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LETTERS

Strategic Instability is a Bad Buy

The great historical fact of the latter twentieth century is that American military power and resolve thwarted Soviet imperialism, containing the collectivist cancer until, inevitably, it rotted from within. Now oppressed peoples claim their liberty, Germany unites into a pro-West democracy, and Russia itself is being reformed. World War III turned out to be the Cold War, and it's just about over. We've won.

That's why your editorial (April 1990) sounds hollow to me. You're arguing as though the doves were right all along and perhaps soon the dovish viewpoint will prevail with the elimination of certain weapons systems. But dovish analyses of "strategic instability," couched in the symmetrical terms ("Superpower A vs. Superpower B") that ignored the nature of the USSR, offered little relevance to the real world. Recent experience has been unkind to such views. America developed military systems that doves call "worse than useless" and confronted the Soviets with resolve that doves call "paranoia," and the result is turning out to be a freer and safer world.

Soon we may indeed be able to lay most of our weapons aside and stop spending much money developing new ones. Your specific proposals may well have merit as initial steps along the way. You detract from their credibility, however, by linking them to failed arguments of the past.

Your closing paragraph raises a separate, extremely important question: What will become of our peace dividend, as military expenditures recede? I can't agree with you that politicians should get to spend it, certainly not on more expensive socialized education; that's throwing good money after bad. The decline in educational quality in this country over the past quarter century coincides with increased spending and greater intrusion by the federal and state governments into local schools. A better way to improve education would be through privatization. A better investment of tax dollars in our children's future would be to pay off the national debt.

Allan Walstad
Physics Department
University of Pittsburgh
Johnstown, PA 15904

Redirect SDI Instead of Cutting It

Your editorial (April 1990) proposed saving $3 billion per year by cutting back SDI to pure research. Another, perhaps more palatable, option might be a "plowshares" program, in which pursuit of SDI technology would be rechanneled into civilian projects.

One such project might be to use the large gravitational potential difference between the moon and earth surfaces to generate cheap power in space and launch earth vehicles into low earth orbit (LEO). Stretched-out packets of low-density material would first be launched electromagnetically from the moon or an asteroid toward the earth. Using SDI-type sensor, guidance, steering and global-positioning technology, the gravitationally-accelerated material could be made to home in on and impact "pusher plates," e.g. on LEO satellites or initially-slow vehicles lifted by air-breathing ramjets to points just above the atmosphere. By using shock absorbers and multiple impacts (as in Orion project nuclear-bomb propulsion) thermal-mechanical power generation and non-damaging acceleration of even relatively fragile vehicles into LEO should then be possible.

Homing could be carried out either by small detachable reusable smart-rock or brilliant-pebble steering rockets (themselves designed to just barely avoid impact), or by external laser pulses that would steer the impact material by thrust-producing surface ablation. The power generated in LEO could be beamed by microwave to antennas on earth or in space, perhaps via geostationary relays. In a kind of contact-less siphon process, a small fraction of the power could also be beamed to a large antenna on the moon to provide power for the electromagnetic mass-drivers or other devices needed to launch the lunar impact material in the first place.

Louis A.P. Balazs
Department of Physics
Purdue University
West Lafayette, IN 47907

The Delight of Physics

At a time when some physics departments in England are facing closure or merger due to financial constraints, it is heartening to know that our Malaysian child prodigy, Ti Ming, has decided to read physics at Caltech. Obviously in making that crucial decision money making was not foremost in Ti Ming's mind. It is love for the subject that precludes mundane considerations. It is a classic case of knowledge for knowledge sake. In our increasingly materialistic world, people like Ti Ming give us a refreshing outlook regarding choice of career prospects.

How many of us have the courage to do what we like to do instead of what others expect us to do? Self-determination is a fast-diminishing privilege. Indeed to do things one enjoys is the source of happiness.

From a mercenary perspective, one has to admit that physicists as a whole do not earn as much as, say, physicians. On the other hand they are not that impoverished either. Students still enroll to read physics at our Malaysian universities. Touch wood, physics departments in Malaysia are very much alive and kicking. Physics graduates on the whole easily find employment soon after graduation. Education, research, public service and industry are the main employers of physicists. Owing to the recent upturn in the electronic industry, many physicists are absorbed into that sector with a good starting salary too.

A subject that can attract and challenge the geniuses like Galileo, Newton and Einstein must have tremendous intellectual appeal. It must also have intrinsic beauty. Indeed the beauty of physics is that it deals with the entire universe. To confront this universe, a good physicist must have the childlike curiosity and inquiring mind to unlock its secrets.

The scope of physics ranges from the microscopic to the galactic. Indeed no other discipline offers one such wide latitude to explore. Hence what physics has failed to guarantee in monetary return is more than made up with lifelong mental stimulation and delight.

To those who relish a philosophical flavor, physics is an obvious candidate. Many of us are attracted to the discipline precisely because of these profound underpinnings. As long as humans have this sense of adventurous search for truth in the universe, physics should have a place in our society.

Koh Aik Khoon
Department of Physics
Universiti Kebangsaan Malaysia
Bangi 43600

ARTICLES

Israeli Ballistic Missile Capabilities

Steve Fetter

In a class I teach on Science and National Security, I came across a good example of how to apply a knowledge of basic physics to an important public policy problem — the proliferation of ballistic missile technology. On 19 September 1988, and again on 3 April 1990, Israel launched a satellite. The example given below shows how one can calculate, from knowledge of the satellite's orbital parameters, the payload that the same rocket could deliver at a given range if it was used as a ballistic missile.

The physics of ballistic trajectories

The first satellite was placed in an elliptical orbit with a perigee of 250 km, an apogee of 1150 km, and an inclination of 148 degrees; the perigee and apogee of the second satellite were 200 km and 1450 km. The latitude of the launch site was 32 degrees, and the satellite was launched due west over the Mediterranean Sea (1).

The velocity needed to put the satellite into orbit is given (2) by

$$v_c = \left[GM_e\left[\frac{2}{R_e} - \frac{1}{a}\right]\right]^{\frac{1}{2}} \tag{1}$$

where G is the gravitational constant ($6.67\text{X}10^{-20}$ km^{3}s^{-2}kg^{-1}), M_e is the mass of the earth ($5.98\text{X}10^{24}$ kg), R_e is the radius of the earth (6370 km). The semi-major axis of the satellite orbit, a, was 7070 km for the first satellite and 7210 km for the second satellite, which gives v_c=8.30 km/s and 8.36 km/s, respectively.

To get the burnout velocity of the missile, we must add to Eq. (1) the component of the earth's rotational velocity in the direction of the launch (dv_r) and an amount to compensate for the effects of air resistance and gravity on the rocket during launch (dv_a):

$$v_b = v_c + \delta v_r + \delta v_a \tag{2}$$

$$\delta v_r = \frac{2\pi R_e}{86164}\cos(\Phi)\;|\cos(\Omega)| = 0.33\ \text{km/s} \tag{3}$$

where F is the latitude, W is the orbital inclination, and 86164 is the number of seconds per sidereal day.

Israel's missile probably has three stages; the plume of the first stage, as recorded on film, clearly indicates that it is solid-fueled. Assuming that each stage provides the same dv or increase in missile velocity, the total mass of the rocket would be given (3) by

$$M_r = m_s\left[1 - f\left[1 - e^{-v_b/3v_e}\right]\right]^{-3} \tag{4}$$

where m_s is the mass of the satellite payload, f is the ratio of the total mass of each stage to the propellant mass, and v_e is the exhaust velocity of each stage. (This is the optimal solution if all stages have equal f and v_e, as I assume here.)

If the same rocket were used as a ballistic missile, the payload mass for a given burn-out velocity v would be given by

$$m_b = M_r\left[1 - f\left[1 - e^{-v/3v_e}\right]\right]^3 \tag{5}$$

The ratio of the ballistic-missile payload mass to the satellite payload mass is therefore given by

$$\alpha = \left[\frac{1 - f[1 - e^{-v/3v_e}]}{1 - f[1 - e^{-v_b/3v_e}]}\right]^3 \tag{6}$$

The burnout velocity v necessary to give a ballistic missile a range of r is given (4) by

$$v = \left[\frac{GM_eR_e(1 - \cos\phi)}{(R_e + h)^2\sin^2\theta - R_e(R_e + h)\sin(\theta-\phi)\sin\theta}\right]^{\frac{1}{2}} + \delta v_a \tag{7}$$

where h is the burnout altitude (assumed to be 250 km, the perigee of the satellite orbit) and f=r/R_e.. The maximum range (i.e., minimum-energy trajectory) is given by Q=(f+p)/4.

All that remains is to substitute values for f, v_e, dv_a into Eq. (6). For solid-fuel rockets, typical values are f = 1.05, v_e = 2.5 km/s, and dv_a = 1 km/s (5). To estimate the effect of uncertainties in these values I used the following equation

$$\sigma_\alpha^2 = \sigma_f^2\left[\frac{d\alpha}{df}\right]^2 + \sigma_{v_e}^2\left[\frac{d\alpha}{dv_e}\right]^2 + \sigma_{\delta v_a}^2\left[\frac{d\alpha}{d\delta v_a}\right]^2 \tag{8}$$

where s_a, s_f, sv_e, and sdv_a are the uncertainties in a, f, v_e, and dv_a.. I assumed that s_f = 0.02, sv_e = 0.2 km/s, and sdv_a = 0.2 km/s.

The ratio of the ICBM payload mass to the satellite payload mass predicted by Eqs. (6)-(8) is shown in Fig. 1 as a function of the maximum range of the ICBM.

The author is at the School of Public Affairs, University of Maryland, College Park, MD 20742.

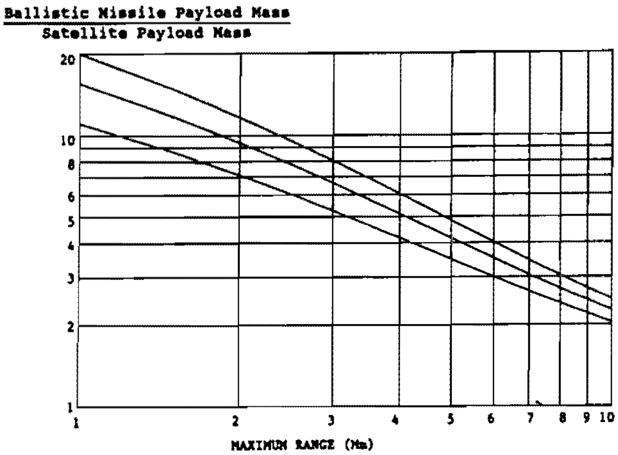

Figure 1. The ratio of the payload mass if the rocket is used as a ballistic missile to the satellite payload mass as a function of the maximum range of the ballistic missile.

Israel's ballistic missile capabilities

The mass given by the Israelis was 156 kg for the first satellite and 170 kg for the second satellite; including a guidance and control package would bring the total payload mass to at least 200 kg. If this

The missile could deliver an 800 kg payload at a range of 4000 km.

is correct (there is no way to independently verify the mass of a satellite), then Israel could loft a 3±1 tonne payload 1000 kilometers.

How much might an Israeli nuclear warhead weigh? The first US bombs, Little Boy and Fat Man, weighed 4000 and 4900 kg. There are reports that Swedish scientists had by 1958 designed a 20-kt fission bomb weighing only 600 kg, in which they had high confidence without nuclear testing (6). Israeli scientists could do at least as well, and may have designed nuclear weapons weighing as little as 100 to 200 kg. A first-generation inertial guidance system might weigh 100 kg. An Israeli nuclear ballistic missile payload, including the warhead, reentry vehicle, guidance system, and arming and fusing mechanisms, would probably weigh no less than 400 kg and no more than 800 kg (a=2 to 4).

