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LETTERS

Tagging Technologies

Ruth H. Howes ("Tagging Technologies and Reduction of Conventional Forces in Europe," January 1990) gives needed exposure to the important question of tags and seals. But she does herself and the field a disservice by concluding, "It seems unlikely that either side would agree to electronic tags that could be monitored by satellites since these tags might conceivably provide targeting data or enough information on deployment to be militarily useful."

I have carefully explained (1) that monitoring electronic tags by satellite can give important verification that the treaty-limited item (TLI) is where it is claimed to be, within tens of meters. Yet for reasons both of cost and to prevent the use of this verification system as a targeting aid, such interrogation would be physically possible only with the cooperation of the operator of the TLI. The tag on the TLI would communicate not by radio but by infrared (like the remote control on your TV) to a relay box maintained by the host country. The protocol in the arms control agreement would provide for the host country, on request, to move such a box to within a few meters of the tag on the TLI, and to provide power to the relay so that the relay box itself could communicate by radio with the monitoring satellite, as well as (by infrared) with the tag on the TLI.

It is thus physically impossible for the electronic tag to provide any information about the TLI except with the explicit consent and cooperation of the operator of the TLI.

At least one well-known advocate of non-electronic tags continues to make statements like the one quoted above, although he readily concedes that electronic tags would normally be designed and used in such a way that there would be absolute protection against obtaining information other than that voluntarily revealed. He argues, however, that there is "a perception" that tags would provide targeting information — reminding me of the young man whom I threw himself on the mercy of the court as an orphan, having been convicted of murdering his father and mother.

1. R.L. Garwin, "Tags and Seals for Verification," *Bulletin of The Council for Arms Control*, October 1988 (London).

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Response:

Since the enormous political changes in eastern Europe continue to propel us toward a CFE agreement, verification issues must be debated now. I am grateful to Richard Garwin and *Physics and Society* for encouraging this debate.

Garwin correctly points out that it is possible to devise electronic tags with read-out systems that prevent them from providing information that could be used for targeting. On the other hand,

the systems used during the read-out and the electronic tags themselves are technologically fairly complex. While such devices might work well for mobile strategic nuclear weapons systems, where a few hundred weapons manned by elite troops are fielded under carefully monitored conditions usually in a limited geographic area, a CFE Treaty would involve tens of thousands of weapons deployed over an enormous geographic area and manned by all types of troops who are often less than careful in handling their weapons.

Even if the electronic tags themselves can be made rugged enough to survive field deployment, including not only the hazards of weather and rugged terrain but also the harsh chemicals used to decontaminate equipment during training with chemical weapons, supplying portable reading devices to remote posts in all weather conditions may prove difficult. In order to obtain a reading for verification, each treaty party is dependent on the technological skill of a nation being inspected and manning the reader. Each nation must provide its own satellite receiver or rely on that of its allies. Particularly in view of the recent rapid political changes in Europe, it seems unlikely to me that participants in a treaty likely to involve 23 nations would agree to such a complex and potentially expensive scenario.

Life-cycle costs of a complete satellite system consisting of 2-3 satellites with one or two ground stations and operating costs and expenses would be \$150 to \$200 million annually (1). Data on detailed costs vary widely, but this number can be compared to the \$50 million annual budget of the On-Site Inspection Agency which verifies the INF Treaty. Included in the budget are expenses for training, equipping and fielding inspection teams, support personnel, escorts for Soviet inspectors on U.S. territory and the cost of stationing personnel at the permanent monitoring station at Votkinsk. Rule of thumb costs are \$60,000 to field a ten person inspection team for two weeks in the field and \$0.5 million annually per inspector stationed at a permanent monitoring station or Soviet territory.

These rough budget numbers and consideration of field conditions for verifying limitations on conventional weapons demonstrate the advantages of keeping verification technology as simple as possible. Tags like intrinsic surface fingerprints can be applied by troops in the field, will require a minimum number of on-site inspections and promise the durability needed for a long-term treaty regime. Verification technology should be subject to the KISS rule used in planning military operations: Keep It Simple Stupid.

