation-resistant commercial-scale spent fuel treatment facility by 2025
- Fuels needed by industry to deploy advanced reactors by 2040 capable of destroying the dominant radiotoxic components of spent fuel through transmutation

The AFCI program has four technical objectives that guide the research and development:

- Reduce the long-term environmental burden of nuclear energy through more efficient disposal of waste materials
- Enhance overall nuclear fuel cycle proliferation resistance via improved technologies for spent fuel management
- Enhance energy security by extracting energy recoverable in spent fuel and depleted uranium, ensuring that uranium resources do not become a limiting resource for nuclear power
- Improve fuel cycle management while continuing competitive fuel cycle economics and excellent safety performance of the entire nuclear fuel cycle system

To address these objectives the program is developing technologies that could eliminate the need for more than one geologic repository for nuclear waste in this century. The keys to reducing the environmental impact are the removal and destruction of dominant radiotoxic and heat-producing actinides and fission products. The current once-through fuel cycle will require a Yucca Mountain-sized repository every thirty years if nuclear power stays at the same capacity in the United States. Efficient closure of the fuel cycle can extend the repository capacity by a factor of sixty. To reduce the proliferation potential associated with the weapons-usable materials inherent in spent fuel, the program is developing the means to transmute a large portion of the transuranic (TRU) waste in storage and develop improvements in monitoring and instrumentation during spent fuel processing.

The AFCI program is organized by elements spanning all activities necessary to support advanced fuel cycles. The major program elements include separations technologies, fuels development, transmutation engineering, and systems analysis.

Transmutation Engineering Overview

Transmutation engineering activities focus on developments in physics and materials that support the implementation fast neutron spectrum transmuter systems. Transmutation physics provides the nuclear data needed for accurate predictions of the overall performance of transmutation systems. The transmutation materials activities include the development, testing, and modeling of structural materials, as well as research and testing of coolant materials and systems for advanced fast reactors.

Transmutation is the process of transforming components of spent nuclear fuel dominating waste disposition issues into less troublesome forms. The isotopes ^{241}Am, ^{241}Pu, and ^{237}Np dominate the long-term heat load and radiotoxicity of waste and impact repository performance and packing density, while weapons-usable ^{235}U and ^{239}Pu dominate global nuclear material management issues. Thermal neutron spectrum systems such as the light water reactor (LWR) are effective in destroying certain isotopes of Pu, but are net producers of Np and Am. Fast neutron spectrum systems such as fast reactors (FRs) and accelerator-driven systems (ADS) destroy all isotopes of Pu, Np, and Am efficiently because of the high fission-to-capture ratio. Fast spectrum burner reactors with low conversion ratios have the potential of transmuting these isotopes with the minimal presence of U fuel, therefore avoiding the significant production of additional Pu during irradiation. System studies show that each GW-thermal of fast spectrum transmutation reactors can destroy the TRU (plutonium and higher actinides) that are produced by 4 GW-thermal of conventional LWRs. If it is assumed that the TRU undergoes recycle in LWRs (primarily to destroy the ^{239}Pu) then the support ratio increases to seven or more.

Cross-Section Measurements

To reduce the uncertainties in transmuter design, transmutation physics activities continue to focus on development of nuclear data to allow accurate prediction of transmutation rates. The 237Np fission and capture cross-section measurements, which marked the production of the first AFCI-funded actinide fission and capture cross sections in FY 2004, were completed in FY 2005. Results indicated reduced systematic errors and uncertainty in measurements and provided useful insights into guiding new theoretical evaluations for this isotope. The data measurements are unique in that the cross sections for fission and capture reactions span ten decades of incident neutron energy. This is accomplished using two separate instruments at the Los Alamos Neutron Science Center (LANSCE). Data is currently being taken for the isotopes ^{240}Pu and ^{242}Pu. With special measurement foils being produced by the Idaho National Laboratory (INL), isotopically pure samples will be developed for the other actinides of interest.

In addition, to support the materials research activity, the transmutation physics team measured gas production cross-section measurements on tantalum (Ta) and chromium (Cr) to determine the amount of [hydrogen (H) and helium (He)] gases produced via neutron interactions. These gases can lead to significant detrimental changes in material properties such as embrittlement and swelling. The results will be used to accurately predict gas production in the fast spectrum transmuter structural materials while in service, and therefore allow accurate prediction of material lifetimes.

Structural Materials Research

To provide for efficient transmutation in fast spectrum burner reactors, it is necessary that the fuel and cladding survive very high burn-up and attendant neutron dose. New cladding alloys are necessary to safely reach the desired dose and avoid irradiation-induced material degradation. Structural materials testing is being performed to evaluate material properties (e.g., strength, fatigue, ductility) under varying temperature and dose conditions. The effects of fast neutron irradiation on the tensile properties of potential AFCI structural materials such as JFMS (Japanese Ferritic-Martensitic Steel) and HT-9 were recently investigated showing that these alloys hold promise for future transmuter use.

Radiation damage processes, including He production, diffusion, trapping, and clustering, are inherently multi-scale phenomena involving a wide range of length and timescales. A significant part of the materials research activity is to develop a first principle model that can be used to accurately predict alloy behavior under intense radiation conditions, thus shortening the time necessary to develop, irradiate, analyze and qualify new materials. At the atomic scale, molecular dynamics (MD) simulations and kinetic Monte Carlo (KMC) code are used to study the formation and evolution of defect microstructure under irradiation. These modeling activities will provide necessary insight on the effect of defect microstructure and gas inclusions on macroscopic materials properties. Recently a Modified Embedded Atom Method (MEAM) MD model for Fe-Cr system was developed to determine defect configurations and geometries in body-centered cubic (BCC) Cr. The model reasonably predicted various defect properties of the Cr system. In addition, the temporal evolution of the embryonic gas bubbles was predicted using the KMC model. The simulations produced cluster-size distributions and reaction rate constants that can be used to quantify microstructural evolution of the irradiated metal. The radiation damage modeling effort is starting to produce interesting results as the first *ab initio* calculations are now being performed to make qualitative predictions of materials behavior. Validation experiments will provide the data necessary to benchmark calculations in the future and improve the models.

Liquid Heavy Metal Coolant Corrosion

Coolant options for the fast spectrum transmutation reactors include sodium and lead. Attributes of heavy liquid metals (lead or lead-bismuth) offer the potential for improvements in safety and thermal efficiency over sodium with the downside of increased corrosion of stainless steels at temperatures above 400 degrees C. Thus as part of the materials research efforts, transmutation engineering is developing techniques for mitigating corrosion in these systems. The primary workhorse is the DELTA (Development of Liquid Metal Technologies and Applications) loop at Los Alamos National Laboratory. Recent long-term (1,000 hours) corrosion tests included thirty different materials and surface treatments.The DELTA loop produces a unique oxygen-controlled flowing lead-bismuth eutectic (LBE) environment for materials testing. Temperatures up to 550 degrees C are possible. The research team has developed a thorough understanding of the corrosion process, and has determined that certain alloying elements in stainless steel can be added that develop a stable oxide surface that passivates the bulk material and eliminates corrosion. Other surface treatment and coating techniques have produced similar results. The next phase in the development is to test materials in flowing lead at temperatures up to 700 degrees C in collaboration with researchers from the University of Nevada Las Vegas and the development of a large-scale engineering test at the INL.

Material Test Station Design

The irradiation testing of fuels and materials in a prototypic environment is essential to the implementation of fast spectrum transmutation reactors. With the shutdown of the FFTF and EBR-II reactors in the early 1990s, the United States has no fast spectrum irradiation capability. Some irradiations are possible in foreign reactors, but these are difficult, time consuming, and expensive. To alleviate this problem, considerable effort has been put into the design of a materials test station (MTS) at LANSCE. Using the existing proton accelerator and a very large unused experimental area, the MTS will produce an intense neutron irradiation environment very similar to a fast spectrum reactor. The MTS would use the existing LANSCE 800 MeV high power proton beam in conjunction with a spallation target to generate the neutrons. Because each proton creates about fifteen neutrons, a total neutron flux of 1.2e15 n/cm2/s is generated. Design reviews and initial estimates for the MTS cost and construction schedule have been completed. If funding continues and needed upgrades to the LANSCE accelerator are implemented, the MTS could be completed and operational by 2009 at a total project cost of about $50 million. The potential for upgrading the accelerator to higher power in the future would enable the MTS to double the neutron intensity, therefore shortening irradiation times by a factor of two.

Future Activities

Assuming the implementation of a fast spectrum transmutation demonstration reactor in the 2014 time frame, several transmutation engineering activities must be completed before hand. At the current pace, all of the actinide isotopes of interest will be measured for fission and capture cross sections, and the nuclear data evaluated and incorporated in the Evaluated Nuclear Data File by 2011. With respect to the development of structural materials, by the end of 2012, a validated model for predicting irradiation performance in alloys will be complete. And, with respect to the coolant technology, the maturity of the lead or lead alloy option will be raised to a sufficient level by the end of 2009 such that a decision on its use in future transmuters can be made.

Seal Performance of Metal Cask Under Drop Accident

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Abstract

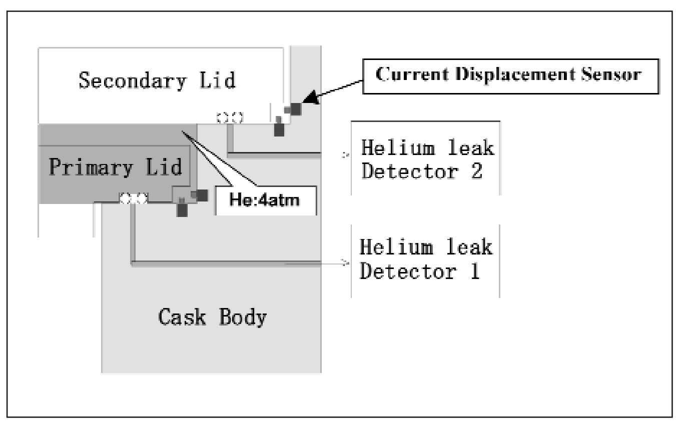
Although there have been many tests and analyses reported for the evaluation of drop tests of metal casks, no quantitative measurement has ever been made for any instantaneous leakage through metal gaskets during the drop tests due to loosening of the bolts in the containments and lateral sliding of the lids. In this study, leak tests were performed using a full-scale cask without impact limiters simulating drop accidents in a storage facility, with the aim of measuring and evaluating any instantaneous leakage at the impact. Instantaneous leak rates were quantitatively measured at the drop tests. The amount of leakage was insignificant. The relationship between the maximum sliding displacement of the lid and the leak rate was obtained.