Assuming a satellite payload of 200 kg, the missile could therefore deliver an 800 kg payload at a range of at least 4000 km, which would put the entire Arab world (plus most of Europe, including European USSR) within its range. If payloads as light as 400 kg are available, the missile would have intercontinental range.

Of course, even if Israel possesses a suitable nuclear warhead, a reentry vehicle would still have to be developed. But if an RV *is* developed and tested, Israel will have a truly formidable ballistic missile capability.

References and notes

1. J. Diehl, "Israel launches satellite into surveillance orbit," *Washington Post*, 4 April 1990, p. A35; S. E. Gray, Lawrence Livermore National Laboratory, personal communication.
2. S. Glasstone, *Sourcebook on the Space Sciences* (van Nostrand, Princeton, 1959).
3. Although I have not been able to find a reference for this equation, it is easily derived. Note that as the number of stages becomes large, $(m_f/M_0) \approx \exp(-fv_f/v_e)$.
4. The range equation is developed in several textbooks. See, for example, R. R. Bate, D. D. Mueller, and J. E. White, *Fundamentals of Astrodynamics* (Dover, New York, 1971).
5. Glasstone, *op cit.*; also E.H. Sharkey, "The Rocket Performance Computer," RM-2300-RC (The RAND Corporation, Santa Monica, CA, 1959).
6. C. Larsson, "Build a Bomb!" *Ny Teknik*, 25 April 1985, cited in L. S. Spector, *The Undeclared Bomb* (Ballinger, Cambridge, MA, 1988).

Symposium: International Safeguards on HEU and Plutonium

On 12 March 1990, at the Anaheim meeting of the American Physical Society, the Forum sponsored a session on international safeguards on highly enriched uranium (HEU) and plutonium. We reprint here the four papers from that session. The question of a ban on the production of fissile materials (a "fissile cut-off") has recently become envigorated because of the possible large cuts of nuclear weapons under future START treaties, and because the production reactors in both countries are having technical difficulties. David Swindle, former technical advisor to the six-nation "Hexapartite Safeguards Project" (HSP) and presently at Martin Marietta Energy Systems, delivered a paper on verifying the absence of HEU in gas centrifuges, as presently carried out under the HSP arrangement. Jim Lovett, former International Atomic Energy Agency (IAEA) official, examined the safeguardability of plutonium reprocessing plants under the present IAEA regime, as well as under newer approaches. John Taylor, Sandia National Laboratory, and science advisor to the US Ambassador to the START negotiations, examined the historical aspects of the various fissile cut-off proposals. Lastly, Charles Hebel, of Stanford University and the Xerox Corporation, examined the verifiability of the recent fissile cut-off proposal of the Soviets and of the US House of Representatives. The session was chaired by Dave Hafemeister.

Verifying the Absence of Highly Enriched Uranium in Gas Centrifuge Enrichment Plants

D.W. Swindle

Introduction

During 1981-83, representatives from the US, Britain, Federal Republic of Germany, Australia, Netherlands, and Japan, together with the inspectorates of the International Atomic Energy Agency (IAEA) and EURATOM, developed and agreed to a technically sound and effective approach for verifying the absence of highly enriched uranium (HEU) in gas centrifuge enrichment plants. This effort, known as the Hexapartite Safeguards Project (HSP), led to the first international concensus on techniques and requirements for effective verification of the absence of weapons-grade nuclear materials production. Since that agreement, research and development has continued on the radiation detection technique that confirms the HSP goals are achievable. Issues such as design and operating conditions unique to each gas centrifuge plant, concern about the potential for sensitive technology disclosures, and on-site support requirements have hindered full implementation and operator support of agreements reached during the HSP negotiations. In future arms control treaties that may limit or monitor fissile material production, negotiators must recognize and account for these realities and practicalities in verifying the absence of HEU production.

Background

To understand the difficulties and practicalities of verifying that a gas centrifuge plant is not producing HEU, we first note the availability of uranium enrichment technologies and the attractiveness of the gas centrifuge technology in enriched uranium production. Currently, thirteen countries have openly acknowledged that they have operating uranium enrichment production or pilot plants or are conducting uranium isotope separation research: Argentina, Brazil, China, Federal Republic of Germany, France, India, Japan, Netherlands, Pakistan, South Africa, USSR, Britain, and the US. Of these, nine operate gas centrifuge facilities, five operate gaseous diffusion facilities, five are nuclear weapon states, five have not yet signed the nuclear nonproliferation treaty (NPT), eight are actively pursuing laser isotope separation technology, and two are developing ion or chemical enrichment technology for uranium isotope separation. As illustrated by these statistics, the predominant separation technology adopted by these countries is the gas centrifuge.

Why has the gas centrifuge emerged as the uranium isotope technology of choice? First, it is ideally suited for uranium isotope separation and consequently HEU production. The gas centrifuge technology has a high separation factor which, using typical values, implies that the uranium hexafluoride (UF_6) produced as product from the gas centrifuge is at least 20% richer in ^{235}U isotope contained than the feed UF_6. By comparison, in a gaseous diffusion converter, the product is generally less than 1% richer in ^{235}U isotope than its feed material per separation unit.

> *Four to twelve unannounced on-site inspections are necessary to achieve high assurance.*

Second, gas centrifuges have a small in-process uranium inventory that makes them an attractive choice for uranium isotope separation. By comparison, the in-process cascade inventory in a 1000 tonne separative work unit (SWU) per year gas centrifuge plant is on the order of about 0.2 tonne of uranium as gaseous UF_6 as compared with several hundred tons of UF_6 inventory in a 1000 tonne SWU/year gaseous diffusion plant. This is very important both because of economic investment in the facility as well as the concern of nuclear criticality when producing HEU.

Third, gas centrifuges have a short equilibrium time. This is particularly important in HEU production in that the time required for the separation process to reach equilibrium and therefore produce the desired product assay is relatively short. Gas centrifuge equilibrium can be reached in about one day for an ideal HEU cascade in contrast to several months for HEU production equilibrium in a gaseous diffusion cascade or several years for chemical exchange processes.

Fourth, gas centrifuges have low energy consumption rates. Typically, a gas centrifuge will consume ~100 kWh/SWU, which is equivalent to about 3% or 4% of the electrical energy consumed per SWU produced by a gaseous diffusion facility.

Furthermore, most of the basic materials and technology required are currently available to moderately developed countries. And the engineering or technical complexity of this technology is "moderate" in comparison to the laser isotope separation process. Finally, gas centrifuge technology can be deployed in small-scale operating units that can be expanded over time as capacity needs change using add-on modules.

Key conclusions of the HSP

The primary assessment resulting from the HSP was a political consensus that the detection of HEU production was of greater relevance than the detection of low enriched uranium (LEU) diversion. The conclusions adopted in the HSP included the following:

- Inspector access to cascade halls of the gas centrifuge enrichment plants must be among the safeguards measures.
- The "limited-frequency unannounced-access" (LFUA) strategy (i.e. on-site inspections of limited frequency and duration without prior announcement) is necessary in order to have an effective inspection/verification regime.
- These LFUA inspections need to occur randomly between four to twelve times per year for facilities up to 1000 tonne SWU/year to achieve high assurance of no HEU production.
- For routine inspections not involving cascade hall access, inspection frequencies between 12 and 15 times a year for facilities up to 1000 tonne SWU/year are necessary.

The HSP participants also acknowledged that the LFUA inspections could occur during routine inspection of the plants. However, the plant operator would have to provide access to the cascade halls at his site within 2 hours of the request for an LFUA inspection. The 2 hour time-frame was considered necessary to give the operator time to ensure that no sensitive information could be obtained inadvertently by the inspectorate. Two hours was also considered the limit within which there would be insufficient time for the operator to remove all evidence of any illegal activity without a high probability of being detected.

Description of the verification approach

The gas centrifuge technology verification approach that has been internationally adopted includes two important elements: nuclear materials accountability verifications and LFUA strategy inspections. The purpose of nuclear materials accountability verifications is to verify the absence of LEU diversion by verifying nuclear material flows and inventories normally associated with routine operation of a LEU production facility. The purpose of LFUA strategy inspec-

The author is director of technical integration for the environmental restoration program, Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee. Martin Marietta is the operating contractor of the Oak Ridge National Laboratory, the Oak Ridge Gaseous Diffusion Plant, the Y-12 Plant, and the Paducah Gaseous Diffusion Plant for the US Department of Energy. *This paper has been authored by a contractor of the US Government under contract No. DE-AC05-840R24100. Accordingly, the US Government retains nonexclusive, royalty-free license on and to any copyright that may cover this publication.*

tions, as agreed to in the HSP, is to verify the absence of HEU production by conducting nondestructive assay (NDA) measurements and visual inspections inside the gas centrifuge plants cascade halls. Because the focus of this paper is on verifying the absence of HEU production, I will focus the remaining discussion on the LFUA strategy for verifying the absence of HEU production.

The function of LFUA verification is simply to verify operations as declared and to verify that the design of the plant is as declared by the State or facility operator. In verifying operations as declared, the inspectorate is verifying with high confidence that all nuclear materials flows and operations are as declared and that the plant is in fact only producing LEU for civil purposes. Also in verifying plant designs as declared, the inspectorate is confirming that the cascades, which are the basic operating units of the gas centrifuge plants, are connected as so stated and that any sampling points where nuclear material could be introduced or withdrawn from the cascades are also as declared.

HSP verification activities include: visual observations, NDA measurements, sampling, and use of tamper-indicating seals. The NDA measurements conducted inside the cascade halls have become known as LFUA cascade header pipe measurements because the NDA measurements are conducted on the main header pipes that supply UF_6 feed and withdraw UF_6 product and tails from the cascades.

Visual observations. The function of this activity is to visually verify the process operations as declared and to verify design information as provided to the inspectorate.

In typical centrifuge cascades, one sees repetitive pipe work, uniform engineering, and many hundreds of identical gas centrifuge machines that are interconnected to make up the basic operating unit or cascade. The visual inspection process relies on the "transparency" of such facilities. During visual verifications, this transparency makes any discrepancies that might exist due to changes in interconnections that might be indicative of HEU production easily detectable.

LFUA strategy NDA cascade header pipe measurements. These measurements involve gamma ray measurements on individual cascade header pipes using portable radiation detection equipment. The objective is to statistically confirm the absence of HEU in the process gas flowing through the piping in an operating facility. This measurement approach is based on a two-phase measurement technique. The phase 1 measurement is a passive gamma ray measurement of the total ^{235}U signal using a wide collimated geometry. The phase 2 measurement is an X-ray fluorescence (XRF) measurement of the total uranium concentration contained in the gas and a simultaneous measurement of the total ^{235}U signal under a highly collimated geometry. The two measurements of 185.7 KeV gamma rays from the ^{235}U using the two geometries determine the amount of ^{235}U present only in the gas phase. The ratio of the gas-only ^{235}U signal to the gas-only total uranium signal results in a pressure- and deposit-independent measure of the UF_6 gas enrichment.

The detection equipment consists of a portable high-purity germanium (HPGe) detector, a portable battery-powered multichannel analyzer, and an XRF source holder-source collimator that has been designed and/or modified for specific pipe sizes. The portable detector used to measure the gamma ray and X-ray emissions from the header pipes can be stored at room temperature and only requires liquid nitrogen cooling immediately prior to and during operation. The detector is designed to include an internal graded back shield and an external graded collimator fabricated of tungsten and copper which is intrinsically mounted on the detector to reduce extraneous background noise. The end of the external collimator is contoured to fit flush against the header pipe and can be rotated to interface with either a horizontal or a vertical pipe. The multichannel analyzer has built-in decision analysis firmware that guides the user through the measurement procedure, accumulates data from the detector, and provides on-the-spot analysis of the data. Besides numerous premeasurement and post-measurement activities, the intent of this highly automated approach is to make a go/no-go determination as to whether or not the process gas is above an agreed-to threshold (i.e. >20% contained ^{235}U).