1. Hans Günter Brauch, editor, *Verification and Arms Control Implications for European Security: The Results of the Sixth International AFES-PRESS Conference, Part 1*, p. 42 (AFES-PRESS, Mossbach, 1990).

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ARTICLES

Forum Award Lecture: Comparing Risks—A Hazardous Undertaking

Richard Wilson

[Editor's note: Richard Wilson is winner of the 1990 Forum Award for promoting public understanding of the relation of physics to society. His citation is given in the April 1990 issue. The following paper is based on his lecture at the Forum Awards session held 16 April 1990 at the Washington DC APS meeting. He is Mallinckrodt Professor of Physics at the Department of Physics and the Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138. For the award banquet, Barbara Levi, past Forum Chair and our resident poet, wrote a limerick "About Richard Wilson and Risk Assessment":

In pollution the world seems to wallow.
Dick gives us a guide we can follow.
What risk, do you think,
In water we drink?
For some, it is too much to swallow.]

Understanding problems of the environment, and particularly those associated with energy consumption, involves an understanding of numerical magnitudes. Physical scientists, physicists and chemists, develop this understanding automatically as a result of their work. Many people, including many scientists in the biological and medical fields, do not.

My involvement with explaining the risks and dangers of life to people began about earth day 20 years ago when I was asked some questions by undergraduate students. They were eager to get my help in understanding the problems of nuclear energy, and thought that I as a nuclear physicist was an ideal man to help them. It did not take long for me to realize that the problems, and even the issues of nuclear energy are very little to do with nuclear physics: the problems are of engineering, and of perception.

*These studies confirmed what
the industry had badly presented:
that nuclear power produces
fewer fatalities than most other
electricity generating schemes.*

Nevertheless, they are amenable to calculation and analysis.

For me a nuclear reactor had been a source of neutrons and isotopes for experiments. I had to learn about the nuclear power industry from scratch. I was, and still am, disappointed with their advertising. The public, and the technology, deserve better.

In 1970, the claim that no one in the public had been killed as a result of radiation from a licensed nuclear facility worried me. It would be incorrect if cancers produced by low levels of radiation were included according to a linear dose response relation. It was not relevant for comparison purposes, because much less electricity had been generated from nuclear power than from other sources of energy. I therefore produced, in a letter to *Physics Today*, my own table of deaths including those calculated but not directly observed, from producing electricity from all sources, divided by the amount of electricity produced (Table 1). Thus one can find a more relevant measure — deaths per kilowatt hour. I was helped in this undertaking by the fact

that I was born and brought up in London and every November we had the notorious London fogs which not only affected visibility, and had obvious effects on those with respiratory ailments, but also in many ways made life less pleasant.

Table 1. Deaths per kilowatt hour in USA
(based on 1965 figures)*

Coal mining	
black lung disease	10^9
accidents	6×10^{-11}
Petroleum refining	
oil-well accidents	7×10^{-12}
Uranium mining cancers	
no breeder	1.5×10^{-11}
breeder	7×10^{-14}
Uranium processing, fuel fabrication,	
accidents (estimate)	
no breeder	2×10^{-11}
breeder	2×10^{-13}
Coal/gas/oil air-pollution deaths	3×10^{-9}
Radiation cancers, normal operation	
(0.1 mr/yr at year 2000) of reactors	
and processing plants	3×10^{-13}
Potential reactor accidents (1 per 30 years of	
WASH 740 severity by year 2000)	
direct deaths	3×10^{-11}
possible extra cancer deaths	3×10^{-11}
Gas main explosions:	3×10^{-12}
Gas poisoning:	6×10^{-12}
Dam failures (1 per 50 years as in	
Vaiont, Italy):	6×10^{-10}

*Reprinted from *Physics Today*, Vol. 25, p. 73 (1972).

Not everyone liked this comparison. According to one of my spies, the President of Boston Edison company told a staff meeting that I was "an intervenor type" and a pain in the neck! Presumably because I referred at that time to "the conspiracy to whitewash coal" in which the Sierra Club have for the last 15 years supported the burning of coal by the utility industry. I wish that he had put his complaint in writing. I would use it as a letter of recommendation.