Introduction

For drop accidents of a metal cask, two types of accidents are assumed, i.e., an accident during transportation and an accident during handling in a storage facility. Impact limiters are installed on a metal cask during transportation, but not during storage. There have been a lot of tests and analyses reported for evaluation of drop tests of metal casks.[1, 2] However, no quantitative measurement has ever been made for any instantaneous leakage through metal gaskets during the drop tests due to the loosening of the bolts in the containments and lateral sliding of the lids. In order to determine a source term for radiation exposure dose assessment, it is necessary to obtain a fundamental data of the instantaneous leakage. In this study, leak tests were performed using a full-scale cask without impact limiters simulating drop accidents in a storage facility, with aim of measuring and evaluating any instantaneous leakage during at the impact.

Figure 1. Overall view of the horizontal drop test

Figure 2. Leak rate measurement positions



Drop Test

Drop tests of a full-scale metal cask without impact limiters were carried out simulating drop accidents during handling in a storage facility. The target was designed to simulate a floor of a reinforced concrete in the facility. The first test was a horizontal drop from a height of 1 m (Figure 1). The second test was to simulate a rotational impact around an axis of a lower trunnion of the cask from the horizontal status at a height of 1 m.

The main measurement items are the sliding and lid opening displacements of the primary lid and the secondary lid, leak rates, and pressure of helium in the space between the primary lid and the secondary lid. The lid structure of this cask and the position of leak rate measurement are shown in Figure 2. The double type metal gasket is installed on the bottom of each of the primary lid and the secondary lid, and the containment is kept by metal gaskets. Instantaneous leak rates were quantitatively measured at both the primary and secondary lids by the helium leak detectors. In this test, 4 atm (gauge pressure) of helium was filled in the space between the lids. On the other hand, eddy current displacement sensors (accuracy of ±0.01mm) were used for displacement measurement of lids.

Horizontal Drop Test

Figure 3 shows a test condition. The cask was dropped horizontally from a height of 1 m. In this test, the front trunnion collided with the concrete floor directly.

Figure 3. Horizontal drop test condition

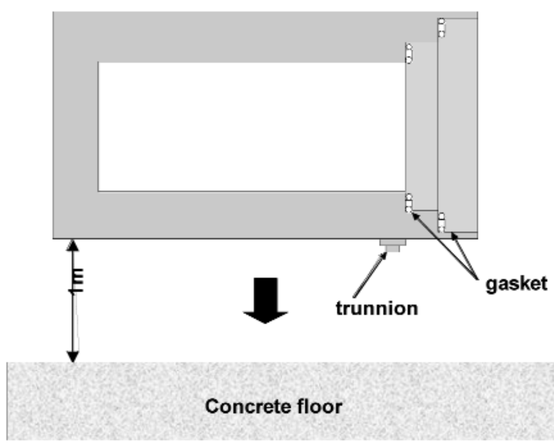


Table 1 shows summarized results of this test. Figure 4 shows time histories of the sliding displacement of the primary lid. Figure 5 shows time histories of the opening displacement of the primary lid. Figure 6 shows time histories of the sliding displacement of the secondary lid. Figure 7 shows time histories of the opening displacement of the secondary lid. Here a positive value is defined for the direction that a lid moves apart from the shell of the cask body. Whereas, a negative value is defined for the direction that a lid moves toward the shell. Figure 8 shows time histories of the leak rate from the primary lid. Figure 9 shows time histories of the leak rate from the secondary lid. The amount of penetration to the concrete floor by the trunnion was about 100 mm and the average acceleration of the cask body center was about 50 G. The maximum sliding displacements were about 0.4 mm and about 0.3 mm at the primary lid and the secondary lid, respectively. These were observed at 0° direction (the direction of the drop).

The tendency of the sliding displacement was that the lids moved toward the shell at 0°, they did not move at 180°, and they moved away from the shell at 90° and 270°. Therefore, it is considered that the cask body was transformed into an elliptical shape.

On the other hand, no significant opening displacements were observed as for both of the primary lid and the secondary lid. Moreover, no decrease of the pressure between lids was observed right after the drop impact.

The value of leak rate from the primary lid rose by one order of magnitude after the impact immediately, and ten minutes later, it returned to the background level. However, the leak rate rose again by one order of magnitude after about twenty-five minutes and returned to the background level. After that, this did not recur during six hours of observation. Therefore, the leak rate seemed to have returned to the background level completely.

Table 1. Results of the horizontal drop test

Acceleration	Main body	50G
	Lid	16G
Primary Lid	Sliding	0.4mm
	Lid opening	No significant change
Secondary Lid	Sliding	0.3mm
	Lid opening	No significant change
	Axial stress of bolt	No significant change
Maximum leak rate	Primary lid	2.38×10^{-10} Pa · m³/s
	Secondary lid	2.85×10^{-9} Pa · m³/s
Leak rate after 6 hours	Primary lid	1.52×10^{-11} Pa · m³/s
	Secondary lid	7.90×10^{-12} Pa · m³/s
Pressure between lids		No significant change

On the other hand, the leak rate value from the secondary lid rose by two orders of magnitude immediately after the impact. The high leak rate remained for about one hour. After that, the leak rate seemed to have returned to the background level.

The amount of helium gas leakage was calculated by integrating the leak rate with time. The total amount of helium gas leakage from the primary and secondary lids was 1.99×10^{-6}Pa•m³. This value is 9.61×10^{-9}% of the initially installed helium gas. The amount of leakage was insignificant.

Rotational Impact Test

Figure 10 shows a test condition. This test was to simulate a rotational impact around an axis of a lower trunnion of the cask from the horizontal status at a height of 1 m. In this test, both of the front trunnion and the cask corner collided with the concrete floor directly.

Table 2 shows summarized results of this test. Figure 11 shows time histories of the sliding displacement of the primary lid. Figure 12 shows time histories of the lid opening displacement of the primary lid. Figure 13 shows time histories of the sliding displacement of the secondary lid. Figure 14 shows time histories of the lid opening displacement of the secondary lid. Figure 15 shows time histories of the leak rate from the primary lid. Figure 16 shows time histories of the leak rate from the secondary lid.

The amount of penetration to the concrete floor of the trunnion was about 50 mm and the average acceleration of the primary lid center was about 48 G.

The maximum sliding displacements were about 0.6 mm and about 1.0 mm at the primary lid and the secondary lid,

Figure 4. Time histories of sliding displacement of the primary lid (horizontal drop test)

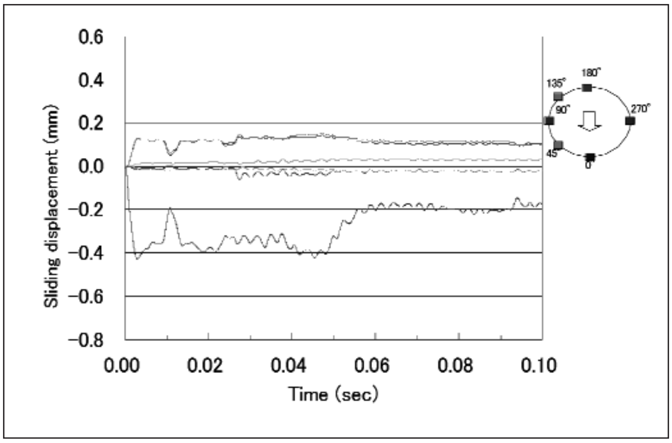


Figure 5. Time histories of opening displacement of the primary lid (horizontal drop test)

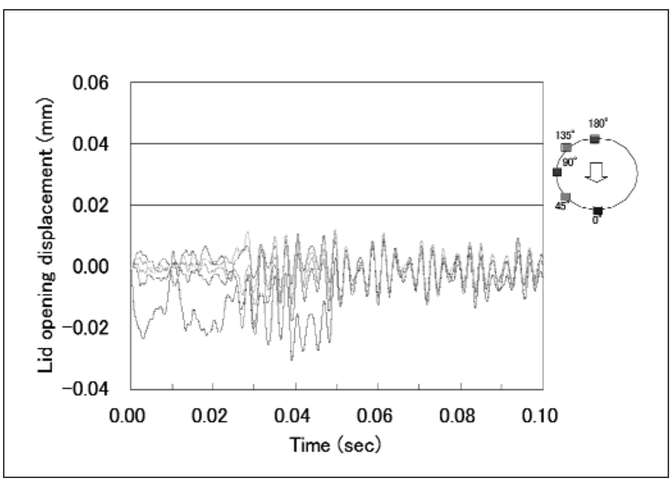


Figure 6. Time histories of sliding displacement of the secondary lid (horizontal drop test)

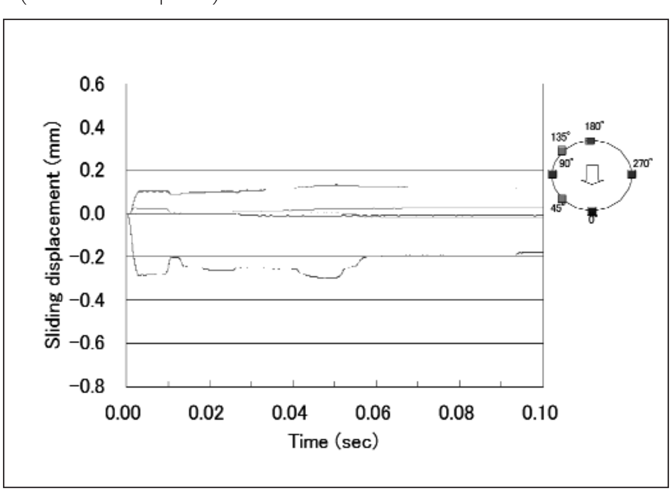


Figure 7. Time histories of opening displacement of the secondary lid (horizontal drop test)

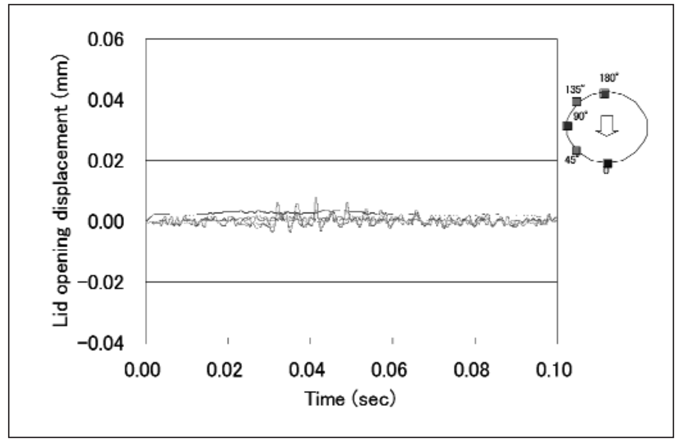


Figure 8. Time histories of leak rate from the primary lid (horizontal drop test)