Sampling. In this activity, gas samples of UF_6 may be taken directly from the cascades or from vessels or pipes directly connected to and traceable from the cascades. The function of this sampling is to verify, with high probability, the presence of LEU in the process gas at the time the sample was taken. The operator has a major concern with sampling; sampling can introduce light gases during the operation of making a physical connection to the cascade and thus increases the risk of disrupting or damaging process operations. Sampling has not been agreed to as a routine inspection measure. It has been acknowledged as necessary for clarification and/or resolution of anomalies that may be indicated during the visual inspections or the NDA cascade header pipe measurements.

Seals. The fourth activity involves the application, verification, and placement of tamper-indicating seals on selected process piping valves and flanges, as well as any inspection equipment that is left unattended in the cascade area for longer-term monitoring. These tamper-indicating seals allow the inspector to maintain continuing knowledge of the status of the process system and/or his verification equipment's status. This can be particularly useful during plant commissioning and decommissioning activities where changes from steady-state operations are very common and the introduction of new UF_6 feed material as well as the withdrawal of UF_6 could in fact be indicators associated with HEU production.

Status

Implementation of the LFUA strategy was agreed to commence fully within 1 to 2 years of the conclusion of the HSP. For many practical reasons, the techniques have not yet been implemented. In the United Kingdom, for example, only recently in January 1990 has the equipment been adapted to the Capenhurst facility. Inspector training occurred in February and the first true in-plant inspector use is scheduled for March 1990. Likewise, 7 years after the HSP concluded, the Japanese are only now adapting and accepting the technology for use in their plant at Ningyo Togo, with calibration occurring in January 1990 and the first inspector use occurring in February 1990.

Unfortunately, the Dutch and German gas centrifuge facility operators and governments are "still investigating the technique," although it was proven feasible over 7 years ago.

Summary and conclusions

If fully implemented, the LFUA verification approach coupled with nuclear materials accountability verification techniques offers an effective and efficient set of measures capable of verifying with high confidence the absence of HEU production in gas centrifuge enrichment plants. Implementation has been hindered by delays in technology adaptation to specific plant conditions, concerns by operators and owners of the technology holders over the loss of sensitive technology to the inspectorate, operator reluctance to allow foreign inspectors in their operating facilities, and recognition that each gas centrifuge plant is of a unique and different design, therefore requiring slightly different and unique technical solutions for each plant.

In order to have an effective verification approach that could be transferable to the arms control community and applied during nuclear materials cutoff verification inspections, a recommitment to the LFUA verification approach from the gas centrifuge technology holders and from those governments wishing to achieve high confidence levels for arms control treaties is required.

International Safeguards for Reprocessing *Can* Be Effective

James E. Lovett

[A copy of the original lengthier version of this article, with 14 references, can be obtained from the author.]

Background

Speaking before the United Nations General Assembly in December 1953, President Eisenhower outlined a proposed Atoms for Peace plan. In simplest terms, the US offered to share materials and technologies needed for peaceful nuclear power in return for international acceptance of an effective system of safeguards, specifically including on-site inspections, to ensure that nuclear materials were used for nuclear power and not for nuclear explosives. The idea was an instant winner; the Statute of the International Atomic Energy Agency (IAEA) was adopted in 1957, and the first IAEA safeguards inspections were performed in 1961.

In the late 1970s President Carter, alleging that reprocessing plants could not be safeguarded effectively, ordered a halt to US commercial plutonium reprocessing, and made a serious effort to convince other countries that they too should forego reprocessing in the name of nonproliferation.

In both instances, the operative words are "effective international safeguards." Both leaders recognized that the consequences of a world proliferation of nuclear weapons would be unacceptable, but President Eisenhower concluded that the potential benefits from nuclear energy out-weighed the small risk that would remain after effective safeguards were in place. Analyzing the same tradeoff, President Carter concluded that safeguards did not measure up to the required standards, at least with regard to plutonium, the most useful nuclear weapon material.

In 1977 reactions to President Carter's pronouncement were varied. US government agencies took the position that safeguards for reprocessing could never be effective, and R&D efforts which might have demonstrated otherwise languished for a number of years. Some IAEA member states took a strong contrary position, arguing for public relations reasons that "current safeguards are effective in existing reprocessing plants." Unfortunately it was then only a short step to the further argument that current safeguards would also be effective in future reprocessing plants if a few straightforward problems like a better input measurement were addressed.

> *There are still those who argue that current safeguards are effective.*

Other IAEA member states, notably Japan and Britain, recognizing that reprocessing was an essential element in their national energy policy, undertook to support a concerted R&D effort to develop better safeguards, and it became my task to coordinate this R&D work for the IAEA. It would be politic for me to state that the IAEA strongly supported these efforts, but the truth is that the IAEA was at best an indifferent supporter of R&D for reprocessing.

Where do matters stand now, over a decade later? My personal view in 1977 was that current IAEA safeguards were not effective, but that with a reasonable R&D effort they could be made effective. It is still my opinion that safeguards for reprocessing can be effective, but unfortunately it is also still my opinion that current safeguards for reprocessing are not effective. Moreover, most problems at this point are political rather than technical. There is some R&D work yet to be done, but the major technical hurdles have been surmounted. The IAEA has it in its power to define an effective safeguards approach for reprocessing, but actual efforts to do so are unconvincing. There are still those, the IAEA included, who argue that current safeguards are effective, and who see little need to improve a system that is already working.

Safeguards goals and inspection criteria

It is sometimes suggested that failure of the general public to perceive safeguards for plutonium as effective is primarily a public relations problem. I do not agree. There are significant technical differences between current practices and the standards that have been adopted as defining effectiveness.

The purpose of international safeguards is to provide the world with a credible assurance that nuclear material, in this case separated plutonium, is not being diverted. If the world is assured, if the world is prepared to accept reprocessing and plutonium reuse as a part of the total nuclear fuel cycle, then safeguards are effective. If the world is not assured, then safeguards are not effective, because they have failed to provide the assurance they were instituted to provide.

By this reasoning, safeguards for reprocessing are not effective. Lacking a more definitive opinion survey, the general perception is that Americans are prepared to accept nuclear power, at least in terms of proliferation risks, but they are not prepared to accept separated plutonium. To state it bluntly, the public is not satisfied, therefore safeguards are not effective.

Each year since 1977 the IAEA has reported to its Board of Governors concerning safeguards during the preceding year. Each report has stated that diversion has not been detected, and that absence of detection should be equated with absence of diversion. The Board of Governors has never seriously challenged those statements. The IAEA's governing bodies truly believe that diversion has never occurred.

If one looks purely at the statistical evidence, the IAEA's statements are eminently defensible. In 1987 the IAEA devoted over 9500 man-days of effort to over 2000 inspections worldwide. The data for 1988 and 1989 are comparable. Much of this effort was devoted to the inspection of nuclear reactors and is not directly relevant here, but the effort devoted to reprocessing was consistent with published safeguards approaches and the extent to which the facilities in question actually operated. The IAEA's failure to satisfy the world's desire for

The author is a former International Atomic Energy Agency official, and is the Chief Executive Officer of Lovett Associates, Inc., 901 Second St., Bay City, TX 77414.

a credible assurance of non-diversion has not been for want of trying.

In the late 1970s the IAEA adopted a set of safeguards goals; those relevant here are a detection sensitivity of 8 kgs total plutonium, coupled with a detection timeliness of about ten days for separated plutonium or about one month for plutonium in spent fuel. This calculation assumes a bare fast critical mass, which may oversimplify things. A nuclear device based on a fully reflected critical mass might require only 2-3 kgs Pu. On the other hand, the calculation is conservative in terms of a simple nuclear device, because it makes no allowance for the dilution and poisoning effects of even-numbered isotopes or for the spontaneous neutron problems introduced by ^{238}Pu.

The IAEA's annual report, however, is based on a set of inspection criteria, not the 1978 safeguards goals. Unlike the safeguards goals, which are based on outside considerations of what a true assurance of non-diversion demands, the inspection criteria are prepared internally, largely by the inspectors themselves, based on what ought to be achievable using available resources. Although there have been some efforts to develop criteria applicable for a number of years, actual practice has been to revise the inspection criteria each year.

There are two problems here. One is that the inspection criteria are very specific as to both equipment to be used and procedures to be followed. New equipment capable of doing the same job better has a good chance of being accepted, although at times the approval process can move with all the speed of a lethargic snail. Proposals to accomplish some general safeguards objective in a completely new manner tend to be blocked by the objection that the new procedures violate IAEA policy as defined in the inspection criteria.

A second problem is that when resources are reduced, as they have been annually for the past several years, the definition of effectiveness in the inspection criteria is revised downward accordingly. Since the annual report still says that safeguards are effective, as it always does, the Board of Governors sees little reason to respond to requests for budget increases. As the saying goes, if it ain't broke, why are you trying to fix it?

Materials accountancy

The IAEA inspector's safeguards problem and the bank examiner's financial audit problem have many elements in common. First the reprocessing plant (bank) must prepare a material balance (financial statement) showing that all nuclear material (money) can be accounted for. The IAEA inspectors (bank examiners) then must examine the material balance (financial statement) and verify the accuracy of the data recorded on it. Verification in both cases specifically requires that at least some of the data be subject to procedures that confirm the absence of deliberate falsification.

Current IAEA safeguards procedures concentrate almost exclusively on the verification problem. In general, inspection criteria do not discuss materials accountancy, they discuss procedures for the detection and resolution of "anomalies," a broad term that includes both data falsifications and "anything that doesn't look right." These procedures for the most part are designed to detect data falsifications at the 8 kg Pu level.

The important question, however, is whether the plant operator can prepare a material balance capable of demonstrating that all nuclear material can be accounted for. If the inherent accuracy of the unfalsified material balance is significantly worse than 8 kgs Pu, there is little reason to search for data falsifications at that level. At the present time the IAEA judges the acceptability of the operator's material balance in terms of an accountancy verification goal (AVG) based on measurement capabilities as they were estimated to be in the late 1960s. For a 4 t/d reprocessing plant the IAEA's current AVG is 250 kgs Pu [7]. In the mid-1980s the IAEA decided not to update the AVG to reflect current measurement capabilities, on the grounds that doing so would penalize plant operators for adopting good measurement procedures.

Can materials accountancy really account for an annual throughput of 8000 kgs Pu to an accuracy of ±8 kgs Pu? Using conventional procedures based on a single material balance once per year, probably not. However, conventional materials accountancy can do considerably better than 250 kgs Pu. Reporting at an IAEA safeguards symposium in 1986, Marsh and Foulkes suggested that ±0.1% should be attainable. They have since backed off somewhat from this optimistic value, but still support ±0.2% as an attainable objective. Others have more conservatively suggested ±0.4%. A mid-point estimate of ±0.3% is probably as good a guess as is currently available. This leads to an AVG of 75 kgs Pu, not worth a gold star, but considerably better than 250 kgs Pu.

However, this conventional materials accountancy system calls for only one material balance per year. It has been shown that reprocessing plants can take in-process physical inventories every few days, based solely on volume and concentration data derived from intermediate buffer storage tanks. Referred to as near-real-time (n.r.t.) materials accountancy, this in-process accountancy system makes use of two important facts, first that at any given moment most of the plutonium in a reprocessing plant is in buffer storage tanks, and second, that the remainder is approximately determined by the plutonium concentration in the aqueous solution fed to the process. By breaking the total plant into process units and measuring the Pu concentration in buffer tanks that separate and feed these process units, accurate material balances based on in-process physical inventories can be prepared.

It is my opinion that current safeguards are not effective. Moreover, the problems at this point are political rather than technical.