This crude risk comparison stimulated others, in particular Dr. Leonard Hamilton of Brookhaven National Laboratory, who is a physician, also born in England, and unusual in that he has a clear understanding of quantitative magnitudes. These studies, done for the DOE, and other similar studies in France, UK, and Italy, confirmed what the industry had badly presented: that nuclear power produces fewer fatalities than most other electricity generating schemes.

Such studies led naturally to wondering why this point seems so hard for most members of the public to believe, understand and accept. One reason, most analysts surmise, is that when something goes wrong with nuclear energy many people are affected by one accident, as for example in the Ukraine after Chernobyl. But that is not the whole reason. Hundreds of people

have died in single aircraft accidents, as for example in the Azores where two loaded passenger jets collided on the ground. No one has even suggested banning airplane travel. Hundreds of people have been killed in single failures of hydroelectric dams; yet I have heard no clarion call for emptying all reservoirs. Therefore a simple comparison of risks, even if weighted by the number of people involved in a single accident, while instructive, does not enable us to decide on public acceptance.

In 1976 I added chemical risks to my repertoire. This was in response to a request of a former Harvard student working as VP of Air Products. In 1977 Donald Kennedy, then administrator of FDA and now President of Stanford, got into trouble by proposing to ban saccharin. Table 2 shows the risks of a number of chemical additives before him at that time.

Table 2. Food and drug administration issues of 1977:
Cancers/yr (my calculation)

Aflatoxin B1	3000
Saccharin	500
2,4,DAA (hair dye coupler)	
drunk	6
on hair (before measure)	1/30
on hair (in 1988)	1/1000
Vinyl Chloride plastic bottles	less than 1/100
Lead Acetate	1/100

Of these, the Environmental Defense Fund was concerned about hairdyes; both the 2,4,DAA (Clairol Hairdye coupler), and Combe, Inc's lead acetate (Grecian formula). The table shows that these give smaller calculated effects on health than saccharin. How could a good scientist even listen to EDF if he did not propose to ban saccharin?

My comparison of risks seems to have convinced some people that I was in the pay of a wicked nuclear power industry. I received several anonymous letters enclosing articles by some of the more virulent, and less quantitative opponents of nuclear power. Yet at that time I had even insisted on paying for my own coffee from the cafeteria at a power station. Although troubling, those letters and phone calls convinced me that someone was listening to and reading what I said, a conviction that I have not always had in high energy physics. So I continued.

About this time also I wrote an article, "The Daily Risks of Life," explaining how we take risks every moment of our lives, and how we might, if we so chose, express our decisions quantitatively. Of course we do not usually so choose! It took me a year to get this article published. No one wanted it. The Harvard Business Review thought that I was playing a joke on them. But Technology Review, of MIT, accepted it. Within two weeks the dam had burst. It was reprinted in the Chicago Tribune, Honolulu Advertiser, Miami Gazette, and the San Francisco Chronicle. The article included a table of risks (Table 3) which included a risk of drinking water.

When a reader asked the chief engineer of the Miami water supply what he thought of my number (calculated for the risk of chloroform in the drinking water) of the risks of drinking Miami water, he replied that the risk is small compared to the risk to Professor Wilson if he ever gets his hands on me! Regretfully, I have never met him, although if I did I would watch his hands as closely as someone in a western movie watches the hands of a gunfighter in a saloon.