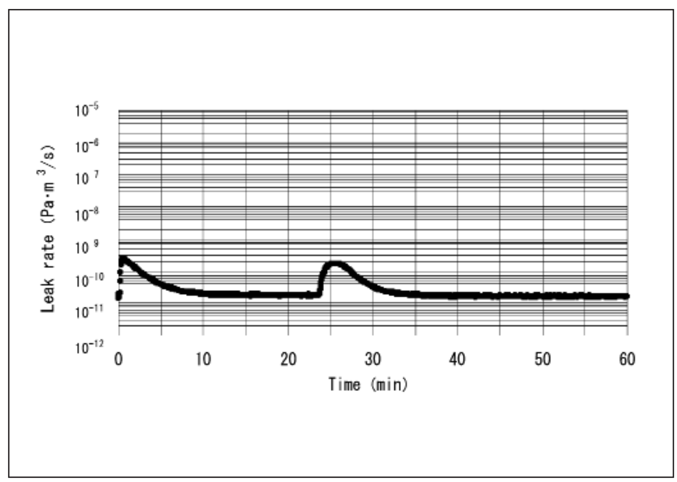


Figure 9. Time histories of leak rate from the secondary lid (horizontal drop test)

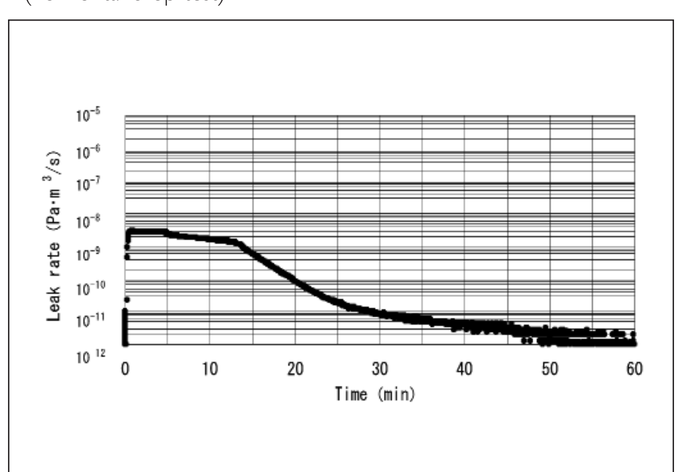
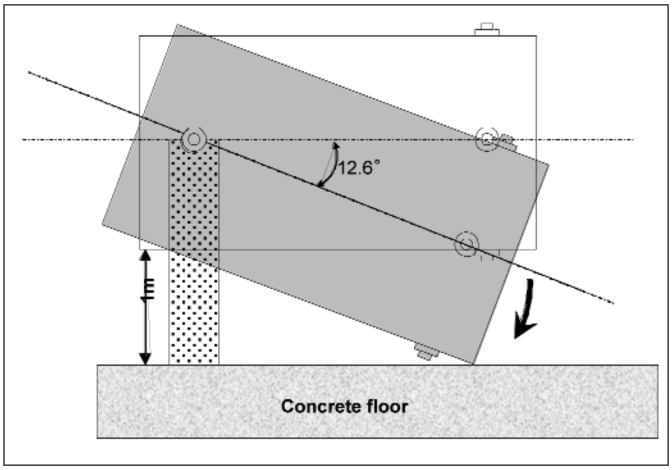


Figure 10. Rotational impact test condition



respectively. It was considered that both 0° and 180° directions of the secondary lid touched the shell of the cask body. Tendency of the sliding displacement was that lids moved toward the shell at 0° direction, and they moved away from the shell at 90° and 270°. The large lid opening displacement exceeding 0.1 mm was observed at 0° from the primary lid. On the other hand, no significant opening displacement was observed in the secondary lid. The axial stress of the secondary lid bolt increased about 50 MPa at 0° for 0.02 seconds during the impact. It returned to the initial value after the impact. The sliding displacement was larger than that of the horizontal drop test, and the lid opening displacement was observed. Therefore, the leak rate was larger than that of the horizontal drop test.

Table 2. Results of rotational impact test

Acceleration	Main body	16G
	Lid	48G
Primary Lid	Sliding	0.6mm
	Lid opening	0.11mm
Secondary Lid	Sliding	1mm(0°), 0.6mm (45°)
	Lid opening	No significant change
	Axial stress of bolt	Increase of 50MPa
Maximum leak rate	Primary lid	3.86×10^{-9} Pa · m^3/s
	Secondary lid	8.37×10^{-9} Pa · m^3/s
Leak rate after 6 hours	Primary lid	4.91×10^{-10} Pa · m^3/s
	Secondary lid	2.64×10^{-10} Pa · m^3/s
Pressure between lids		Decrease of 0.006MPa

The total amount of leakage from the primary and secondary lids was 1.74×10^{-5}Pa•m^3. This is 8.45×10^{-8}% of the initially installed helium gas. This value was larger than that of the horizontal drop test. Nevertheless, the amount of leakage was also insignificant.

The decrease in pressure between lids was observed, which means the helium gas leaked. The leak seems to be from the helium filling port, not from the lid gaskets because the leak rate that was calculated by the pressure drop greatly exceeded the detection range of the helium leak detector, which means the detector malfunctioned.

Conclusions

Instantaneous leak rates were quantitatively measured in drop tests of a full-scale metal cask simulating drop accidents in a storage facility. Two tests were performed using a full-scale metal cask. The first test was a horizontal drop from a height of 1 m. The second test was to simulate a rotational impact around an axis of a lower trunnion of the cask from the horizontal status at a height of 1 m. Negligible helium leak was observed in both cases. At the rotational impact test, the amount of leakage was larger than that of the horizontal drop test. However, the amount of leakage was insignificant in these tests.

Acknowledgments

This work has been carried out under the contract from the Ministry of Economy, Trade, and Industry of Japan.

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Figure 11. Time histories of sliding displacement of the primary lid (rotational impact test)

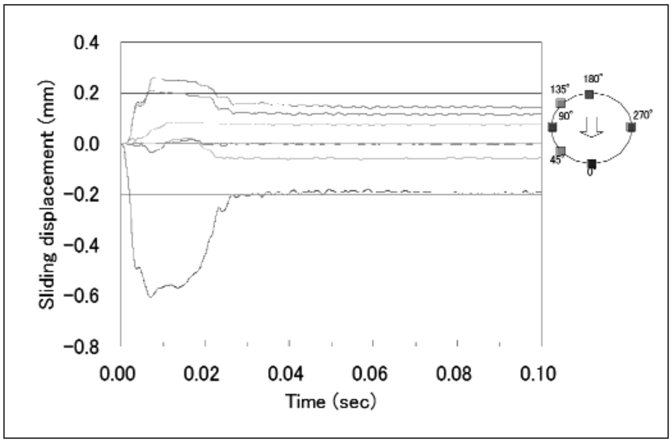


Figure 12. Time histories of opening displacement of the primary lid (rotational impact test)v

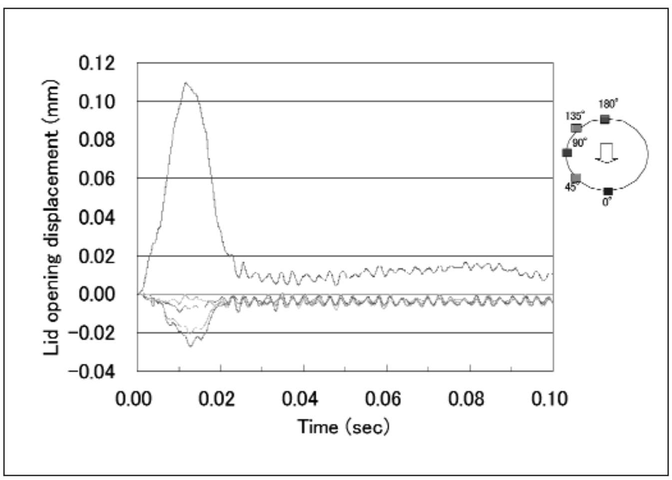


Figure 13. Time histories of sliding displacement of the secondary lid (rotational impact test)

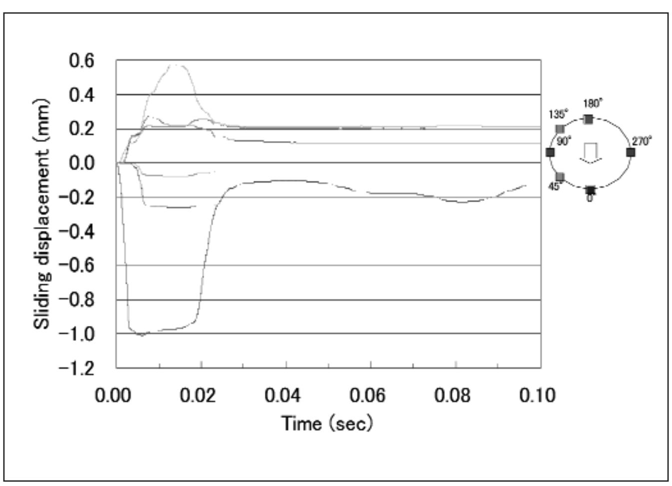


Figure 14. Time histories of opening displacement of the secondary lid (rotational impact test)

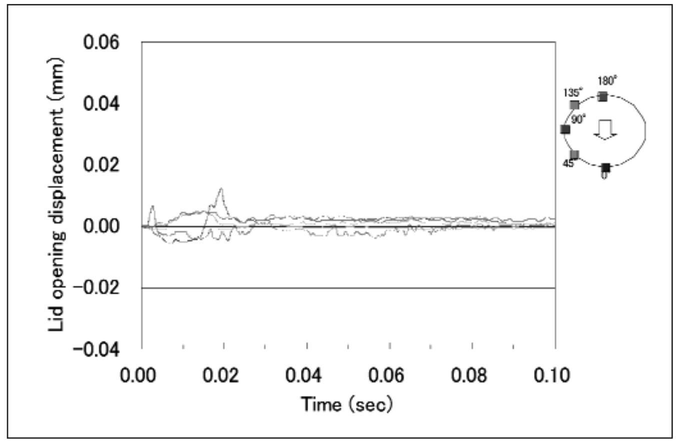


Figure 15. Time histories of leak rate from the primary lid (rotational impact test)