Implementation of n.r.t. accountancy improves both material balance sensitivity and timeliness, a point that is not yet universally accepted. With 40-50 time-ordered data points, safeguards statisticians can use more powerful statistical techniques that evaluate material balance data in terms of past experience. A number of tests have been investigated; the consensus favors "Page's test" applied to standardized MUF residuals. Conceptually this test examines whether the slope of a cumulative MUF line is changing. The test is extremely sensitive; in fact its biggest problem may be that it is too sensitive.

Gupta and Bicking, using the traditional ±1% measurement uncertainty value, estimate that n.r.t. accountancy can provide a credible assurance of non-diversion at the level of 18 kgs Pu for a one week material balance or 24 kgs Pu over a period of one year. A linear extrapolation from ±1% to ±0.3% is not strictly correct, but more qualitatively, achieving measurement uncertainties of ±0.3% should also permit achieving an 8 kg Pu safeguards goal.

A new safeguards approach for reprocessing

Adoption of n.r.t. accountancy and the accompanying sequential statistical evaluation procedures is not the only change needed in IAEA safeguards. A completely new safeguards approach is needed, one that begins by addressing the 8 kg safeguards goal rather than current inspection criteria. It is unrealistic to expect that this can be achieved by patching the existing safeguards approach; in the long run it will be better to start with a clean slate.

The new safeguards approach must also recognize the existence of practical constraints, including limitations on inspector access to potentially hazardous nuclear materials or process areas, limitations on inspector access to commercially sensitive reprocessing technology, and budgetary restrictions. These constraints are not simply political roadblocks, introduced as surrogates for fundamental objections to the implementation of safeguards, as is sometimes argued. For the most part they are serious practical problems inherent in all operations using potentially hazardous nuclear materials.

Balancing these constraints while still achieving an 8 kg safeguards goal is feasible. In broad outline, the new safeguards approach must emphasize three elements:

- introduction of multiple levels of independent and redundant instrumentation to eliminate or reduce the need for verification of nuclear material quantities that would be difficult or time-consuming, and to reduce to an absolute minimum the need for inspector access to radiation areas;
- incorporation of new technologies, likewise to eliminate or reduce the need for inspector access to potentially contaminated plant areas, and to minimize the need for offsite shipment of analytical samples; and
- use of near-real-time materials accountancy as a basis for stating that all nuclear material can be accounted for.

Prognosis

Safeguards for reprocessing *can* be effective. A new safeguards approach is needed, but one can be defined that would meet the required safeguards goal of assuring that all plutonium can be accounted for to within 8 kgs, combined with a timeliness goal on the order of 1-2 weeks.

Will it happen? The evidence today is discouraging. Most of the necessary technology exists. Some new R&D initiatives are needed to fill identified gaps in the technology, but since 1986 the number of new R&D projects instituted with IAEA support has been close to zero. Those projects that have been undertaken relate to the improvement of measurement capabilities, and are not relevant to the three identified areas of emphasis. Discussions among the technology holders were initiated in 1988, but some participants are still dedicated to the idea that current safeguards are effective, while others are unconvinced that effective safeguards are possible. There is still time, but the prognosis is not optimistic.

The Utility of a Cutoff: An Historical Perspective

John M. Taylor

History

From the earliest post-World War II arms control deliberations to the present, there has been interest in controlling nuclear weapons by controlling those materials that fuel them, most notably high-enriched uranium and plutonium. Despite discussion in several international fora for over 40 years, this approach, known as cutoff, has never been formulated into an agreement or even set aside for separate negotiations.

During the latter part of the Truman Administration and the early portion of Eisenhower's tenure, proposals for control of the rapidly expanding nuclear arsenals were based on control of the uranium and thorium ores essential for production of nuclear explosives. This approach was initially articulated by Bernard Baruch in 1946 and remained a central component of the US negotiating posture for the next several years. During the Eisenhower, Kennedy, and Johnson Administrations, cutoff was a centerpiece of US arms control policy, reaching something of a pinnacle in 1964 when the US, UK and USSR jointly announced cutbacks in production of fissionable material for weapon purposes. Even though the rationale for these cutbacks was based more on economics and material sufficiency than on arms control, a fact not lost upon outside observers, the actual shutdown of some material production facilities was touted by some politicians as progress toward a cutoff agreement.

The international visibility of cutoff declined precipitously in the late 1960s as nuclear testing, delivery vehicle controls, and nonproliferation came to be perceived as the more critical arms control issues. During the 1970s, and 1980s, cutoff was shunted into the background, although it never completely disappeared. Brief resurgences occurred during the United Nations' Special Session on Disarmament in 1978 and in the scientific media in 1984 and 1985, but until relatively recently the issue remained essentially a pro forma part of the international arms control and disarmament agenda with no substantive constituency lobbying for its acceptance. During the INF ratification hearings in 1988 and throughout 1989, Congressional activity, partially spawned by renewed activity in the public sector, has rekindled both public and legislative interest in the topic.

The cutoff thesis

The basic cutoff thesis is straightforward: nuclear-capable nations would cease production of fissionable material for nuclear-explosive purposes and, in some versions, would transfer material from existing weapon stockpiles to an international agency for eventual use by peaceful nuclear programs throughout the world. Since the demise of proposals for controlling source material (i.e., ore) in the mid-1950s, the form taken by the proposition has remained essentially static. Its advocates have been from the Western nations with some support from the Third World, notably India, although this advocacy has become somewhat more distant, at least on the part of the United States and Britain, in the more recent past.

Although the form has remained constant, the context in which the proposal has been advanced has varied considerably. As discussed earlier, cutoff first appeared as the centerpiece of the US arms control package with issues such as delivery-vehicle controls and test bans tied, but subordinate, to material production controls. These linkages eventually flip-flopped: the arms control proposals that were subordinate became primary and, in cases such as the Limited Test Ban Treaty, the Nonproliferation Treaty, and the SALT, START, and INF negotiations, actually overwhelmed the cutoff aspect completely.

Objections to cutoff

Objections to cutoff have also remained relatively static over the years. The Soviets have consistently maintained that a cutoff in production of fissionable material does little or nothing to limit the actual warmaking capability of the various nuclear nations and therefore,

The author is with Verification Systems and Technology, Division 9241, Sandia National Laboratories, Albuquerque, NM 87185-5800.

that cutoff is at best window-dressing, and at worst a Western ploy to gain access to and control over sensitive Soviet programs. Their counterproposal was first to require elimination of nuclear weapons (as a part of general and complete disarmament) and *then* to impose a cutoff to support this stockpile control.

A second objection has been that a cutoff is not adequately verifiable, particularly those aspects having to do with confirmation of existing stockpiles of both weaponized and nonweaponized fissionable material. Although attempts were made by the French, the British, and the United States to describe systems for verifying a cutoff, the issue always returned to on-site inspection and/or detailed data exchanges, both of which were anathemas from the Soviet perspective. Even in today's world where on-site inspection seems to have acquired greater international acceptance, these issues still do not adequately address questions of stockpile uncertainties and force asymmetries.

Does cutoff have a role?

If cutoff does have a role in today's world, it appears to be a substantially different one from that envisioned by its earliest proponents. Certainly, the extent of modern weapon and fissionable material stockpiles precludes the utility of cutoff as a centerpiece arms-control proposal. Any credible supporting role should be contingent on prior implementation of verifiable constraints on both launchers and delivery vehicles. Even then, however, treaty-mandated restrictions on material availability are likely to be more symbolic than substantive for the established nuclear-weapon states. In fact, because of force asymmetries, the verification difficulties associated with such an agreement may actually make it destabilizing in the long run.

On the other hand, in concert with extant NPT restrictions, material controls may be relatively effective at preventing horizontal proliferation of nuclear weapon capability to non-weapon states.

Limiting and Reducing Inventories of Fissionable Weapon Materials

L. Charles Hebel

As the US and the USSR agree on significant reductions in nuclear weapon delivery systems, they may wish also to dispense with the warheads and bombs for these systems. Such steps could be reinforced if the two nations also institute mutual restraints and reductions in the total amount of fissionable materials available for weapons. Many tonnes of such materials would be made surplus by the START reductions in strategic weapons and the prospective reductions in theater and naval nuclear weapons following the anticipated agreement on conventional forces in Europe.

Over the years several proposals have been made to stop the production of plutonium and high enriched uranium (HEU) for weapons and to transfer the materials to peaceful purposes. The United States made a formal "cut-off and transfer" proposal in 1969, which the Soviet Union rejected. In recent years the Soviet Union indicated definite interest, and in October 1989 they proposed discussions on the subject in preparation for negotiation. But so far the two nations have not adopted the same position at the same time.

A cut-off is timely

A US/USSR production cut-off and reduction in the stockpiles of fissionable weapon materials is timely for several reasons:

- the opportunity to buttress the cuts in delivery systems and warheads by eliminating the fissionable weapon materials thereby made surplus;
- the crucial need to bolster non-proliferation, which endured eroding incidents during the 1980s;
- the need to sustain the nuclear Non-Proliferation Treaty (NPT), which must undergo a critical multi-nation review in 1995;
- the risks and liabilities in maintaining the military nuclear fuel cycle facilities and protecting the stockpiles of fissionable weapon materials against theft or diversion;
- the ongoing advances in the technology for producing fissionable weapon materials, e.g. for enrichment, which underscore the need to strengthen international controls that support peaceful uses of nuclear energy.

Four-step control framework

I will explore the verification issues and problems of the following four-step control framework:

- initiate a verifiable US-USSR cut-off of the production of fissile materials for weapons purposes;
- place the civilian fuel cycles in the US and USSR under full-scope, non-diversion safeguards;
- transfer verified quantities of fissionable material from the military to the safeguarded civilian nuclear supply chains;
- reformulate and fission the transferred weapons-grade materials in safeguarded civilian reactors using the once-through fuel cycle.

The US and USSR could enter into a bilateral agreement to implement the steps, or they could draw on the internationally credible and acceptable infrastructure for controlling and safeguarding nuclear material. The latter approach could use the safeguards procedures, technology, and even the key institution, the IAEA, employed for nonnuclear-weapon states under the NPT. Thus, this review compares the verification issues under a strictly bilateral implementation and an "augmented IAEA/multilateral" implementation.

Overall, the review concludes that the time is propitious for the US and USSR to negotiate controls on their fissionable weapon materials. An effective control framework could be devised, and the process would foster both arms control and non-proliferation.

Feasibility of a cut-off and stockpile reduction

The four-step approach could frame a feasible, verifiable control regime, provided several key issues are addressed.

First, the four-step approach would require conventional IAEA-type safeguards augmented by a bilateral US-USSR arrangement

The author is an affiliated fellow of the Stanford Center for International Security and Arms Control, Stanford, CA 94305, and is also with the Xerox Palo Alto Research Center, Palo Alto, CA 94304.
Work on this review was conducted largely during a part-time residence at the Center during 1988 and 1989. The author greatly appreciates Wolfgang K.H. Panofsky for his many substantial contributions to this review. He also thanks his colleagues at the Stanford Center for International Security and Arms Control, especially George Bunn, Sidney Drell, and Philip Farley, for extensive discussion and comments.

addressing the issues of covert materials production and the monitoring of fissionable materials transfers. That is, the bilateral arrangement would verify that neither party is engaged in significant covert production of fissionable weapon materials, and monitor the delivery of fissile weapon materials on an agreed schedule for transfer to the safeguarded civilian supply chain and, if desired, monitor the process of nuclear weapon destruction.

The framework is consistent with the 1969 US "cut-off and transfer" proposal and with the type of IAEA safeguards agreements now in force under the NPT for civilian nuclear facilities. The verification provisions would draw on some INF Treaty provisions, notably for the exchange of sensitive information, perimeter-portal monitoring, and on-site inspection of declared production sites, and also on the suspect site inspections being negotiated for START.

Second, IAEA-type safeguards at civilian and declared production facilities could be implemented on an IAEA/multilateral basis or a US-USSR bilateral basis. Either basis has advantages and disadvantages. Or a hybrid implementation could gain most of the advantages of an IAEA/multinational approach while avoiding the main disadvantages of a strictly bilateral basis.