Table 3. Risks which increase the chance of death by 0.000001*

Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 ltr of wine	Cirrhosis of the liver
Spending 1 hr in a coal mine	Black lung disease
Spending 3 hr in a coal mine	Accident
Living 2 days in New York or Boston	Air pollution
Traveling 6 min by canoe	Accident
Traveling 10 mi by bicycle	Accident
Traveling 30 mi by car	Accident
Flying 1000 mi by jet	Accident
Flying 6000 mi by jet	Cancer from cosmic rad
Living 2 mos in Denver	Cancer from cosmic rad
Living 2 mos in stone or brick bldg	Cancer from nat rad
Chest x-ray taken in a good hospital	Cancer from rad
Living 2 mos with a cigarette smoker	Cancer and heart disease
Eating 40 tblspns peanut butter	Liver cancer from aflatoxin B
Drinking Miami drinking water for 1 yr	Cancer from chloroform
Drinking 30 12 oz. cans diet soda	Cancer from saccharin
Living 5 yrs at site boundary of nucl power plant in the open	Cancer from rad
Drinking 1000 24 oz. soft drinks from recently banned plastic bottles	Cancer from acrylonitrile monomer
Living 20 yrs near PVC plant	Cancer from vinyl chloride
Living 150 yrs within 20 miles of nuclear power plant	Cancer from rad
Eating 100 charcoal broiled steaks	Cancer from benzopyrene
Risk of accident by living 5 miles of nuclear reactor for 50 yrs	Cancer from rad

*1 part in 1 million

A San Francisco Chronicle reporter was told to interview me about the article by phone. He tracked me down in a Leningrad hotel. I had to explain the whole list of risks. When I got to Aflatoxin B1 in peanut butter the phone went dead. Presumably the person who was listening in on our conversation thought that we were talking in code!

A whole industry of "risk communication" has grown up over the last 10 years to discuss this question of public acceptance. While I agree with much that they say, I reject the idea that public perception of a risk is more important than the actual magnitude of the risk. The public is diverse; the perceptions can change rapidly, both in space and in time in the same way that the political background of eastern Europe has changed in the last 12 months. The risk itself stays the same. Of course we do not know the risk itself; all we know is the perception of that risk by an expert. When we state it this way, a part of the problem becomes apparent. There is an anti-scientific feeling around, as Gerald Holton discusses elsewhere in this meeting. Some people reject experts; and what they say.

I have been repeatedly misquoted by risk communication experts: by Ellen Silberoeld, by Paul Slovic, by Barry Fischeff and by Vincent Covello. Each of these has claimed that I say that everyone ought to make their decisions based solely on the magnitude of the risks. I have never said that; and I do not believe it. What I have said is that a comparison can be a useful part of the decision process. It can also help in understanding. A

comparison can stimulate a person to come forward and say what concerns them. Sometimes that has been disconcerting.

I did not realize it at first, but now I am sure that there are a large number of people who do not want the public to know the truth, or at least believe that they would not understand it. They are not all industry leaders. Some are labor leaders, politicians, or environmentalists. Some are in the EPA. I have had a 10 year argument with the EPA about drinking water. We have to chlorinate our water to get rid of bacteria, otherwise we would have the same high typhoid rate as we had in the last century. The chlorine interacts with any organic matter to produce chloroform. Chloroform produces liver tumors in mice and kidney tumors in rats.

We use a lot of chlorinated solvents in domestic and industrial applications. One of them, trichloroethylene (TCE), produces liver tumors in mice. In Table 4 I show that chloroform is clearly worse than trichloroethylene. We do not have to calculate the full risk to show this, but I merely note that it takes 20 times as much weight of trichloroethylene to produce liver tumors in mice as it does chloroform. Surely therefore, chloroform is more closely regulated than trichloroethylene? No. 20 times more chloroform is allowed (by EPA standards) in drinking water, for a total difference in risk level at the standard of 400 (based on a linear dose response relationship).

Table 4. Risks of chloroform and trichloroethylene

	Chloroform	Trichloroethylene
Toxicity LD50 (mg/kg)	500	5000
Carcinogenic potency (mg/kg day)		
Rat	2.5×10^{-3} (kidney)	Not significant
Mouse	1.1×10^{-2} (liver)	7.3×10^{-4}
EPA Limit	100	5

Possible reasons are obvious. We can reduce TCE if we wish and it is the wicked industry that has to bear the cost. It is much harder to have a viable, pure water supply without chlorination. These reasons are honorable; but the EPA has been reluctant to admit them. Worse still, public health officials do not know the facts, and following only what they hear from EPA give inappropriate advice to people. There are at least three documented cases where a person has been consuming well water at twice the EPA standard and has been advised to switch to treated city water with chloroform at 1/2 the EPA standard. Stated this way, the advice sounds good. But when risks are compared we see that they were being advised to increase their risk 100 fold.