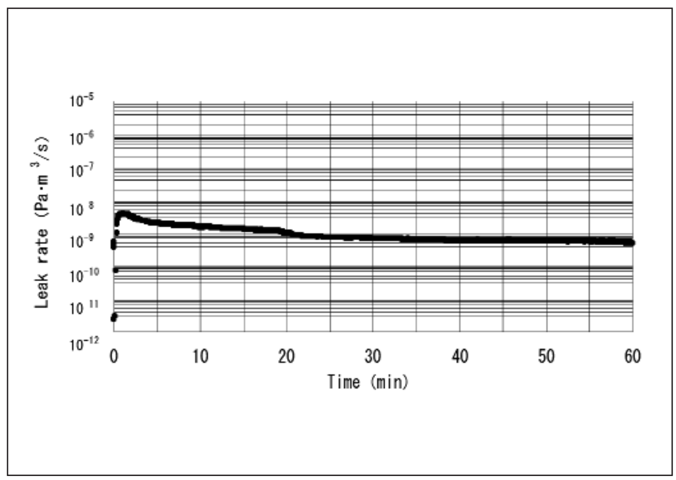
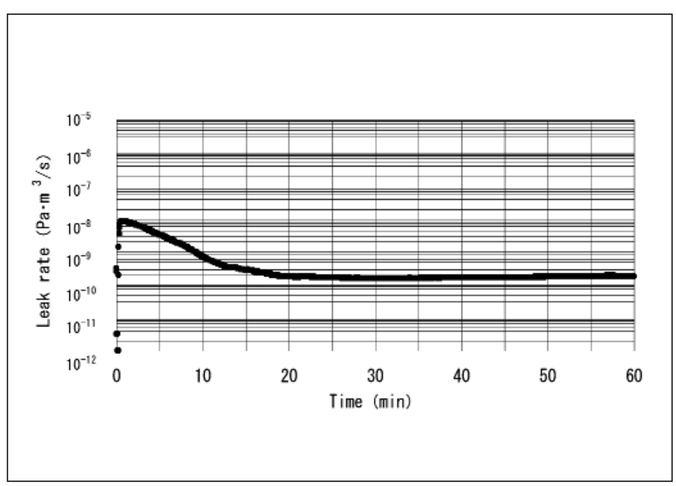


Figure 16. Time histories of leak rate from the secondary lid (rotational impact test)



Proliferation Resistance of Advanced Nuclear Fuel Cycles

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Abstract

This paper proposes a baseline position for the proliferation resistance of advanced fuel cycles (primarily closed fuel cycles), with the objective of initiating a technical debate among the opponents and proponents of closed fuel cycles. The emphasis is on reprocessing and recycling technologies needed to implement the closed fuel cycles. A brief review of proliferation resistance concepts is presented. For implementation of advanced fuel cycles, a technology development and demonstration approach is proposed. The approach aimed at demonstrating a "world standard" in recycling technologies is based on 1) advanced instrumentation development and testing, 2) a "safeguards by design" approach for advanced recycling plants, and 3) development and demonstration of a "safeguard envelope" concept for advanced monitoring of these plants. The implementation of the proposed approach relies equally on a) laboratory to engineering scale testing and b) advanced modeling and simulation.

Introduction

For nuclear energy to play an expanded role in the global energy market, innovative approaches will be necessary to address concerns about potential proliferation risks Any program or project aimed at designing future nuclear energy enterprisesmust properly address the issue of proliferation resistance of the overall system within which the advanced technologies will be deployed. Consequently, enhanced proliferation-resistance is a major goal of the Advanced Fuel Cycle Initiative (AFCI) and Generation IV (GEN IV) programs in the United States.

Unfortunately, in recent years the proliferation-resistance discussion in the United States has degenerated into an absurd[1] debate. For the last few decades, the proponents of advanced nuclear fuel cycles (the author of this paper is one of them) have been put on trial with an undefined accusation. Advanced fuel cycles must clearly be introduced into the energy sector soon to generate clean and affordable energy by nuclear power while maximizing the use of our natural resources and minimizing the nuclear waste.

To achieve that goal, the issue of proliferation resistance must be put within a reasonable technical context. As part of any advanced, sustainable fuel cycle, reprocessing (recycling) has been the target of some well-meaning groups who are worried about its potential misuse.

Clearly, the proponents of closed fuel cycle technologies must do a more convincing job in showing that they can be deployed safely and securely. Unfortunately, reprocessing was also targeted by the anti-nuclear agenda to stifle the potential growth of nuclear energy. The attempts by anti-nuclear groups to purposely obscure the debates resulted in serious barriers to promoting the potential benefits of nuclear energy.

In the 1970s all reprocessing of commercial spent nuclear fuel was halted in the United States. This led to a waste-intensive use of nuclear energy in the last three decades, resulting in the accumulation of about 40,000 metric tons of spent nuclear fuel (SNF) with considerable energy value (considered high-level nuclear waste in the United States). The SNF stockpile in the United States continues to grow at a rate of ~2,000 metric ton/year with no easy long-term solution in place yet. Trying to set an example for the rest of the world by not reprocessing SNF could have been viewed as a noble objective, if it did not coincide, during the same period, with the most rapid increase in nuclear weapon production worldwide. Other countries with heavy reliance on nuclear energy did not buy into the United States where plutonium (Pu) from the SNF is recycled back into the reactors. No diversion of weapons-usable materials from the safeguarded civilian reprocessing plants has occurred to date. However, during the same period, many new countries joined the nuclear-weapons club with materials and technology obtained from other sources. Recent revelations with the discovery of the Khan network have shown that the uranium enrichment technology would be the preferred means of proliferation, especially for countries aspiring to develop their first set of weapons. The "no reprocessing" policy that endured through multiple administrations in the last three decades has left the United States with a large stockpile of SNF, almost choking the potential growth of a clean energy source, while being, at most, marginally effective in its nonproliferation objective.

The United States can no longer afford to stay on the sidelines. A purely reactionary posture by the United States is not sufficient to influence the views in the rest of the world. Instead, the United States must actively participate in (and hopefully lead) the worldwide effort of expanded deployment of the clean nuclear energy source. Among other things, this means taking a leading role in defining the proliferation-resistance standards and the associated technologies that would be universally acceptable. The current U.S. administration appears to be willing to take on this challenge and to review the no reprocessing policy as part of its overall nuclear energy strategy.

This paper is written to establish a baseline position for the proliferation resistance in closed fuel cycles. While the author does not claim that this position is the best available at this time, the objective of this paper is to focus the debate. The pros and cons of the proposed approach must be discussed based on facts. It is the author's belief that once a technically structured discussion on this topic is reestablished the hypes and the myths will diffuse quickly, and logical conclusions on global fuel cycle technologies will follow. *After all, proliferation resistance is more like a direction for a journey than a destination. The immediate goal is to take steps in the right direction. Along the road further choices and trade-offs will likely be required.*

Definition of Proliferation Resistance

One problem with the proliferation resistance discussions in the last decade has been lack of clarity in the debate language. The following definitions, agreed on by world experts,[2] are important to remember and form the basis for some of the subsequent discussions presented in this paper.

"Proliferation resistance is that characteristic of the nuclear energy system that impedes the diversion or undeclared production of nuclear materials, or misuse of technology by the host state in order to acquire nuclear weapons or other nuclear explosive devices."

"Intrinsic proliferation resistance features are those features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of the extrinsic measures."

"Extrinsic proliferation resistance features are those features that result from the decisions and undertakings of states related to nuclear energy system."

The same report cites a number of examples of intrinsic proliferation resistance features, which include:

- Few points of access to nuclear materials, particularly in separated form
- Facilities that are difficult to modify for undeclared production of nuclear materials
- Systems with inventories and flows of nuclear material that can be specified and accounted for in the clearest possible manner
- Systems in which nuclear materials remain accessible for verification, to the greatest extent practical
- Systems that make possible the use of operational and safety-related sensors and measurement systems for verification, taking into account data authentication
- Systems that provide for the installation of measurement instruments, surveillance equipment, and supporting infrastructure likely to be needed for verification

In these definitions and examples, two salient points that must be highlighted are:

1. Proliferation resistance deals with state-related decisions and activities. It is not a substitute for physical protection that is needed, irrespective of the technologies and systems used in the fuel cycle.
2. Intrinsic resistance does not necessarily mean making the separated materials and fresh fuel as *hot* as possible (e.g., meeting spent fuel standard). Advanced safeguards embedded in the system design are a major component of the intrinsic proliferation resistance characteristic.

The second point has caused considerable controversy in recent years. Many people interpreted the intrinsic resistance to mean that the separated materials necessarily had to be radiologically and thermally hot to prevent access and handling. The problem with that proposition is that it makes subsequent fuel fabrication very difficult (if not impossible) and expensive, with implications for reactor operating and safety envelopes.

As discussed later in this paper, the added complication does not really prohibit proliferation, if a state is determined to proliferate. Subsequently, if the United States insists on developing a complicated and expensive fuel cycle, other countries will not implement it. After all, they already have established (or have the capability to establish) a system that is economically viable and that works. The report by the Organization of Economic Co-Operation and Development (OECD) summarizes the world position on nonproliferation quite accurately and can help in establishing a discussion framework within the United States:[3]

"The risk of nuclear weapon proliferation is a major concern raised in connection with peaceful applications of nuclear energy although international nonproliferation and safeguards regime has proven to be highly effective so far. Moreover, since proliferation of nuclear weapons is driven primarily by political incentives and concerns, the goal of non-proliferation must be achieved primarily through political means. It should be noted that, most countries who choose to acquire nuclear weapons did so through dedicated, often clandestine, military facilities rather than diversion from civilian nuclear power programmes, that are mostly under international safeguards. Nonetheless, diversion from civilian programme is one possible route to the acquisition of fissile material, a crucial technical step towards weapons. Accordingly, the non-proliferation regime must be extended to ensure a very high likelihood of detecting, and hence deterring, any such diversion. This is particularly important as nuclear power programmes spread to new regions and countries."

Fuel Cycle Technologies

In the recent years, there were multiple attempts to develop a proliferation-resistant technology that one could "hand over to the enemy and not worry about." Such a technology does not exist. Any enrichment and separations technology can be modified to obtain weapon-usable materials. A brief review of various separations technologies are provided below.[4]

PUREX is the current standard in the world. It is used in England, France, Japan, and Russia on a commercial scale. It separates weapon-usable materials. It relies heavily on safeguards for assurance that weapon-usable materials are not diverted from the plant. *UREX+* is the preferred AFCI technology for reprocessing the light-water reactor (LWR) spent nuclear fuel (SNF). Research on this technology continues under the AFCI program and the results look very promising. UREX+ also is an aqueous separations technology (like PUREX). It can be used to obtain a stream of transuranics (TRU) to be recycled into the reactors. However, with additional stages, it can also be used to obtain a stream of plutonium (Pu) and neptunium (Np), which would be considered weapons usable. It can also be modified to morph into the PUREX process.

Pyroprocessing is being looked at as more proliferation-resistant than aqueous technologies because of its intended use. However, like other processes, it can be modified to directly obtain weapons-usable materials by changing the cathode material, changing the electrolyte salt composition, or drawing down the uranium (U) content of the electrorefiner salt.