The bilateral implementation is simpler and could readily meet national security needs but would only minimally reinforce non-proliferation. An IAEA/multilateral basis could be workable, but more complex when augmented with procedures to deal with covert production and the monitoring of materials transfers. Such a multilateral basis could support non-proliferation and be extendable to other nuclear-weapon states.

Alternatively, in a hybrid structure the sensitive and manpower-intensive monitoring could be carried out bilaterally, perhaps modeled after EURATOM. Audits of the bilateral process and spot inspections could be done by the IAEA. Moreover, such a hybrid implementation could be structured as the initial step toward an eventual IAEA/multilateral management.

Stockpile assessment

As a third issue that must be addressed, information is lacking for a definitive assessment of superpowers' stockpile sizes. Thus an exchange of information on production, with adequate public disclosure to assist debate and build confidence, is a key step.

The precision with which each party knows the residual stockpile of the other will clearly limit an agreement on reductions. A body of information on US production is publicly available in congressional testimony and government publications. Far less information is publicly available on Soviet production.

Based on publicly available information, 23,000 US nuclear warheads use some 105-115 tonnes of plutonium and 415-455 tonnes of HEU, with some fuel-grade plutonium and additional HEU in the stockpile. The precision of these estimates is hard to pin down but is probably better than 20%.

The meager publicly available information for the Soviet case suggests about 33,000 nuclear warheads. Some analyses imply even higher numbers, and the uncertainty may be several thousand warheads. The corresponding stockpile is estimated as 125-165 tonnes of weapons-grade plutonium and 500-650 tonnes of HEU, with an uncertainty of 30-50%.

Fourth, production cut-off with gradual reduction of fissile materials by 25-40% could be feasible even with the present uncertainty in residual stockpiles. However, a future reduction of fissile materials by >50% may not be feasible unless present material stockpile uncertainties are reduced considerably.

The process could begin with the cut-off, phasing in the reduction shortly thereafter. The process would eliminate the surplus materials stockpile that will arise from arms control agreements, and could be consistent with likely requirements of force modernization. The remaining stockpiles would still be much greater than needed for a reasonable implementation of deterrence. The study of methods for reducing the stockpile uncertainty, e.g. evaluating the accuracy and limitations of techniques to verify production information that may be exchanged by the parties, is an important area for further work.

Disposal

The fifth point is that fissioning the weapon materials in civilian power reactors is the disposal option with the least risk to the environment and the public. As an option, the storage of weapons-grade plutonium would be only a temporary expedient requiring continual protection against theft or diversion.

The dilution of HEU with ordinary or depleted uranium gives material which is indistinguishable from that already used for reactor fuel. Plutonium in a mixed oxide form is readily useable as reactor fuel. Submarine, research, and experimental breeder reactors could draw on existing plutonium and HEU stocks.

The "once-through" fuel cycle would be used with the spent fuel isolated in deep geologic repositories, which is the current plan in the United States. The alternative of diluting weapons-grade plutonium, perhaps with reactor-grade plutonium, and encapsulating it with the existing high level defense waste would be less acceptable on environmental grounds. Overall, packaged spent fuel is perhaps the least onerous form for geologic disposal/isolation.

Tritium

The sixth and final point is that the US tritium inventory for weapons is probably sufficient for a number of years if steps are taken to conserve supplies and reuse the tritium from weapons removed from inventory. Yet, prudence suggests that the DOE prepare "with all deliberate speed" for a new source of tritium.

A cut-off would have limited value as a "stand alone" measure, but would buttress START reductions and the non-proliferation regime.

The four-step approach is compatible with limited tritium production under safeguards, to maintain the remaining nuclear weapons inventory and to hedge against a breakdown in the arms reduction process. The reductions presently contemplated in START I amount to about 20% of the total inventory. Reductions in theater and naval nuclear weapons could easily double that percentage. Both together would result in significant reserves of tritium for reuse.

The Department of Energy expects to restart one or more of the Savannah River reactors on reduced power by early 1991 for limited tritium production. New production alternatives have lead times of perhaps a decade. The proper steps at this time are to make a design decision for an alternative source, select a site, and complete the NEPA and licensing groundwork. During this process arms control negotiations may clarify the actual requirements.

Arms and control and non-proliferation implications

The four-step approach would support arms control objectives by lending greater stability to reductions in nuclear weapon delivery systems, e.g. by reducing the likelihood of a circumvention of the

START reduction or the prospective cuts in theater nuclear forces. And the approach would reinforce safeguards and non-proliferation objectives and enhance the prospects for continuing the NPT beyond its critical review in 1995.

A production cut-off per se would have limited value as a "stand alone" arms control or non-proliferation measure. A cut-off of HEU and plutonium production by itself would have but a small effect on weapons, given the existing enormous stockpiles of weapons-grade fissionable materials. For years a number of nations have criticized the superpowers for not fulfilling their commitments as NPT signatories. Thus, a production cut-off in itself would have some beneficial effect for non-proliferation but would redirect criticism at the stockpiles of nuclear weapons and their materials.

For arms control, a production cut-off plus a reduction in fissile weapon materials would buttress the reductions in weapon delivery systems. The combination could reduce the likelihood of a by-pass of START by new delivery systems or a breakout that could divert nuclear materials to weapon systems not constrained by agreements. Such a reduction could, for example, reduce the potential to convert conventional Sea Launched Cruise Missiles to a nuclear version, and reduce pressure for a large-scale, nuclear-armed ABM system. A reduction in fissionable weapon materials could be made in tandem with the schedule for destruction of delivery systems and warheads. Then the decrease in fissionable materials would limit slippage from nuclear arms reductions.

For non-proliferation, a production cut-off plus a reduction in fissionable weapon materials would undergird safeguards objectives and reinforce the vital non-proliferation regime at a critical time. The combination would increase the demarkation between military and civilian fuel cycles, extending to the superpowers safeguards like those that are applied to nonnuclear-weapon states under the NPT. This would ease one of the most aggravating differences between "have" and "have not" nations and enhance the prospects for an NPT extension in 1995. The reduction also would limit the stockpiles of bulk fissionable materials that must be protected.

Implementing full-scope safeguards in the United States and Soviet Union would require an expansion of the overall safeguards activity beyond the current IAEA effort. This could be an expansion-in-kind of the present IAEA practice that is consistent with the existing IAEA safeguards agreements with the two nations, and could undergird international safeguards without compromising the IAEA safeguards applications in other states.

Symposium: The Science of Pseudoscience

Expanding on our custom of reprinting the talks from Forum-sponsored invited sessions, we reprint here the three talks and the introductory remarks from an invited session sponsored by the AAPT Committee on Science Education for the Public. This session was held on 25 January 1990, at the Joint APS/AAPT Meeting in Atlanta. *—Editor*

Introductory Remarks

Lew Slack

The paranormal has always been with us and probably always will be. But in recent decades we have seen ever more serious attention and credence given to such ideas and movements as UFOs, ESP, and New Age mysticism, to name but three. The common thread through these contains a heavy dose of uncritical thinking, a lack of healthy skepticism, a suppression of judgment, and downright ignorance of both the process and the facts of science.

Many organizations have devoted serious attention to pseudoscience. For example, the AAAS physics section has been especially active under Rolf Sinclair. The APS Forum on Physics and Society last year gave its annual Forum Award to James Randi for his work in debunking some of the more egregious claims (see *Physics and Society*, October 1989, pp. 7-9, for Randi's award lecture). The Committee for Scientific Investigation of the Claims of the Paranormal, and its journal *The Skeptical Inquirer*, is a major source of information.

The AAPT Committee on Science Education for the Public is dismayed at the pseudoscience trends. This session emerged from our concern over the absence of recent material targeted for physics teachers.

In this session, we wanted to examine the manifestations of pseudoscience, but not in order to debunk. Rather, we wanted to understand people's needs and the circumstances that promote these ideas. We also wanted to identify and appreciate the distinctions between crackpot science which can usually be ignored, and pseudoscience which cannot. And we wanted to learn how to better discuss with students and the public the methods of science so that we can bring to others an appreciation of what Martin Gardner has called science's "web of consistency" and Paul Treffler the "principle of universality."

These themes were reflected in Jerry Wheeler's first official communication to the AAPT membership as president, appearing in the January 1989 issue of *The Physics Teacher*. Thus it is fitting that his term closes with this session.

The author presided over the session. He is a former AIP officer, now retired, living at 27 Meadowbank Road, Old Greenwich, CT 06870.

How to Tell Scientific Fact from Pseudo-Scientific Fiction

Michael W. Friedlander

The distinction is not always easy

To a professional scientist, a pseudo-scientific work in his or her own research area can be easily recognized. Outside our own areas, although there may be symptoms that are detected by our professional antennae, we have greater difficulty in making such judgments. Accordingly, we should understand the difficulty that non-scientists

The author is on the faculty of the Department of Physics, Washington University, St. Louis, Missouri.

have in coping with the flood of assertions, announcements or artfully implied claims, e.g. ominous positions of planets, nuclear fusion under near-domestic conditions, remarkable cures for all sorts of afflictions. At issue is the ability to evaluate these claims critically, to distinguish science from non-science, even the need to see a reason for being skeptical.

There is a broad spectrum of claims for discoveries. At the one extreme are those discoveries that receive our immediate acceptance, even though carrying revolutionary implications for accepted wisdom. An example is the 1957 discovery of the non-conservation of parity. At the other extreme are the claims of the Velikovskys and cancer curers. Between is a gray region, populated by topics such as deviant galactic red-shifts, cold fusion, fifth forces and polywater. In this penumbra, there are reports from reputable scientists, and these have often stimulated considerable professional interest, at least for a short time. Many of these reports have not yet received either confirmation or explanation. Perhaps there have been experimental errors or instrumental or computational artifacts. But we need to recognize that some claims are *never* clearly confirmed or disproven. The scientific literature has many examples of this sort - fascinating, tantalizing, perplexing, not fitting into the well-understood structure of science, by-passed by time and the accumulation of yet more examples that do confirm our conventional ideas.

The identification of the more blatant pseudo-scientific claims can sometimes be aided by application of tests against criteria such as those suggested by Irving Langmuir (*Physics Today*, October 1989) or Mario Bunge (*The Skeptical Inquirer*, Vol. 9, #1), but these tests are not foolproof and, as always, we need to be cautious in their use, for some genuine discoveries can start as low-level signals that seem to find no place among accepted laws and observations. In the pseudo-sciences, it is often the behavior of the discoverer, even more than the claimed discovery, that raises the danger flag.

Sorting pseudoscience from science in the classroom

An appreciation of the difficulty in making some of these distinctions, in the drawing of some of the lines, should appear in *all* of our introductory courses, not only those directed towards non-science students. Our traditional courses are over-burdened with content, good and true facts that are easy to include in tests, problem-solving techniques that lend themselves to homework and exams but often do not test understanding. By the end of the semester, many of us have surely had the saddening experience of finding how little our students have understood even before the inevitable exponential decay commences. We can, I feel, make a more enduring impression if we introduce some case studies to illuminate problems in methodology, pointing to the problems of sorting the science from the pseudoscience.

For example, in my astronomy courses I have often prescribed readings from Velikovsky's writings, to be discussed after we have reviewed the workings of the solar system in the orthodox way. A careful analysis of Velikovsky's methods can then be revealing, and the shortcomings and ambiguity of plausible but erroneous claims can emerge from classroom discussion. The topic chosen is a matter of personal choice, but there is no shortage of material (although we may have to do some scavenging and copying). In all, we need to get away from presenting our students with only the accumulated successes of science. Some excavation of our scientific landfill can be rewarding.