We can make a similar comparison of aflatoxin in peanut butter and accidental contamination of soil by 2,3,7,8 dibenzo-o-dioxin (or just dioxin). The two chemicals give similar numbers of tumors in rats and mice at similar absolute levels. Aflatoxin

is a mutagen whereas TCDD is not. Yet the FDA only regulate dioxin in peanut butter above 20 ppb, and the center for disease control calls 1 ppb in soil "a source of concern."

These studies are simple, but time consuming. when explaining things to the press one has to know ones' facts, however trivial. That means work. They are also expensive. I counted over 130 cases where some newsman called me soon after Chernobyl. They wanted to know all of physics in an hour: all of nuclear engineering in another 1/2 hour, and all of medicine in 15 minutes more. In many cases I had to return phone calls from airports while changing planes. I calculated that I spent over \$500 of my own money in so doing.

I talked to one agitated lady from Ohio. "My daughter is going to Europe for a vacation. Should she fly through that radiative cloud?" Comparisons are here of limited help. Of course you get a higher radiation exposure by flying at 30,000 feet, and Table 1 suggests that aircrews have a high occupational exposure. Moreover detailed calculation shows that, as a group, they are the highest exposed of any radiation workers (although they are not so classified). But that is not calming.

Nor do people understand the inverse square law. "The only plane that I do not want to be on is the helicopter hovering over the plant and dropping lead and sand," I said, with no effect.

"You must understand that I am talking as a mother" she persisted.

"You are not unique: there are roughly a billion of you," I replied!

Some people like what I say. I have had thanks from several secretaries of DOE. But such thanks merely get me on another unpaid hard-working advisory committee. The thanks do not affect staff further down. When I ask for my research funds in high energy physics I have been told more than once that I do not need them; I am spreading myself too thin by my work on risks. Fortunately in the last few years, it is not always that way. I have found that lawyers pay for the advice you give them, and a lawyers' rate of pay is higher than that of most physicists.

Over the last 10 years I have had the excellent help in much of this work from several collaborators. I want to particularly single out Dr. E. A. C. Crouch and Dr. Lauren Zeise. They have helped me to sharpen my understanding and ensure that the risk assessments stand up to scrutiny. This award is partially owed to them and many other collaborators. I give them my thanks.

I will now come to the worst hazard of comparing risks: boring ones friends and family. All scientists get consumed by what they are doing, and get particularly concerned by politicians and others who seem to delight in ignoring the truth. I tend to talk about it at all moments. My wife has borne all this with her usual patience for 20 years. She is after all, the daughter of a physicist and her sister married a physicist. I see her in the audience. Therefore at this time I will stop and I will bore her and you, no longer. I thank you and the APS for paying attention.

Israeli Ballistic Missile Capabilities

Steve Fetter

[This article appeared in the July 1990 issue. Unfortunately, a computer mistake rendered many in-text mathematical symbols unrecognizable. I apologize. Herein, we try again! —*Editor*]

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.

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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

$$v_c = \left[GM_e \left(\frac{2}{R_e} - \frac{1}{a} \right) \right]^{1/2} \quad (1)$$

where G is the gravitational constant ($6.67 \times 10^{-20} \text{ km}^3 \text{ s}^{-2} \text{ kg}^{-1}$), M_e is the mass of the earth ($5.98 \times 10^{24} \text{ kg}$), and 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 $v_c = 8.30 \text{ km/s}$ 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 (δv_r) and an amount to compensate for the effects of air resistance and gravity on the rocket during launch (δv_a):

$$v_b = v_c + \delta v_r + \delta v_a \quad (2)$$

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

where Φ is the latitude, Ω 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 δv or increase in missile velocity, the total mass of the rocket would be given (3) by

$$M_r = m_s \{ 1 - f [1 - \exp(-v_e/3v_s)] \}^{-3} \quad (4)$$

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

$$m_b = M_r \{ 1 - f [1 - \exp(-v/3v_e)] \}^3 \quad (5)$$

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

$$\alpha = \left\{ \frac{1 - f [1 - \exp(-v/3v_e)]}{1 - f [1 - \exp(-v_b/3v_e)]} \right\}^3 \quad (6)$$