Gaseous processes (such as fluoride volatility) rely on volatility differences of different actinides. Thus, in principle, separate streams of actinide fluoride can be collected at different locations. The more exotic *plasma processes* typically rely on a compact machine with no need for additional materials and equipment. The processes can be modified to separate the individual actinide elements by changing the operating conditions of the machine.

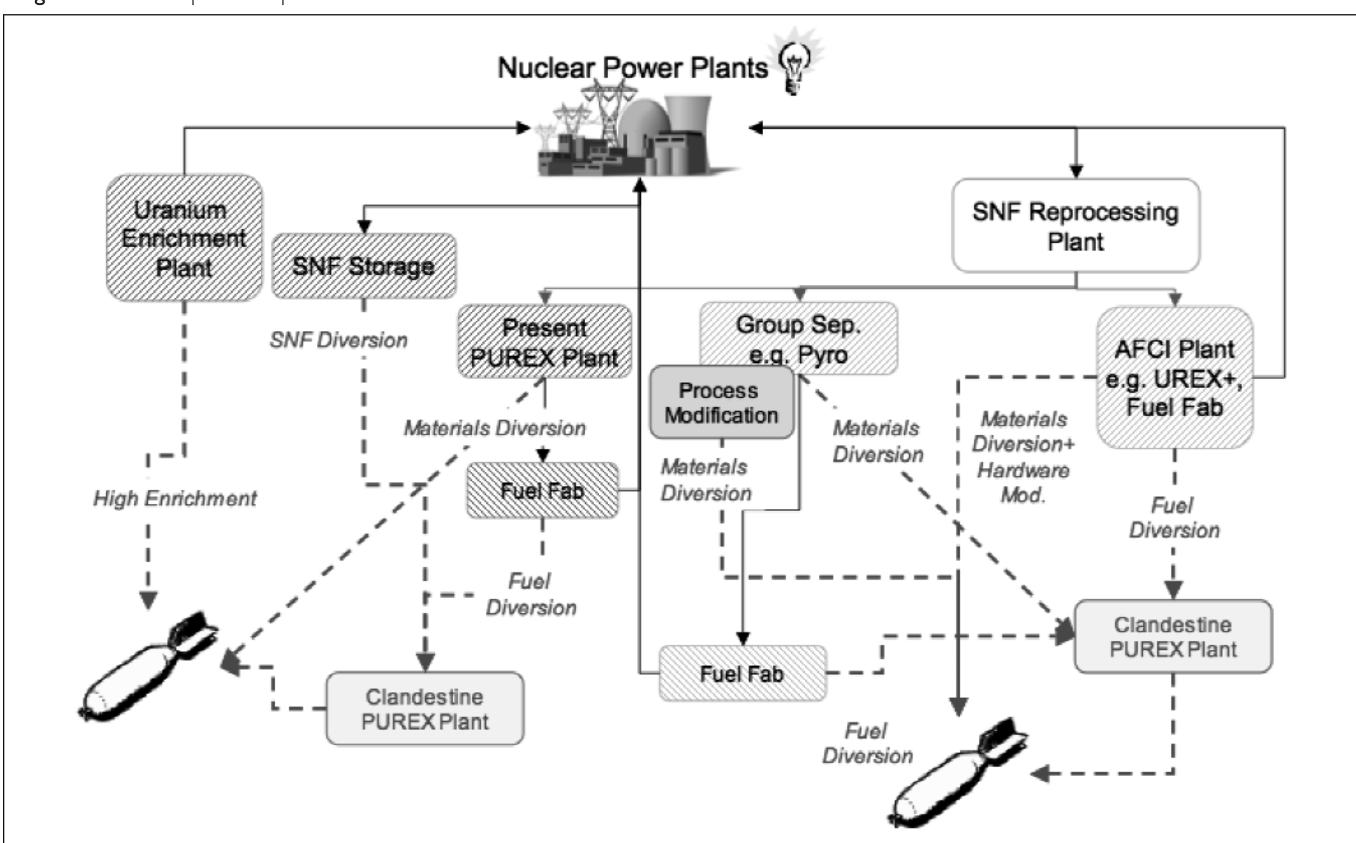
The situation is further complicated by the fact that the uranium enrichment and PUREX technologies are no longer technological mysteries. Pandora's box is open and the technologies are widely known worldwide. Based on recent revelations, we must assume that any country willing to proliferate can do so through either enrichment or separations in small clandestine plants. The countries can develop such capabilities based mostly (if not solely) on indigenous capabilities. North Korea (probably the poorest country in the Northern Hemisphere), Pakistan, and Iraq are testimony to this.

Given this situation, different means of proliferation available to a determined state with possession of nuclear materials is shown in Figure 1. The primary messages from this figure are 1) uranium enrichment is possibly the easiest and cheapest path to proliferation, and 2) the key to controlling the proliferation risk is in controlling the nuclear materials.

Proliferation-Resistance Strategies

In assessing the proliferation resistance of a fuel cycle, focusing solely on technology choices is not correct. As discussed above

Figure 1. Potential paths for proliferation



there is no single silver bullet that makes a fuel cycle proliferation proof. The overall fuel cycle system including the political, social, and technical infrastructure surrounding it must be analyzed to properly assess the proliferation resistance of a fuel cycle.

As shown in Figure 2, in simple terms, the proliferation resistance of a system can be assessed by the following parameters:

Response Time (RT) < Proliferation Time (PT) – Detection Time (DT)

The proliferation time (PT) (also referred to as breakaway time, in some literature) is defined as the time between the state's decision to proliferate (initiate physical activities in that direction) and the development of an actual nuclear weapon. PT includes the time required for the acquiring the necessary materials and for successfully assembling them into a weapon.

The detection time (DT) is the time between the state's decision to proliferate and the detection of such intentions by the international community. Obviously, the DT is always less than or equal to the PT. In the total absence of intelligence, the detection occurs simultaneously as proliferation. The response time (RT) is the time required for the international community to take decisive action to terminate the proliferation activities. In an effective proliferation resistance strategy, the difference between PT and DT must be greater than the RT.

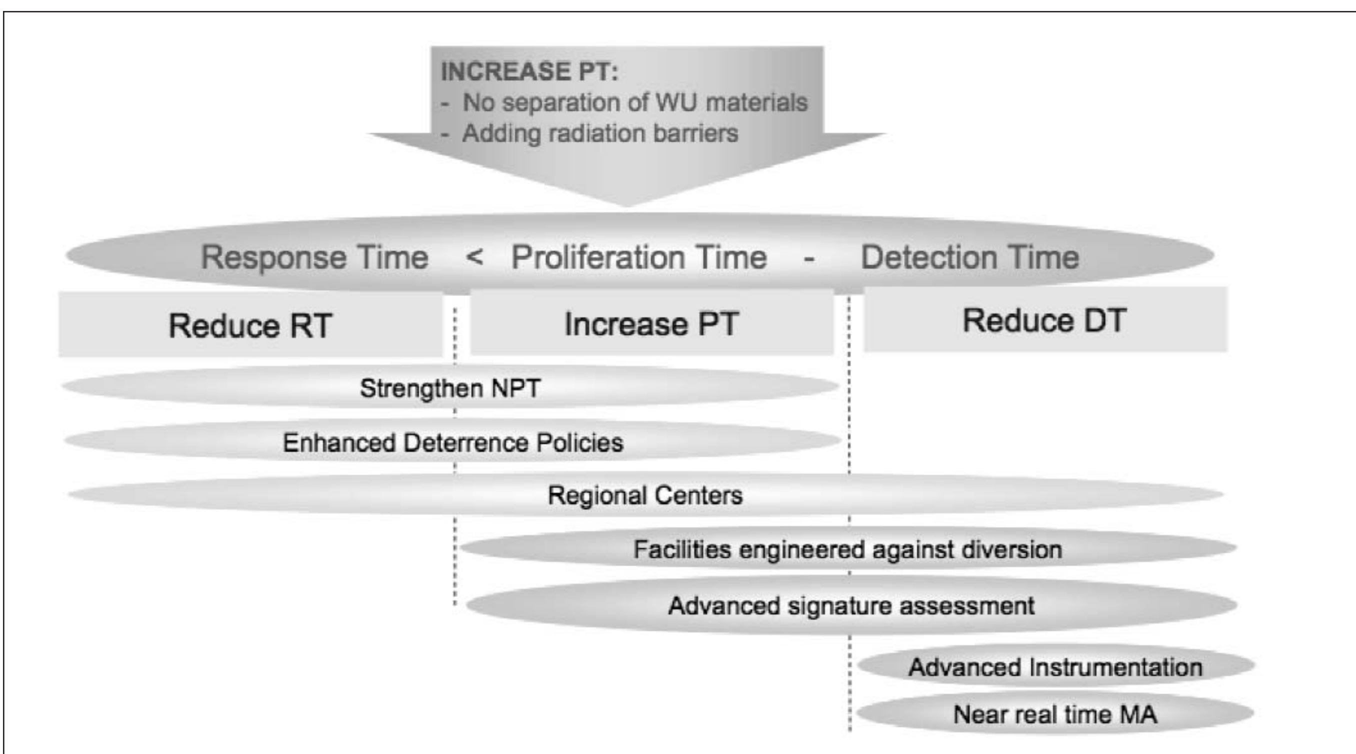
As discussed above, until now the debate on proliferation resistance as it applies to reprocessing has focused on attempting to argue an increase in the PT by not separating a pure stream of weapons-usable materials and by further contaminating the separated materials by radiation and thermal barriers. This approach has serious negative impacts on the fuel cycle in terms of cost and efficiency and is not likely to find many followers in the international community. Furthermore, concentrating on just one single term of the equation is not enough until the issues with the RT and PT also are resolved. This paper promotes an integrated approach to strengthen all aspects of proliferation resistance.

The efforts in reducing the RT are primarily political and diplomatic in nature. Readers interested in the policy issues on nonproliferation are referred to the recent report by the Carnegie Endowment, as an example.[5]

One policy related topic that has serious technological implications for the United States is the concept of "user-supplier states" or "regional centers," concepts being referred to and promoted by various speeches of U.S. President George W. Bush and IAEA Director Mohamed General El-Baradei. While these concepts are similar from their technological implications, the policy component of these concepts may be quite different.

The user-supplier state concept promotes restricting all enrichment and separations technologies to a limited number of supplier states, presumably existing weapons states.

Figure 2. Proliferation-resistance parameters and strategy



Whether or not this political structure would be acceptable to so-called user states remains to be seen. There may be some reluctance in signing on to this concept because of heavy dependence on another state for the vital source of energy. National pride and perceived concerns about interference with sovereignty might be hurdles that such a policy would have to overcome.