Scientifically-based problems will continue to confront everyone, and be evaded by most: radioactive waste, global warming, the reliability of drug tests, the hazards of smoking, the powers of crystals. Some may need legislative action, others require personal decisions. Some issues will be publicized in our daily newspapers, others at the checkout counters of our supermarkets. One thing we can be sure of is that if *we* do not try to provide an introduction to scientific skepticism, no one else will do it, and our students, in their post-graduation lives, will be no better placed to consider the pseudoscience issues.

Virtually every college student must take a few science courses. We are not making use of this great opportunity to provide a truly significant addition to their education.

The Science and the Religion of the Creation-Science Movement

James W. Skehan, S.J.

Sorting out the problem

Although the creation-science movement is one of the chief contributors to the pseudoscience phenomenon, it could only have developed in the present-day environment in which science is seen as the established "sacred knowledge." Science appears to occupy in our culture the place of esteem that theology did in the middle ages. Creation-science is simultaneously a bizarre scientific phenomenon and an unusual religious movement that mixes up science and religion in an extraordinary fashion, apparently seeking to have its religion bask in the sunshine of scientific respectability (1).

It has already been demonstrated to the satisfaction of the courts in Arkansas and Louisiana that creation-science does not have the scientific credentials to be taught in public school science courses (2). However, creation-science continues to flourish not only at the grass roots among parents and many public school administrators, but is actively promoted by many scientists who are religious fundamentalists. Though having little scientific credibility among peers, many of the leaders of the creation-science movement have advanced degrees in science and technology.

Creation-science is a strongly motivated but misguided and bitter reaction to the careless equating by scientists of *scientific* knowledge about origins with an *exhaustive* knowledge of origins. Thus some scientists have unwittingly helped stimulate the creation-science juggernaut. As Gilkey has noted, "each time a child comes home and says to his parents, 'my teacher told us today that Genesis was wrong about creation,' two new creationists are produced (2). I wish to provide some insights about why this bizarre mish-mash of popular science and popular religion is growing in popularity and influence, especially in North America and Australia.

Religious discourse and theory

Since the starting point of creation-science is the Book of Genesis, it is critical for us to understand clearly what constitutes religion and what constitutes science. This understanding on the part of creation-

The author is at the Weston Observatory and the Department of Geology and Geophysics, Boston College, 381 Concord Road, Weston, MA 02193.

science, of mainline churches, and of reputable scientists themselves may differ radically.

Religious language has been described (2) as discourse that "refers to God, an intelligent, purposeful being or reality, one who is transcendent, that is who is not part of the system of creaturely things but precisely their source and ground. In referring to a transcendent being, this language is symbolic or analogical, not precise and univocal." Religious theories explain by speaking of God's actions or purposes, e.g. the purpose of the Flood, not finite causes. When finite things or persons are related to God, there is religious discourse or theories about them. When we ask how the whole system arose, and we give God as its origin, then we are not providing a scientific explanation but a religious one.

"A *scientific theory* seeks to explain the facts of experience by means of law, i.e. universal patterns of behavior which are necessary and automatic. These laws can appeal to or point to only natural or human causes or powers, forces within the creaturely world, within the system of nature and history. No supernatural force or cause from outside the system can be part of a scientific explanation (2).

Creation, the act of God as primary cause, does not explain to us the process by which we as individuals or as a race, came to be; our parents and ancestors are secondary causes of our existence. Creation, however, opens up to us that we are here because of the power and purpose of God as primary cause.

Age of the earth from the Bible?

The Book of Genesis, Chapters 1-11, a unique kind of literature, deals with the creation of the world, the creation of man and woman, Adam and Eve, and Noah's Flood. This book is the starting point for discussions by proponents of creation-science of the age of the earth as determined by calculating the interval of time between major events of the Old Testament. On this basis some ultrafundamentalist biblical scholars, over the past two centuries, determined that a factual reading of the Old Testament yields an elapsed time from Adam to Christ of about 4,000 years, which yields about 6,000 years as the age of the Earth.

Noah's Flood

St. Augustine (354-430 A.D.) and other students of the Bible attempted to discover whether Noah's Flood was factual or was a mythical story intended to show God's stated purpose of punishing sinners (Gn 6:1-22) and later showing his benevolence to Noah and his descendants by a perpetual covenant (Gn 9:1-17). My fellow Jesuit, Athanasius Kircher, S.J. (1602-1683) undertook an investigation to determine whether the dimensions of Noah's Ark as given in Genesis could actually accommodate the 310 kinds of life forms that he had enumerated in his circum-Mediterranean travels. Kircher's reconstruction of the ark and detailed space allocations by each kind including supplies are a fascinating exercise to aid in interpretation of the genre of literature to which this part of Genesis belongs (3).

A century after Kircher, Carl Linnaeus (1707-1778), the Father of Modern Taxonomy, had identified 15,000 "kinds" that would require sheltering on the Ark. By this time it became clear that the Ark was becoming overloaded and that the factual interpretation of the narrative had to yield to a strictly religious message embellished by mythological story. Today biologists have identified many millions of species, a number of the kinds of life forms that would have needed protection in the Ark too great for a factual interpretation. We now know that almost every civilization had a flood story as part of its heritage as, for example, the Mesopotamian flood myth (3).

Sources of Genesis

Today we have much more information available as to how the Bible came into being than did our predecessors. In years gone by the Bible was accepted as God's word in the narrow sense as though God had dictated every word to Moses just as we have it in our Bible. Modern biblical scholarship holds that Genesis was written under divine inspiration, but that human authors assembled the materials from written and oral sources that were readily available, such as the Babylonian creation myth and the Mesopotamian story of a "worldwide" flood.

Over the past two centuries or more, biblical scholars have analyzed the oldest available texts and have developed the "documentary hypothesis" that the Hebrew manuscript of Genesis, produced at least by 400 B.C., was a composite product of several authors or traditions. The documentary hypothesis is the most satisfactory explanation of how the basic materials of Genesis, and in fact, the books of the entire Pentateuch or Torah, have come to be assembled. Some current challenges by serious scholars to the validity of the documentary hypothesis have not, in the judgment of most scholars, eroded the hypothesis. The documentary hypothesis is rejected by creation-science proponents because they hold that the Pentateuch was dictated word by word by God to Moses, a position rejected by mainstream biblical scholars.

Some scientists have unwittingly helped stimulate the creation-science juggernaut.

Additional insights into Genesis have been provided by the discovery and analysis of stone tablets found in the ruins of the Library of King Ashurbanipal (c. 668-630 B.C.) at Nineveh. These tablets record the polytheistic Babylonian creation myth, *Enuma elish*, a story that became well known to the Israelites during their nearly 50 years of captivity in Babylon (587-538 B.C.). This story was adapted by the Priests of Israel to present a monotheistic theology of the "One, true God," Yahweh, in strong contrast to the Babylonian story which in other respects was so similar. Creation-science rejects these insights for reasons similar to those noted for the documentary hypothesis.

Scientific aspects

Let us now examine how modern science relates to creation-science. Darwin's investigations during the voyage of the Beagle produced a vast amount of data on the basis of which he ultimately formulated in 1859 a theory for the origin of species. Darwin's method followed the accepted canons of science resulting in what has come to be known as a theory of evolution, a theory whose statement in its broadest terms has come to be accepted as "a fact" by most scientists today even though Darwin's specific theory has undergone many revisions, even rejection, and has led to the formulation of new theories of evolution.

On this point Newell (4) states:

> "In making much of the idea that scientists do not agree even among themselves about evolution, the creationists fail to distinguish between the *fact* of evolution, and the theories of evolution. According to Webster's dictionary, a 'fact' is 'an occurrence, quality, or relation, the reality of which is manifest in experience or may be inferred with certainty.' From many converging lines of evidence biologists and paleontologists long ago accepted organic evolution as a fact. Scientific

theories, however, are not facts, but constitute scientific explanations of scientific information or knowledge. Such theories are ideas (for example, Darwin's theory of natural selection), and they are continually under study as they are used in the search for new facts and new explanations. The statements must therefore be modified from time to time in order to accommodate new discoveries resulting in new viewpoints."

Creation-science proponents, however, reject evolution in any formulation in the strongest possible terms as the most repugnant concept in science because of their perception that evolution is the cause of all evils in the world. For example, Morris states (5):

"The origin and early history of the earth and man is a marvelous and fascinating story....given by revelation in the Bible and now strikingly confirmed by modern science. The theory of evolution has dominated our society, especially the schools, for almost a hundred years, and its influence is largely responsible for our present day social, political and moral problems. Many people today, including scientists, find that evolution is merely an unreasonable theory, containing many scientific fallacies. Creation, on the other hand, is a scientific theory which does fit all the facts of true science, as well as God's revelation in the Holy Scriptures."

This, however, we must recognize as religious and social discourse and not a scientific statement.

Thus the heart of creation-science's rejection of evolution is not scientifically founded, but is religiously based. Whenever science attempts to respond to questions of ultimate concern or when scientists introduce their humanistic views as science, then it is that science takes on the aspect of religion. Morris's statement on evolution is such an approach.

Besides rejecting evolutionary theories, creation-science repudiates all geochronological investigations and resulting models for an ancient age for the earth. For about the past 25 years geologists have agreed that the earth is approximately 4.6 billion years old.

Problems for society from creation-science

There are several problems with creation-science that are important for us scientists and society at-large to understand. There are also some fundamental distinctions that will permit us to differentiate science as religion from science as inquiry into observable data, distinctions that are important for an understanding that there is no conflict between science and religion at either the theoretical or practical level.

The creation-science position holds that creation-science and evolutionary science represent the only two views of origins. We know, however, that worldwide there are many such views, e.g. in India, Japan, China.

Moreover creation-science is in error because it equates science with the facts rather than with the theories that explain the facts, and overlooks those rules of science that specify what sorts of theories are science and what sorts are not. As a result, it fails to understand that scientific explanations have certain intrinsic limits that differentiate them from religious theories or explanations. Consequently, it mistakenly regards its own religious concepts and theories as alternatives or rivals to scientific ones. It appears to hold that religious belief and scientific theory, insofar as each can be understood to be true, represent precisely the same sort of "truth" (2).

The other side of the coin, however, is that many scientists and engineers lack a knowledge the history of their own discipline, let alone of science generally, and have little formal understanding of the philosophy of science or the philosophy of religion. As a result, it is a short step to the belief that scientific knowledge represents all of knowledge and that religion is merely an anachronism left over from a primitive pre-scientific age. It seems that creation-science is a modern aberration that could only have developed in a culture in which science and technology is the only established, cherished and secure knowledge. Creation-science has tried to join the scientific establishment by proclaiming that their religious knowledge is scientific. Moreover, they derive their scientific information and theories from their one religious source, the Bible.

Thus, while I claim that there is no inherent conflict between science and religion, that claim is based on the premise that both science and religion recognize their limits. While they may interact, their methodologies and the object of their methods are different. One of the benefits of having both a liberal arts and a science component of undergraduate education is an understanding of the nature of both science and religion. This kind of understanding is most conveniently garnered from courses in the philosophy of science and the philosophy of religion. Unless such distinctions can be generally made by the public-at-large, creation-science will continue to grow. It is a phenomenon that can flourish only in a dominantly scientific culture. I believe that creation-science ultimately has the potential to cripple even topple the scientific establishment if left unchecked.

References

1. H. M. Morris, *The Biblical Basis for Modern Science* (Baker Book House, Grand Rapids, Michigan, 1984).
2. L. Gilkey, *Creationism On Trial: Evolution and God at Little Rock*, (Winston Press, Minneapolis, Minnesota, 1985).
3. J. W. Skehan, S.J., *Modern Science and the Book of Genesis*, (National Science Teachers Association, Washington, D.C., 1986).
4. N. D. Newell, *Creation and Evolution: Myth or Reality?*, (Praeger Scientific, New York, 1985).
5. H. M. Morris, *The Remarkable Birth of Planet Earth*: (Dimension Books, Bethany Fellowship, Inc., Minneapolis, Minnesota, 1972).