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

$$v = \left[\frac{GM_e R_e (1 - \cos \phi)}{(R_e + h)^2 \sin^2 \Theta - R_e (R_e + h) \sin(\Theta - \phi) \sin \Theta} \right]^{1/2} + \delta v_a \quad (7)$$

where h is the burnout altitude (assumed to be 250 km, the

perigee of the satellite orbit) and $\phi = \pi/R_e$. The maximum range (i.e., minimum-energy trajectory) is given by $\Theta = (\phi + \pi)/4$.

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

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

where σ_α , σ_f , σ_{v_e} , and $\sigma_{\delta v_a}$ are the uncertainties in α , f , v_e , and δv_a . I assumed that $\sigma_f = 0.02$, $\sigma_{v_e} = 0.2 \text{ km/s}$, and $\sigma_{\delta v_a} = 0.2 \text{ km/s}$.

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.

Ballistic Missile Payload Mass
Satellite Payload Mass

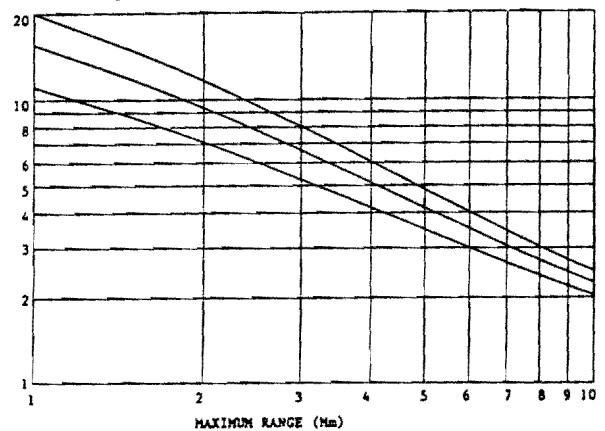


Fig. 1. The ratio of the payload mass if the rocket is used as a ballistic missile to the satellite payload mass as a function of the maximum range of the ballistic missile. The upper and lower graphs represent uncertainties around the central graph.

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 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

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

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 50 kg. An Israeli nuclear ballistic missile payload, including the warhead, reentry vehicle, guidance system, and arming and fusing mechanisms, might weigh less than 400 kg ($\alpha=2$), and certainly no more than 800 kg ($\alpha=4$).

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, $(m/M_s) \approx \exp(-fv_s/v_e)$.
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: Health Effects of Nonionizing Radiation

The Forum sponsored a session on the health effects of nonionizing radiation at the April 1990 APS meeting in Washington, DC. Out of the four papers presented at that session, I have received two manuscripts, reprinted here. The second of these, by M. Granger Morgan, was in the form of the transparencies used to outline the talk; I believe that readers will find this outline useful. The other two papers were "Substrates of Electromagnetic Field Interactions in Biomolecular Systems," by W. Ross Adey, Veterans Administration Medical Center, and "Nonionizing Electromagnetic Radiation Activities and Issues," by Joe A. Elder, US Environmental Protection Agency.

Desiring a well-rounded view of this controversial topic, I contacted Robert K. Adair of Yale University to help provide balance to what I assumed would be a presentation of the four symposium papers. Adair agreed, and I informed the four symposium participants about the addition of this paper. Adey then declined to have his paper appear alongside Adair's. Thus, Adair's paper is printed here without the "other view" that Adey's paper might have provided. A controversial topic, indeed! I invite responses.