On the other hand, the concept of a regional center involves multiple nations in partnership in supplying the fuel cycle services in a highly safeguarded and inspected location. A regional partner in such an enterprise would be most sensitive in any diversion or misuse attempt by another partner. Cheating the system would be more difficult under the watchful eyes of a partner with equal access to all data. Likewise, a partner with full continuous access is more likely to detect misuse attempts fairly quickly. Thus, the regional center concept brings in a natural self-protection to complement the additional international safeguards and monitoring. The regional center approach does not only reduce the RT, but it increases the PT and reduces DT as well.

In addition to standard physical protection measures applied to the facilities, other means of increasing PT would be to a) limit the access points to separated materials through the process, b) engineer the system for making any modification to critical parts difficult without hindering maintenance activities, and c) develop more sophisticated signature analyses methods using multi-variable surveillance such that multiple detection systems must be defeated.

There are also possible advances to be made in the area of detection technology. Developing advanced safeguards instrumentation, and implementing near-real time monitoring capability into the plant design would reduce the DT. In addition, multivariable signature analyses techniques and engineered barriers introduced into the design would reduce the DT in addition to increasing the PT.

Proliferation-Resistance Assessments

To assess the proliferation resistance of a given fuel cycle, or a given system within that fuel cycle, a number of metrics have been developed. As described in a recent review article,[6] the methods developed for assessing the proliferation-resistance fall under two categories: a) proper decision analysis approach, and b) barrier approach. There is currently no universally accepted approach because all models rely on subjective judgment to a certain extent based on *expert* opinion and the attributes and their relative importance used in the models are not universally accepted.

As a result, there are two major efforts to develop a more universally acceptable assessment methodology for proliferation resistance. Under the GEN IV International Forum (GIF), a new methodology is being developed by the Proliferation Resistance and Physical Protection (PRPP) expert group. A parallel effort also is ongoing under the International Atomic Energy Agency (IAEA), referred to as INPRO.[7] The utility of these approaches remains to be seen as the methods are developed and results are published for international debate. By virtue of international participation in these efforts, the acceptance is expected to be wider in the nuclear community. However, it will be interesting to see how the methodologies will stand up to criticism by anti-nuclear groups on the metric-based approaches.

In general, metric-based approaches (other than the obvious fact that they all have some degree of subjectivity) are criticized for many reasons. Typically, the metric is averaged considering multiple attributes with different weighting factors, which are not universally accepted. Some of the attributes that make a certain set of technologies proliferation resistant can be fundamentally rejected. For instance, most available approaches use the cost of deployment for a given technology as an important attribute: i.e., if a technology is expensive it will be less likely to be used for proliferation. However, one can argue that if the given technology is the only one available to the proliferators, the cost is likely not a deterrent (referring back to the example of North Korea). It can also be argued that increasing the cost is not a deterrent and will unduly burden the use of nuclear energy since the proliferators will always have access to alternate technologies (uranium enrichment, PUREX) that can be deployed in a clandestine fashion.

The objective of this section is not to dwell on the shortcomings of metric-based approaches but to recognize that they have their limitations. The approach proposed by the author does not include the development of an alternative overall assessment methodology. Instead, it heavily relies on advanced safeguards to develop a "safeguards by design" strategy and to assess the potential failure of that strategy on a mechanistic basis, which provides quantifiable risk data to decision makers. The proposed approach is discussed further in the next section.

Proposed Approach

The objective of the proposed approach is to develop a new world standard for proliferation resistance in fuel cycle technologies. To achieve that objective, a multi-prong research and demonstration program is proposed. **The research tasks are aimed at developing and demonstrating engineered systems that increase the PT and reduce the DT.** The approach includes state of the art instrument development and testing and advanced modeling, as illustrated in Figure 3, and described in detail in this section.

One major motivation in advanced instrumentation development is to enhance the accuracy of the detection instruments. A typical commercial plant processes on the order of 1,000 metric tons of SNF/year, corresponding to ~10 metric tons/year of Pu. Considering that the IAEA significant quantity for Pu is 8 kg, better than 0.1 percent accuracy in detection is needed to account for each significant quantity in a year. This is a challenging task and way beyond the current state-of-the art for the monitoring and materials accounting technology.

Instrumentation Research. Any recycling and fuel fabrication plant designed for safeguards will include the standard measurements such as:

- Density measurements
- Scales and balances
- Flow meters
- Temperature measurements
- Pressure indicators
- Conductivity measurements
- Feed indicators
- Neutron monitors
- Plutonium alpha monitors
- Gamma spectroscopy
- Radiation monitors
- Chromatography
- Mass spectrometry

Ideally, in order to achieve near-real time monitoring, the measurements method would provide an online measuring device that determines precise amount of materials without intrusion or a device that samples and measures streams with a higher, automated repetition rate.

Using the sampling approach during continuous processing, for instance, will require higher repetition sampling systems. The number of data points needs to be optimized; otherwise computer databases could become swamped. Also, there is a need for an automated sampling system to avoid an excessive number of plant personnel.

As part of the research, advanced technologies must be evaluated for:

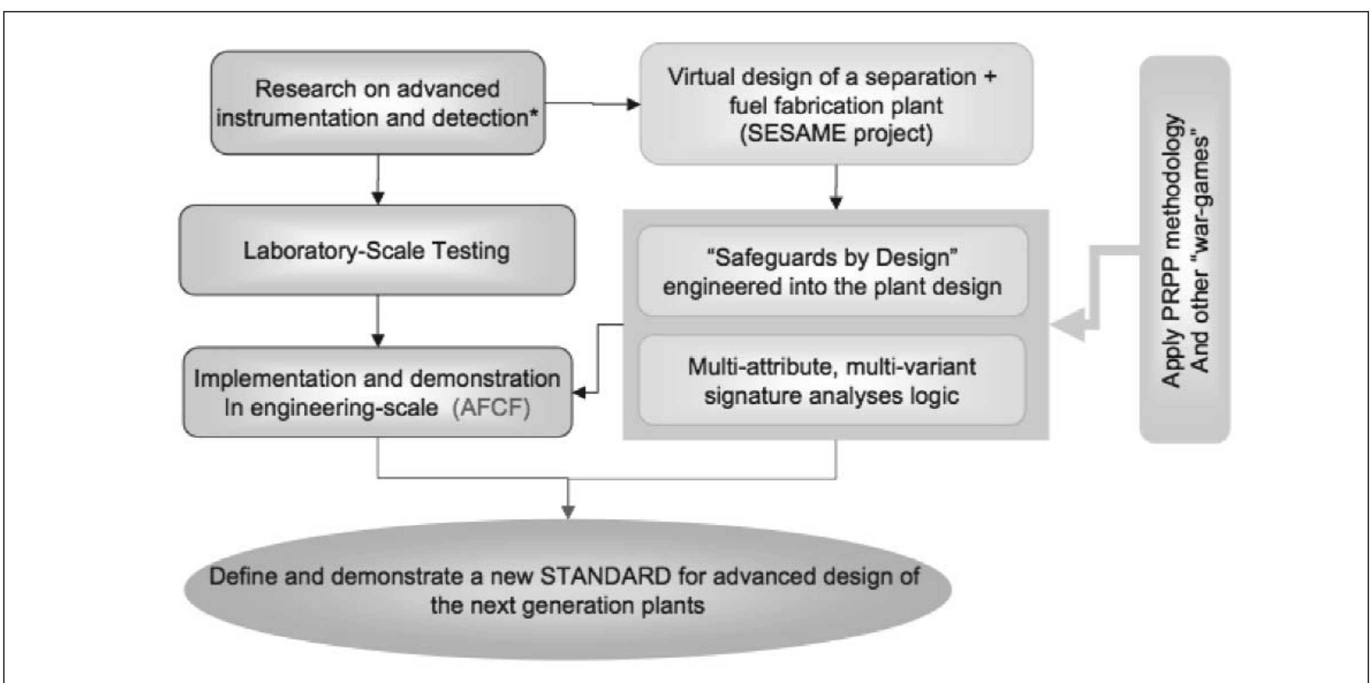
- Precision
- Sampling rate
- Measurement
- Reliability
- Durability
- Cost

For direct materials accounting, the advanced technologies would rely on active or passive measurement techniques. Passive measurements are possible when a signature radiation exists and it has sufficient penetration and intensity to provide timely data. For passive measurements, Pu + Np stream as currently being investigated as one of the options in the UREX+ process (being developed under the AFCI program) may have an advantage over a pure Pu stream used in PUREX. However, this advantage must be further quantified and demonstrated.

If radiation signatures can be stimulated, active measurements have added advantages. Using active measurement strategy, near-real-time *in situ* measurements are possible. The energy and intensity of interrogation radiation (IR) can be varied to provide the required response intensity and to activate different responses from different nuclides. Because IR can be adjusted and turned on or off, in theory, measurement in environments with large background radiation can be accommodated.

For active, nondestructive, quantitative fissionable material identification, the following techniques are being investigated:[8]

Figure 3. Proposed approach for advanced safeguards development



- Accelerator stimulated X-ray fluorescence (AXRF)
- Neutron integral cross section spectroscopy (NICS)
- Delayed neutrons
- Delayed neutron lifetime measurements (DNL)
- Delayed gamma rays

Accelerator stimulated X-ray fluorescence (AXRF) differs from conventional XRF by the energy of excitation and detected X-rays. In AXRF one uses stimulation radiation of very high energy (MeV), which allows copious production of K X-rays, which are detected by high-resolution gamma spectrometry. For high Z elements like Pu K X-rays are ~ 100 keV in energy and thus are not readily affected by the material matrix. Very high sensitivities for Pu, U, and other heavy elements have been demonstrated at ~ few ppm, in demanding applications such as waste container assay. Because XRF is an atomic phenomenon, only elemental information is available.[8]

Neutron Integral Cross-section Spectroscopy (NICS) takes advantage of the unique energy dependence of the fission cross section in the resonance region for the various fissionable nuclides. An accelerator driven slowing down spectrometer (SDS) produces neutron pulses whose energy is related to time.

The SDS produces neutrons with energies in the resonance neutron range ~ 1eV to 10keV. Samples, which may be a pipe carrying the material stream, will respond as the neutrons pass through with energies that match the sample's resonant levels—resonant (n,f) and/or (n,gamma) reactions. Detectors around the sample respond releasing fast neutrons or gammas. This signal is characteristic of a particular nuclide, i.e., MA and Pu have unique cross sections in the resonance region.[8]

Delay neutron lifetime (DNL) measurements determine the amount and time dependence of photofission-induced delayed neutron emission. A pulsed bremsstrahlung photon is used to induce photo-fission reactions in fissionable nuclides. The resulting delayed neutron emission, recorded between irradiating pulses, indicates quantity and decay of delayed neutron emission, and detects which fissionable isotope is present.[8]

Delayed Gammas rely on measuring natural and induced gamma emissions.