Combating Pseudoscience in the Classroom: Hardball, Softball, and Oddball Approach

Steven Hoffmaster

Pseudoscience's damage

Recent reports have verified what most of us have suspected: the scientific knowledge of the average student is not what we would like it to be. In fact in some cases it seems unlikely that the individual can make the decisions needed in a technically developed democracy.

I don't pretend to know solutions to such a dilemma. What I would like to discuss are some approaches to limiting the damage produced by one aspect of this scientific illiteracy, belief in the many fields of

The author is on the faculty of the Physics Department, Davidson College, Davidson, NC 28036.

pseudoscience. This belief is often reinforced and encouraged by an ignorance of scientific principles and process. If that knowledge exists, it is often so narrow that its connections to the "outside" world are not perceived.

Belief in the paranormal, it has been argued, is relatively harmless. This is often the case. However there are many documented cases of suicide, murder, and just general depravity based on pseudoscientific revelation. Even more perfidious, I feel, is the observation that belief in many pseudosciences encourages an intellectual irresponsibility. The basic belief often boils down to something like, I wish phenomenon A were true, and because it would be nice if it were and I really want it to be, it is true. This is a somewhat more subtle variation of Jiminy Cricket's, "when you wish upon a star." The world just doesn't work this way, particularly the physical world. These beliefs excuse the individual from facing the hard decisions usually found in life. If this irresponsibility is widespread we will all eventually pay for it.

What can teachers do?

What can we do, in an academic setting, to minimize this irrationality? After twenty years of addressing this, let me offer some observations. In that time my attitude toward the pseudosciences has gone from reasonably positive to rather negative and that "paradigm shift" has been reflected in my classroom strategies.

First, I try to address the problem in every introductory class I teach. Obviously there are time and material constraints depending upon the course. But if you want to deal with it, even one lecture devoted to the paranormal can be effective. If there is little free time, clearly the choice of topics covered is critical. However, I believe that the approach taken is even more critical. By that I suggest that attitude and demeanor are key in determining the effectiveness of your effort.

There are three general approaches that one might take. I shall call them the hardball, the softball, and the oddball approach.

Hardball

If the world were a fair and reasoned place the hardball approach would be highly successful: just relay the facts and let the debunking chips fall where they may. Be completely honest. Early in my career I tried this approach and it usually failed miserably (at other times it was just counterproductive). It is viewed by the students as very combative and the instructor is seen as an authoritarian dogmatist. With any reasonably popular paranormal belief, part of the class will believe in it, part will not and the rest either don't know or don't care. The first group, the believers, are seldom going to change because of anything you might say. By coming on strongly, you not only solidify this group's belief but you may take the undecided students and so alienate them that, as a reaction to you, they are more sympathetic to the particular belief. The third group, those who are skeptical, are often embarrassed by this approach.

Softball

The softball approach is the one that I am least comfortable with. It is a teaching technique that seems to have entered the university in the 60's and 70's. It is a result of the "I'm ok, you're ok" school of pop psychology. It lends itself to small group discussions where everyone has tremendous insights to share. Every point of view and belief is to be treated with equal sincerity and respect. Please do not misunderstand. There may be situations where such an approach is productive. It is my contention that this is not one of them. In addition to being time-consuming, this approach treats all phenomena alike: crystal power, extra-sensory perception, and quantum mechanics. Some things are just plain wrong and in a content-oriented field like physics, this ought to be clearly understood. The softball approach tends to give too much legitimacy to the 'crackpot' beliefs by treating them with the sincerity and profundity usually associated with this method.

Oddball

Somewhere in between is the oddball approach. It is a lecture-oriented, light-hearted approach that allows you to treat sheer drive with respect it deserves. They key here is attitude. One tries to avoid the hardball sledgehammer approach while still being intellectually honest.

Typically paranormal topics will be a diversion from the presentation of physical principles and phenomena. Why not treat the material with the levity that it often evokes? By looking at the bizarre and unusual in the paranormal and showing weaknesses, one sets the stage for an impressive comparison to relativity and quantum mechanics later in the course. These latter two subjects are, at first sight, every bit as bizarre as the paranormal. Perhaps physics is not the methodical plodding that it all too often appears to be. This is also a nice place to sneak in something about the scientific method without resorting to the more mind-numbing traditional examples.

Attitude and demeanor are key in determining the effectiveness of your effort.

There are certain tricks (pedagogical techniques, if you prefer) that can help this approach be successful. Look for patterns. Physicists are supposed to be good at that. There are so many different pseudosciences and they seem so tenuously related. Any common factors will drastically cut down the amount of repetition and will help you sort out weaknesses in the material. Typically the pseudosciences give the believer the option of taking the easy way out. For every difficult problem encountered, there is a paranormal cop-out. One of these overriding themes is the something-for-nothing approach found in pyramid power, crystal power, and the more physical aspects of ESP. The conservation of energy principle is quite useful here although it may not be convincing. Frequent use of analogies among the topics will allow students to generalize this analysis to future paranormal revelations.

Often a student is drawn to the paranormal because of some personal occurrence. You have to be extremely careful in analyzing such events. The oddball approach's lighter touch helps. A negative analysis of such events is then seldom taken as a direct personal attack. The seriousness of the other two approaches often leads students to such a conclusion. Along these lines, creationism is a particularly sensitive topic. I do not know it (or evolution) that well and many people believe deeply in it. For these reasons I prefer not to discuss it. By showing the weaknesses in related fields, I hope to give students the ammunition to do some critical analysis on their own. When the time is right, students will have that reserve to draw on. A clearly presented case study allows them to draw valid analogies between these topics and creationism. If it is brought up in class, I will make a few observations and then refer the student to those better able to handle the discussion.

Several analytical themes are useful in dealing with personal anecdotes. The first involves the unreliable nature of human perception and the observation that our minds tend to fill in details so that almost immediately human memory is flawed. Some statistics will be needed in an attempt to demonstrate unusual from chance events. Most people have an amazingly poor perception of coincidence and tend to seriously exaggerate the unlikelihood of a particular event. It has been useful to me to have a couple of examples of each of these when asked about personal experiences (as I always am).

Admitting ignorance

If you deal with the paranormal, you are going to be repeatedly forced to admit ignorance of certain fields. This stuff can be generated at rates orders of magnitude larger than can be analyzed. Often students ask about a topic that you have never heard of and could easily have done without. The analogies here are most useful.

If you have extra time, an assigned outside reading with associated scientific analysis is productive. Students must look at a new situation and use scientific procedures in this appraisal. My most enjoyable efforts in this area are debates. If there is enough class time, I set up a debate with a student on a topic that is clearly nonsense. I argue for the topic's validity while the student is told to argue the debunking side. I always win. The class knows that I do not believe what I am saying. And they know it most likely is trash. This makes them more aware of the techniques used by paranormalists: questionable facts and experiments, faulty reasoning, and factoid prefabrication (often called lying).

There is so much that can be done to analyze the paranormal and it is so complex that no matter what you do, you always come away with mixed feelings. Maybe you should have done more or done it differently. Perhaps you have belabored the wrong issues. Each class is different and a successful mix for one will not be optimum for the next. The oddball approach gives you a bit more flexibility to adapt your approach to the particular class. Of course with this approach you always run the risk of not being taken too seriously. But then we are trying to make links with the real world, aren't we?

Resources

If you are interested in these issues and are just getting started, I might mention a few sources. A quarterly, *The Skeptical Inquirer* (SI) is the publication of the Committee for the Scientific Investigation of Claims of the Paranormal. Two anthologies appearing in the early issues of SI provide concise summaries and analyses of many popular pseudosciences. They are both edited by Kendrick Frazier and published by Prometheus Books, Buffalo, NY. The titles are *Paranormal Borderlands of Science* and *Science Confronts the Paranormal*. The articles found in these anthologies also provide a useful list of sources for further reading. Most recently a Whole Earth Catalog, *The Fringes of Reason*, has been published by Harmony Books and edited by Ted Schultz. It is not as analytic or judgmental as SI. However, it presents a nice overview of many paranormal fields and provides an excellent list of references after each discussion.

There is no reason to limit yourself to the classroom. After a little practice you should be ready to try this approach in the real world. Library societies, local radio and television shows, church groups and many others are interested in the paranormal. There are many varied opportunities for you to publicly risk humiliation and embarrassment. In the process you may actually teach some science and increase the overall rationality of the planet (or at least decrease the irrationality). And it might actually be fun.

NEWS

[You'll notice an over-use of exclamation marks in the news section. They represent calls for *you* to be active in *your* Forum! One of the many things that the world needs now is the active involvement of physicists, as physicists, in societal affairs. So lend a hand! *-Editor*]

Forum Election Results

Tom Moss, our present vice-chair, automatically becomes our new chair. Our new vice-chair is Ruth H. Howes. Our two most recent chairs, Richard Scribner and Barbara Levi, are automatically members of the Forum Executive Committee. Our newly elected members of the Executive Committee are Michael I. Sobel and Alan Sweedler. Henry Barschall was re-elected to a second 2-year term as secretary-treasurer.

Forum Officers for 1990-91

- Chair: Tom Moss
- Vice-chair: Ruth H. Howes
- Secretary-treasurer: Henry Barschall
- Representative to the APS Council from the Forum: David Hafemeister
- Representatives to the Forum from APS Council: Steven Brush, Kurt Gottfried
- Past Chairs: Barbara Levi, Richard Scribner
- Executive Committee: Sam Baldwin, Rustum Roy, Michael I. Sobel, Allan Sweedler, Valerie Thomas
- Newsletter editor (appointed, non-voting): Art Hobson

Call for Nominations!

Help suggest nominees for next year's Szilard and Forum awards, for next year's APS/Forum Fellows and for next year's Forum officers!

Awards

The Szilard Award is given to an individual or group who has applied physics in the public interest, while the Forum Award is given to an individual or group who has promoted the public understanding of the relation of physics to society. The awards will be presented at the Spring 1991 meeting of the APS.

In 1990, Theodore A. Postol of the Massachusetts Institute of Technology received the Szilard Award for his technical analysis of national security issues, especially ballistic missile basing, submarine survivability, effects of nuclear war, and implications of accidental launch protection systems. Richard Wilson of Harvard University received the Forum Award for his research in comparative risk analysis and promotion of public understanding of environmental hazards, especially in the area of reactor safety. *Physics and Society* plans to publish their award lectures, presented at the Spring 1990 meeting of the APS, in its next (October 1990) issue.

Send nominations for these two awards, with supporting material, by 1 September 1990 to Henry Barschall, Department of Physics, University of Wisconsin, 1150 University Avenue, Madison, WI 53706!

Fellows

Among the newly-elected APS Fellows announced in 1990 were six Forum-sponsored candidates: Caroline Littlejohn Herzenberg, Allan R. Hoffman, Henry C. Kelly, Richard A. Meserve, Rustum Roy, and Carl E. Sagan. Each Forum-sponsored Fellow had contributed significantly at the interface of physics and society. For their citations, see *Physics and Society*, April 1990, pp. 14-15, or see *Bulletin of the American Physical Society*, February 1990, p. 87.

Send nominations for new Forum-sponsored APS Fellows, with supporting material, by 1 September 1990 to Richard Scribner, Georgetown School of Foreign Service, Georgetown University, Washington, DC 20057!

Officers

Forum elections will be held in January 1991. We will be electing a vice-chair and three executive committee members. Send your nominations, with supporting material, by 1 September 1990 to Elmer W. Colglazier, Energy and Environment Center, University of Tennessee, 327 S. Stadium Hall, Knoxville, TN 37996!