Editor

Interaction of Extremely-Low-Frequency Electric and Magnetic Fields with Humans

T.S. Tenforde

The interaction with living systems of electromagnetic fields in the extremely-low-frequency (ELF) range below 300 Hz will be summarized briefly in this paper. In materials with the electrical and magnetic properties of living tissues, a 60-Hz field has a long wavelength (~5000 m) and skin depth (~150 m). As a consequence, in their interactions with humans and other living organisms ELF fields behave as though they are composed of independent electric and magnetic field components. This "uncoupling" of the orthogonal electric and magnetic components of an ELF field is commonly referred to as the "quasi-static approximation," which permits the radiating properties of the field to be neglected in describing its interaction with living organisms.

The electric and magnetic components of an ELF field have several distinctly different features in their interactions with humans and other living organisms (1). First, the electrical conductivity of tissue is approximately 14 to 15 orders of magnitude greater than that of air at ELF frequencies. Consequently, the body behaves like a good electrical conductor in ELF electric fields (Figure 1A). As a result, an electrical charge is developed on the surface of a living object in an external ELF field, and the electric field penetrates into the body only to a very limited extent ($E_{in} \leq 10^{-7} E_{out}$). The significant conductivity of the body

relative to air also has the important consequence that the local field in air near regions of the body with small radii of curvature (e.g., the head or the fingertips) is larger by more than an order of magnitude than the external field at a distance of several meters from the body. This phenomenon is referred to as the "field enhancement effect," and it greatly complicates the dosimetry of ELF electric fields in the proximity of the body.

In contrast, the magnetic component of an ELF field does not induce a surface charge and it penetrates the body without significant attenuation since the magnetic permeability of tissue is nearly identical to that of air (Figure 1B). As a consequence, the dosimetry of ELF magnetic fields in and near a living organism is relatively simple in comparison to the dosimetry of ELF electric fields. Another feature of ELF electric and magnetic fields that differs is the pathway of induced currents within the body. Induced electric currents in tissue flow predominantly in the direction of an external ELF electric field, whereas the electric currents induced in tissue by an external ELF magnetic field circulate in planes that are orthogonal to the direction of the applied field (Figure 2).

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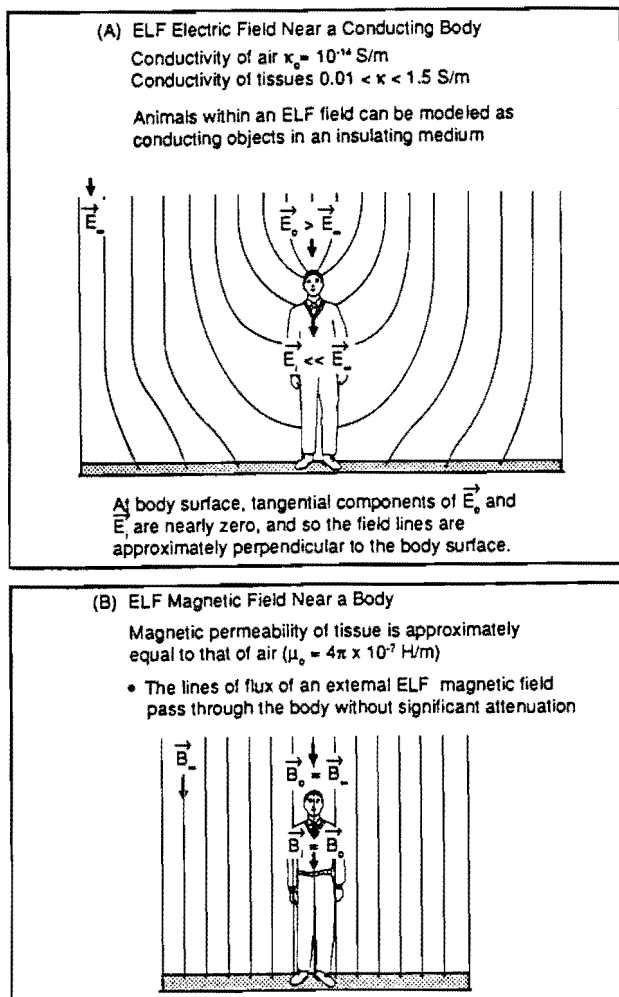