The natural gamma-emissions of Pu packed in the center of a sand-filled 55-gallon drum waste package and the delayed gamma emissions after sixty-second interrogation with a 20 MeV linac have been investigated.[8]

RF Electron Linacs will produce an intense, highly forward directed photon beam, using a high Z converter. This method has flexible output characteristics, and pulses variable in amplitude, duration and frequency. This is a robust technology, available off the shelf. It is relatively inexpensive and small. This method takes advantage of the fact that a large number of physical processes are induced by photons.[8]

Advanced control system. In addition to developing advanced instrumentation, the proposed approach also involves the development of an integrated control system that uses all available instruments through an intelligent data analyzer. In this approach all the plant data (safety and operational control data in addition to safeguards data) are analyzed via an intelligent analyzer using cross-correlation among various measurements. Because data coming from non-safeguards instrumentation are used, this approach requires the development and implementation of a tamper-proof data authentication method.

The advanced control system involves developing multi-variable correlations among many measurements, including the standard non-nuclear measurements (pressure, temperature, tank level) and nuclear measurements. Based on multi-variable and multi-attribute signature analyses, a safeguards envelope will be developed. When the correlated parameters fall outside the safeguards envelope, the data analyzer will trigger an alarm, which will prompt further assessment of the plant conditions. The development of the advanced control system relies heavily on plant modeling and simulation and it requires an engineering-scale facility for demonstration.

Advanced Modeling and Simulation. In the area of advanced modeling and simulation, a program called SESAME (Simulation Enabled Safeguards Assessment Methodology) has been initiated. SESAME provides a virtual design of a separations and fuel fabrication plant using "Safeguards by Design" methodology. Within the virtual test bed provided by SESAME, the following are included:

- Walk-through models and overall system simulation model
- Detailed mechanistic models for plant components (including all instrumentation)
- Control and monitoring system logic

The virtual test bed will be used to:

- Perform engineering design optimization for the plant (with emphasis on safeguards)
- Develop proliferation signatures based on multi-variant and multi-attribute data analyses method to define the "safeguards envelope"
- Directly compare various technology options (with emphasis on their safeguards characteristics)
- Address the plant-scaling issues primarily for instrumentation needs and locations
- Test the proliferation-resistance assessment methodologies being developed in other programs (GEN IV, INPRO, others)
- Perform "war games" on the simulated design to identify areas of vulnerability.

However, it is important to emphasize that simulation and modeling by itself is not convincing unless a parallel experimental program supports it. The overall approach also relies on the availability of research-scale and engineering-scale test facilities.

Test and Demonstration Facilities. The proposed approach assumes that research scale (grams to kilograms level) facilities are available for testing the instruments and developing the uncertainty and error bands of such instruments to be used in the safeguards envelope development. The research-scale facilities do not need to mimic the integrated processes for the separations and fuel fabrication facilities. Rather, these facilities need to address separate effects testing some of which can be done with surrogate materials. But the nuclear materials accounting instruments need to be tested with radioactive materials at sufficient quantities and in relevant environments to properly quantify the instrument characteristics. Therefore, hot-cell environments will be needed for these tests.

The major facility need is an engineering-scale research facility where a scaled version of the total process is duplicated. The Advanced Fuel Cycle Facility (AFCF) being planned under the AFCI program will provide an excellent engineering-scale test and demonstration capability for the advanced safeguards methodology being proposed in this paper. AFCF is being planned for a scale of 10-100 tons/year separations of the SNF.[9] This corresponds to 100–1,000 kg of TRU to be converted to fuel (two to twenty assemblies). This facility will be used:

- As a test bed for advanced instrumentation in a prototypic environment
- To provide engineering-scale benchmark data for SESAME
- To provide the final demonstration of the safeguards system with advanced instrumentation and advanced control logic

In turn, SESAME will provide design input to the facility to optimize and scale-up the safeguards performance.

Summary and Recommendations

The proposed approach focuses on strengthening what is perceived to be the most vulnerable part of the fuel cycle: i.e., the separations and fuel fabrication. During this phase of the fuel cycle, fissile materials are separated from SNF and until they are incorporated into fresh fuel, they are assumed to be vulnerable for diversion. One key proposal is to engineer the facility in such a way that fissile materials are not stored outside the hot cells contained within the combined separations plus fuel fabrication facility (recycling facility). Even within the facility the storage time is minimized by engineering a continuous system with the appropriate interface between the separations hot-cells and fuel fabrication hot-cells (see Figure 4). The proposed strategy relies on advanced safeguards covering three key elements as shown in Figure 5. The key concepts that are being developed are:

- Advanced instrumentation with higher accuracy and reliability for materials tracking
- Safeguards envelope methodology based on multi-attribute and multi-variable correlations among various instruments (including the non-nuclear standard process data
- Safeguards by design approach by incorporating the safeguards concept into the engineered system design

Figure 4. Recycling plant schematic

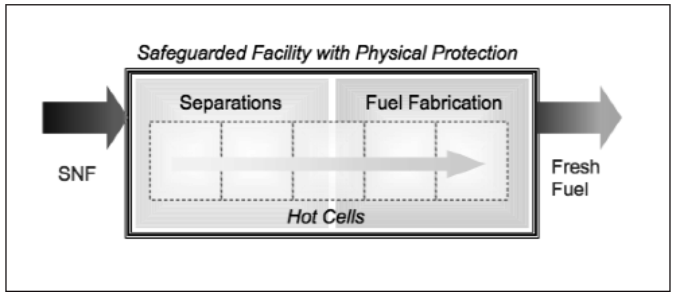
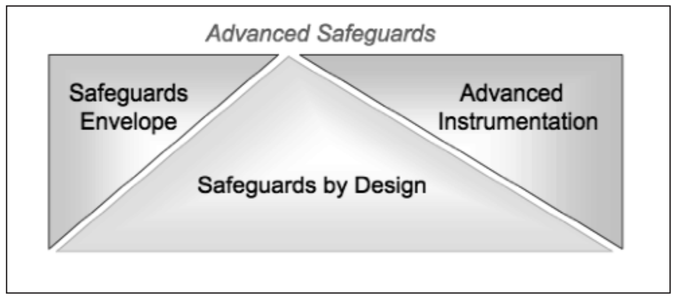


Figure 5. Key elements of the advanced safeguards



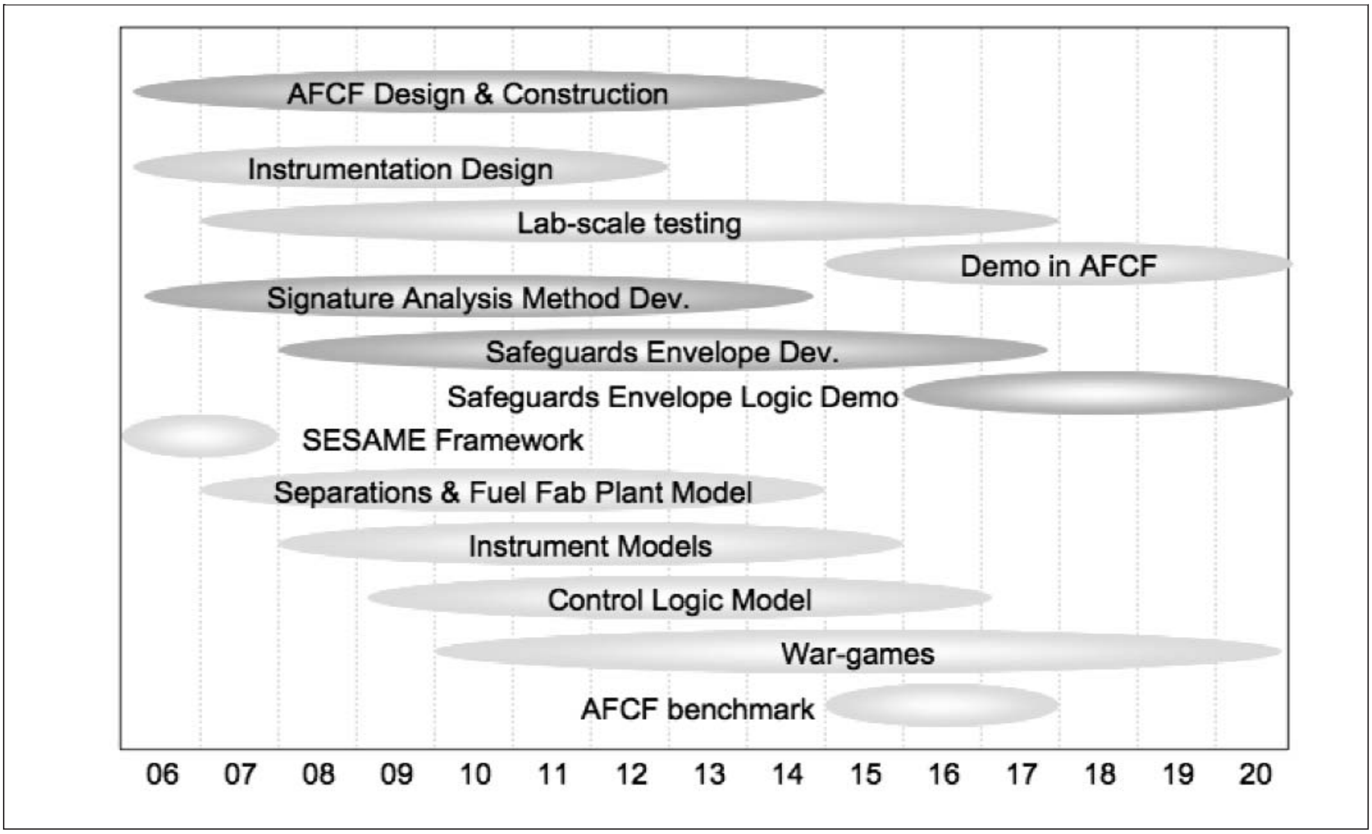
The implementation relies on both experimental and theoretical development along with a large-scale experimental demonstration. Laboratory-scale testing and advanced modeling and simulation (SESAME program) are used for the development. The AFCF proposed under the AFCI program will be the key in actual verification and demonstration of the concept. Using this approach, a new safeguards standard can be developed and demonstrated for industrial applications within fifteen years. Figure 6 shows a notional program schedule.