Forum Councillor's Report

APS will join AIP in its move from New York City to the Washington DC area, in 1992. At its April meeting, the APS Council voted "—APS shall proceed with plans to relocate its headquarters with AIP, and will appoint a Task Force to participate in negotiations with AIP." The bad news is that APS will probably lose many good employees, while the good news is that AIP and APS will stay together, perhaps joining AAPT which is already headquartered near DC in College Park, Maryland. Of course, the Forum issues of science and public policy abound in the DC area, but there will be some chaos over the next few years before all is normal. In a recent *Physics Today* (May 1990, p. 73) article, AIP executive director Kenneth Ford listed several reasons for AIP's move, including the unity of physics (because AIP and probably APS will be close to AAPT and to other physics-related organizations in the DC area, perhaps even co-owning AAPT's present building) and greater involvement in science policy, science funding and science education (because of closeness to the Federal government).

Retiring APS Executive Secretary Bill Havens will be replaced by Dick Werthamer, a former Science Congressional Fellow, in January of 1991. Our thanks to Bill for his help over the years to the Forum!

A new APS Constitution will be up for ratification by APS members this August. Because of the growing size of APS, it is necessary to transfer more of the operational power to the Executive Board. The new APS Council will retain final power, but meet less often, at twice a year. The Divisions will be represented proportionally on the Council, while the Forum (the second largest of the APS Divisions and Fora) will get but one Councillor. The Division of Condensed Matter Physics will have 5 Councillors, some of the Topical Groups will become Divisions, and some of the smaller Divisions will lose their Divisional status.

AAPT will join the APS Spring meeting in April, strengthening the meeting in general, as well as increasing interest in the science and public policy issues.

Studies on nuclear safeguards and on global warming are being considered by the APS Panel on Public Affairs.

David Hafemeister
Representative to the APS Council from the Forum

APS Education Committee

Many members of the Forum have strong interests in improving physics education at all levels, so we summarize here some of the activities of the APS Education Committee. We are sure that the Education Committee would welcome the support of Forum members in many of the projects they undertake! Here is a sampling:

Physics Alliances — A Program for School-College Collaboration. Under a two-year grant from NSF, APS, with the cooperation of AAPT, has stimulated the formation of about 40 local physics alliances of elementary, high school and college teachers. The main vehicle for promoting the alliances has been one-and-a-half day workshops at which teachers learn about forming alliances. The luncheon speaker is a prominent physicist, and the dinner features a program on classroom demonstrations. APS has run 4 workshops — in NC, IN, OK and one using a satellite to link sites in WA, UT, ID and OR. The APS Education Office provides some modest start-up funds and administrative support to new alliances. APS has just requested a continuation grant from NSF to operate at least six more workshops, including at least one in an urban area.

College-High School Interaction Committee (CHIC). This APS/AAPT joint program provides additional support to increase communication among teachers of physics at all levels. The program publishes a regular newsletter.

Physics Olympiad. Among the many activities sponsored by APS is the Physics Olympiad — an international physics competition. They hope that the US will be the site for the 1993 event, in which case, APS will need lots of support from the US physics community.

AIP Programs. The most visible AIP program just now is probably the Introductory University Physics Project (IUPP), an evaluation of the curriculum of the first-year course. Another is a program aimed at the grade school level called Science Education for Equity Reform (SEER). It is attempting to eliminate any possible bias in the presentation of science to girls and minority students. AIP also sponsors Operation Physics, which is similar to the alliance program but aimed at 4-8 grade teachers. They are also collaborating with the American Chemical Society in publishing a monthly science magazine for grade school.

Subcommittee on Academic Recognition. The APS Education Committee formed a subcommittee to explore the academic recognition given to faculty for extraordinary efforts in education. The subcommittee has prepared a report that was to be presented to the APS Council and that included several recommendations.

Planning Grant for Undergraduate Curriculum Development. APS received an NSF grant to stimulate involvement of active physics researchers in the improvement of the undergraduate physics curriculum. The first workshop was scheduled for June in Santa Fe.

Industrial Summer Intern Program. The APS Education Office helps match student applicants with summer jobs at about 30 industries.

Education Fund of the Laser Science Topical Group. This subdivision of APS formed an educational fund for such proposed activities as travel support for students, summer research appointments for undergraduates or annual visiting lectureships. Perhaps your own subdivision can find the resources to follow suit?!

Science Fairs. The Education Committee is considering the sponsorship of certificates at regional science fairs and participation in the international science fair.

If you have ideas about how the Forum itself might become more directly involved in education, let us hear from you!

Barbara G. Levi

Organize a Forum Session!

Forum invited sessions at APS meetings are an important means of communication to the physics community and the public about physics-related societal topics. Their impact is made broader and more permanent by publication of most Forum sessions in *Physics and Society*. Send your suggestions for future invited session topics and speakers to Ruth H. Howes, Department of Physics, Ball State University, Muncie, IN 47306! Better yet, volunteer (again by contacting Ruth Howes, and discussing it with her) to organize a Forum session!

Physics and Nuclear Arms Today

A collection of articles that appeared in *Physics Today* from 1976 to 1989, *Physics and Nuclear Arms Today* explores a variety of issues including the history of nuclear weapons, nuclear weapons effects, testing, offensive strategic weapons, defensive weapons, nuclear nonproliferation, and the social responsibility of scientists. Contributors include Andrei Sakharov, Sidney Drell, Wolfgang Panofsky, Edward Teller, Frank von Hippel, Victor Weisskopf, and Freeman Dyson. The 350 page book is edited by David Hafemeister, and was published this year by the American Institute of Physics. For APS members, the price is $28 for hardcover and $20 for paperback.

Help Increase Forum Membership!

Only about 10% (about 4000) of all APS members (about 40,000) belong to the Forum. Although the Forum has the second largest membership (behind condensed matter at 6300) of all APS groups, this is not nearly enough for a group whose interests and potential impact are as broad as the Forum's.

Surely, in these days of global environmental change, technological and scientific change, nuclear weapons peril and hope, science educational failures and opportunities, tough energy decisions, etc. etc., every physicist should take at least some active interest in physics-related societal topics. So it is not too much to expect that Forum membership should be 50% of the total APS membership, i.e. several times the present 4000—especially since Forum membership is free to APS members.

You can help! Here are a few ways:

- Add "Forum" on your APS membership renewal form, if it is not already listed!
- Enlist colleagues on your campus or in your organization as new Forum members! About joining, see below.
- Ask your library to subscribe to *Physics and Society* (it's free to libraries) and to archive it! See below.
- Distribute copies of *Physics and Society* to your colleagues! Write to the editor (address on p. 2) and request enough copies of the next quarterly issue to pass out to each person in your department or organization. Before distributing, insert a personal note from you to your colleagues.
- Distribute *Physics and Society* at meetings! Attach a note indicating how to join the Forum, emphasizing that it's free to APS members. Write to the editor and request enough copies to pass out at any physics meeting you attend. Remember to ask for copies far in advance of the meeting, so that the editor can put in a request to AIP to print extra copies of the next quarterly issue.

To Receive *Physics and Society!*

Physics and Society, the quarterly of the Forum on Physics and Society, a division of the American Physical Society, is distributed to members of the Forum and to physics libraries. Nonmembers may receive the newsletter upon request by writing to the editor; voluntary contributions of $10 per year are most welcome. Make checks payable to the APS/Forum.

Physics libraries may receive *Physics and Society* free upon request by writing to the editor. The Forum hopes that libraries receiving *Physics and Society* will archive it. Forum members should request that their libraries do this.

If you are an APS member it is easy to join the Forum and receive *Physics and Society.* Just complete and mail (either to the editor or directly to the APS office) the following form, or mail us a letter containing this information.

I am an APS member who wishes to join the Forum:

NAME (print) ______________________________

ADDRESS ______________________________

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COMMENT

Responsibility in the Sci/Tech Age

During public lectures, I often ask the audience to name the most pressing world problems. Typical items are nuclear war, overpopulation, drugs, environmental pollution, rain forest destruction, species loss, the greenhouse effect, the destruction of the oceans, and the energy problem. Science and society matters, at least to these audiences.

Physicists, when asked to name American science's most pressing problems, are likely to list weak science education, non-existent physics education, science illiteracy, lack of financial support, mistrust of science, and the decline of American science and technology. Many recent studies support these views (1).

The public and the scientific problems are synergistically related: we will either seriously attack and begin to solve both, or we will solve neither. Today, despite a lot of talk, we haven't gotten started on either, because on the one hand the public is isolated from any real knowledge of science, and on the other hand scientists are isolated from real involvement in the social implications of science.

The public

The public's intellectual development seems to have gotten stuck somewhere prior to Copernicus. Parents and PTAs put up with grade school teachers who don't know that the sun is a star. Sorority girls pride themselves on their innumeracy. Fraternity boys sign on to easy money in business rather than hard knowledge in science or engineering. Cadres of fundamentalist crusaders battle to inflict creationism on our children. American women bemoan sexual inequality while teaching their daughters that it is OK to be ignorant of machines, OK to opt out of science and math courses.

The scientists

And what of ourselves, the scientists? We pride ourselves on our own awareness and indulge in fine hallway conversation about the greenhouse effect. But how do we spend our serious, working, hours? Do we teach science and its implications to the general public? We fault our children's unknowledgeable grade school teacher, but do we take the time ourselves to teach the teachers? We fault animal rightists for mistrusting science, but do very many of us spend professional time thinking about the greenhouse effect or nuclear weapons?

What do most of us do? Well, most research physicists do military R&D (2), and 25-30 percent of all our scientists and engineers do military work (3). Most other physicists work in universities, but how many do any serious teaching or research on physics-related social problems? Do we devote even a lecture to the greenhouse effect or nuclear war? Do we bother to teach relevant science to the great majority of students who are non-scientists? Do most university physicists teach anything outside of specialized courses for physics majors? In our haste to discover new science, how much time do we devote to teaching of any sort? Do we put professional effort into studying potential social effects as we dash to the presses with our latest breakthrough?

We're not paying our dues

The solutions will not come until we, both the general public and the scientists, turn our pointing fingers around, toward ourselves. We needn't exactly put on hair shirts, but problems mount rapidly in these fast times and we need some perspective on where we're at and where we're going.

The problem lying behind the greenhouse effect, science illiteracy, and all the rest, is that we are not paying our dues in the twentieth century. Public and scientists alike pant for the next high-tech gadget, the next research project. We accept and exploit the possibilities of the sci/tech age, but we do not accept responsibility for it. We Americans are happy, even thrilled, to drive two tons of overpowered machinery across miles of concrete every day, but regard it as an affront to our technology-given freedom to pay attention to the social costs or to require a less toxic product. We scientists delight in new research, scramble after financial support for the next breakthrough, but spend precious little professional time thinking about the consequences of all this research, precious little time communicating its meaning.

Some remedies

Education is the most important remedy. A few suggestions:

- Require laboratory science and math every year for every student, grades K through 12.
- Teach socially relevant qualitative physics to every tenth grade student, plus a more technical 12th grade physics course for scientists and engineers.
- Devote much more university attention to teaching nonscientists, especially teachers. Public school teachers need socially relevant courses in physics, chemistry, astronomy, geology, and biology; science teachers should follow these with more advanced technical courses.
- Universities, especially the large research universities, need to bring their focus back to undergraduate education. First priority should be the non-scientist majority, especially the teachers.

On both the public and the scientific sides of these problems, we are not today accepting responsibility for our actions. As long as this remains so, we can expect further unfortunate consequences.

References

1. Several such studies are reviewed in *National Science Teachers Association Report*, May/June 1989, pp. 7, 18, 19. Also see M. Neuschatz, *Physics Today*, August 1989, pp. 30-36.
2. E. L. Woollett, *Am. J. Phys.* **48**, Feb 1980, pp. 104-111.
3. J. P. Holdren and F. B. Green, *FAS Public Interest Report*, Sept 1986, p. 7.

Art Hobson