Notes

1. Used in a genuinely Kafkaesque sense.
2. IAEA. 2002. STR-332, *Proliferation Resistance Fundamentals for Future Nuclear Energy Systems,* Report on Como meeting held in Como, Italy on October 28–31, 2002.
3. 2000. OECD Report on Nuclear Energy in a Sustainable Development Perspective.
4. Private communication with R. Wigeland, Argonne National Laboratory (April 2005).
5. Perkovich, G. 2005. *Universal Compliance: A Strategy for Nuclear Security,* Carnegie Endowment for International Peace.
6. Cojazzi, G. G. M., and Renda, G. 2005. Proliferation Resistance Characteristics for Civilian Nuclear Fuel Cycle Assessments, *Proceedings of the ESARDA 27th Annual Meeting, Symposium on Safeguards and Nuclear Materials Management.*

7. Haas, E. 2005. INPRO Proliferation Resistance Assessment Methodology, *Proceedings of the ESARDA 27th Annual Meeting, Symposium on Safeguards and Nuclear Materials Management.*
8. Frank Harmon, Idaho State University, Private communications (August 2005).
9. 2005. *AFCF Mission Need and Functions and Requirements Report.*

Figure 6. Notional schedule for development and deployment of advanced safeguards program



DOE Cites University of Chicago for Nuclear Safety Violations

The U.S. Department of Energy (DOE) in March issued a Preliminary Notice of Violation (PNOV) to the University of Chicago, the management and operating contractor for DOE's Argonne National Laboratory (ANL), for nuclear safety violations identified through several safety reviews and inspections conducted by DOE.

A series of reviews and inspections, the most recent of which occurred in 2005, identified breakdowns in the contractor's quality improvement, radiation protection, work process, and independent and management assessment programs. Before 2005, senior contractor management at ANL failed to adequately comply with DOE's nuclear safety regulations that govern these programs. DOE's investigation of the safety review findings found that these issues have existed for a number of years, and the university's efforts to correct these problems were largely ineffective.

The identified deficiencies have not caused significant radiation exposures or other nuclear safety incidents.

Last year, the university appointed a new management team at ANL and has given the new lab director the resources and support necessary to upgrade the nuclear safety program. The new director has already begun to take corrective actions and initiated others to address other problems, including the implementation of a new safety program infrastructure.

The PNOV includes a proposed civil penalty of $550,000 for the identified violations. This penalty, however, is waived by statute for the university. DOE indicated in its letter to the director of ANL that while the enforcement action would normally have been much more severe given the number and duration of the violations, enforcement discretion was being exercised in recognition of the significant corrective actions already taken by the director and the new management team.

Additional details on this and other enforcement actions are available at: http://www.eh.doe.gov/enforce/.

D'Agostino to Lead NNSA's Defense Programs

Thomas P. D'Agostino has been sworn in as deputy administrator for defense programs in the U.S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA). D'Agostino will lead NNSA's weapons programs, which maintain the reliability of our nation's nuclear weapons stockpile. He previously served in NNSA's defense programs office as the assistant deputy administrator for program integration. He has more than twenty-nine years of military service in the United States Navy and is currently a captain in the U.S. Naval Reserves.

D'Agostino will lead NNSA's Defense Programs, including the Stockpile Stewardship Program, as well as manufacturing, maintaining, refurbishing, and dismantling the U.S. nuclear weapons stockpile. Defense Programs oversees and directs the research, development and engineering needed to maintain the safety and reliability of the stockpile. At the direction of the president, by December 2010, the U.S. nuclear weapons stockpile will be reduced to the smallest level since the Eisenhower administration.

Technical Report Confirms Reliability of Yucca Mountain Technical Work

The U.S. Department of Energy's Office of Civilian Radioactive Waste Management (OCRWM) in February released a report confirming the technical soundness of infiltration modeling work performed by the U.S. Geological Survey (USGS) employees.

In March 2005, DOE disclosed e-mails between USGS employees that appeared to suggest that these employees had failed to follow certain quality assurance procedures during their work. This report was developed to assess how issues raised by the e-mails may have impacted some of the scientific conclusions contributing to the Yucca Mountain Site Recommendation of 2002 and the Key Technical Agreements between DOE and NRC. The report found no impact on those conclusions.

The 144-page final report, *Evaluation of Technical Impact on the Yucca Mountain Project Technical Basis Resulting From Issues Raised by E-mails of Former Project Participants,* examined work products developed by the USGS employees—mainly the infiltration contributing to the evaluation of the long-term performance modeling of the underground repository. The report concludes that the net infiltration ranges, as determined by the USGS employees, were consistent with ground water recharge rates determined by other scientists studying other arid and semi-arid regions in the United States and provides reasonable inputs to models used for the 2002 site recommendation.

Although the report's findings indicate that the infiltration rate estimates are corroborated and consistent with other independently derived work, OCRWM will replace or supplement the infiltration modeling work, as needed, and will review or verify the supporting documentation. The technical report is available at http://www.ocrwm.doe.gov/.

OCRWM Selects Sandia as Lead Laboratory

The U.S. Department of Energy's Office of Civilian Radioactive Waste Management (OCRWM) announced it will designate Sandia National Laboratories as its lead laboratory to integrate repository science work for the Yucca Mountain Project. That work, which is currently overseen by OCRWM's contractor Bechtel SAIC, will be led by Sandia once the transition of responsibilities is completed.

Bechtel will continue to be responsible for above-ground design efforts, while Sandia will concentrate on integrating all post-closure science. The move more clearly aligns responsibilities within the competencies of the project's participants and will more effectively leverage the capabilities of Sandia's experience with repository science issues.

As OCRWM's lead laboratory, Sandia will provide management and integration services for all Yucca Mountain scientific programs necessary. These services will support OCRWM's license application and its defense in the Nuclear Regulatory Commission's review process, including the allocation of funding and the assignment of technical tasks to selected supporting organizations such as other national laboratories, subcontractors, federal agencies, universities, and expert panels.

Department of Energy Announces New Nuclear Initiative

The U.S. Department of Energy announced a $250 million Fiscal Year (FY) 2007 request to launch the Global Nuclear Energy Partnership (GNEP). This new initiative is a strategy to enable the expansion of nuclear energy worldwide by demonstrating and deploying new technologies to recycle nuclear fuel, minimize waste, and improve the United States' ability to keep nuclear technologies and materials out of the hands of terrorists.

Through GNEP, the United States will work with other nations possessing advanced nuclear technologies to develop new proliferation-resistant recycling technologies in order to produce more energy, reduce waste and minimize proliferation concerns. Additionally, these partner nations will develop a fuel services program to provide nuclear fuel to developing in exchange for their commitment to forgo enrichment and reprocessing activities, also alleviating proliferation concerns.

U.S. Department of Energy Awards Paducah Remediation Contract

Paducah Remediation Services LLC (PRS) has been awarded a $191.6 million small business contract to perform environmental remediation and waste management activities at the U.S. Department of Energy's (DOE) Paducah Gaseous Diffusion Plant in Paducah, Kentucky. The contract will run through September 30, 2009, and provides incentives to the contractor for managing costs effectively while completing the cleanup work on schedule.

PRS will be responsible for groundwater and soil remedial actions, removing legacy waste, decontamination and decommissioning facilities, operating the site waste storage facilities, surveillance and maintenance activities, as well as other activities. Following a transition period, PRS will take over from Bechtel Jacobs Company LLC, whose contract expires April 23, 2006.

DOE's Portsmouth/Paducah Project Office manages three major contractors at the Paducah site under the Department's Office of Environmental Management. The office is responsible for managing the remediation contract, infrastructure services contractor, Swift & Staley; and the ongoing work of Uranium Disposition Services LLC, which is responsible for the Depleted Uranium Hexafluoride (DUF6) Conversion Project. Opportunities will likely be available for various subcontracts awarded by the major contractors for specific tasks.

Global Nuclear Survey: Public Support for New Power Plants Remains Tentative

An eighteen-country opinion survey sponsored by the International Atomic Energy Agency (IAEA) found that "while majorities of citizens generally support the continued use of existing nuclear reactors, most people do not favor the building of new nuclear plants."

The findings of the survey, conducted by Globescan Inc., show that "six in ten citizens (62 percent) overall believe that existing nuclear reactors should continue to be used, yet six in ten (59 percent) do not favor new nuclear plants being built."

At a time when the nuclear power option is being vigorously pursued in the fast-developing countries of Asia and being reconsidered in some European nations and the United States, the findings raise questions as to whether the nuclear industry and politicians have sufficiently raised public confidence in the safety and efficiency of the nuclear power option.

Regionally, support for nuclear power is highest in South Korea, the United States and India, where clear pluralities support the building of new nuclear plants. In Morocco, Jordan, Saudi Arabia and Cameroon, pluralities prefer that all existing plants be shut down.

The IAEA-sponsored survey was conducted between May and August 2005 in eighteen countries representing all regions. Approximately 18,000 people were polled by telephone and in-person interviews. The opinion poll fielded six distinct questions, ranging from awareness of the IAEA and the effectiveness of IAEA inspections to support for peaceful nuclear applications and views about the security of nuclear materials and facilities and the threat of nuclear terrorism.

Among the findings from the survey:

- Pluralities of citizens in all but three of the eighteen countries surveyed believe that IAEA inspections are not effective in monitoring countries´ nuclear programs. An average of 46 percent of people across the eighteen countries surveyed say that IAEA inspections are not effective, while three in ten people (29 percent say that they are.
- Majorities in fourteen of the eighteen countries—and pluralities in the remaining four countries—believes that the risk of terrorist acts involving radioactive materials and nuclear facilities is high because of insufficient protection. A majority of 54 percent across all countries surveyed believe the risk of nuclear terrorism to be high.
- People appreciate the value of nuclear technology. When asked to consider the peaceful uses of nuclear technology, people in all but three countries are most supportive, by far, of medical applications, followed by electricity generation. Across the eighteen countries surveyed, respondents are most likely to choose the use of nuclear technology to treat human diseases as their preferred application (39 percent). This is followed by electricity generation (26 percent).

Download the full report at http://www.iaea.org/Publications/Reports/gponi_report2005.pdf.

Calendar

May 29–June 2, 2006
ESARDA Annual Meeting
Luxembourg
Sponsor:
European Safeguards Research and Development Association
Web site: http://esarda2.jrc.it/events/esarda_meetings/luxembourg-2006/index.html

June 4–8, 2006
2006 ANS Annual Meeting
A Brilliant Future: Nexus of Public Support in Nuclear Technology
Reno Hilton
Reno, Nevada, U.S.A.
Sponsor:
American Nuclear Society
Web site: www.ans.org/meetings

July 16–20, 2006
47th INMM Annual Meeting
Renaissance Nashville Hotel/Convention Center
Nashville, Tennessee, U.S.A.
Sponsor:
Institute of Nuclear Materials Management
Contact:
INMM
847/480-9573
Fax: 847/480-9282
E-mail: inmm@inmm.org
Web site: www.inmm.org

October 21–26, 2007
PATRAM 07
Marriott Doral
Miami, Florida USA
Host:
Institute of Nuclear Materials Management
Web site: www.patram.org

October 29 – November 3, 2006
International Workshop on Best Practices for Material Hold-Up Monitoring
Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.
Sponsors:
Institute of Nuclear Materials Management and the INMM Central Chapter
Contact:
Donna Sneed at sneedds@ornl.gov

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