Figure 1. The electromagnetic fields near a body

Another point to be made regarding the physical interactions of ELF fields applied to the body through air is that their interactions are primarily nonthermal in nature. This conclusion follows from the fact that the highest electric field level that can be induced in tissue by an externally applied ELF field in air is less than one V/m. Larger fields cannot be induced in tissue

The existence of intracellular responses to ELF field transduction is illustrated by several lines of experimental evidence.

because the externally applied electric field would have to exceed the dielectric breakdown threshold of air. The maximum rate of joule heating of tissue by these weak induced fields is on the order of a nanodegree per second, which is about five orders of magnitude less than the rate of metabolic heating in humans. Because of the efficient heat conduction and convection processes in humans and other living organisms, this rate of tissue heating cannot be detected by presently available techniques.

A careful review of the published literature has demonstrated that the biological effects of ELF fields are directly correlated with the current density induced in tissue (2). A few biological effects have been observed to occur in response to induced current densities that are comparable to the naturally occurring

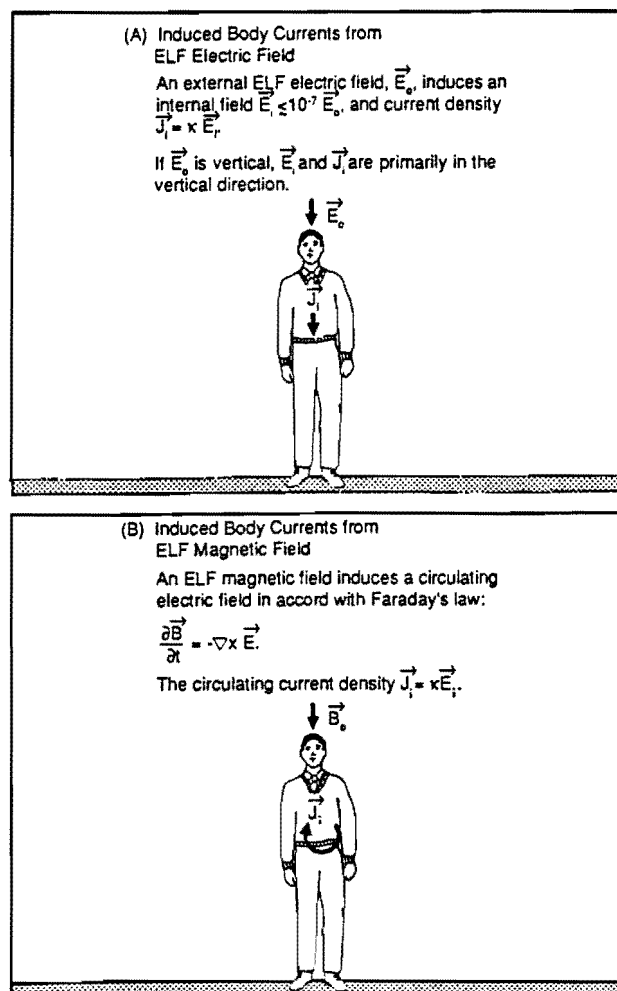


Figure 2. Induced body currents.

currents that flow in the body as a result of endogenous electrical activity of excitable tissues such as the heart and brain, i.e., 0.1 to 10 mA/m². These effects include the visual phenomena known as electrophosphenes and magnetophosphenes, and effects on the circadian rhythm in melatonin synthesis by the pineal gland.

At higher levels of induced current density in the range of 10 to 100 mA/m², a variety of alterations in tissue and cellular properties have been reported to occur in response to the application of ELF fields, including beneficial effects such as the facilitation of bone fracture reunion. With induced current densities in the range of 100 to 1000 mA/m², thresholds for neuronal and neuromuscular effects are exceeded. Finally, at levels above 1 A/m² the induced currents in tissue can produce severe, and potentially fatal, respiratory and cardiac effects. Current densities of this magnitude, however, can be produced only by electrodes in direct contact with the body, and not by fields applied to the body through air.

The major challenge in ELF field research at the present time is the elucidation of mechanisms by which exposure to extremely weak ELF fields can result in reproducible biological effects. A large number of physical and electrochemical models have been proposed in which the cell membrane is viewed as playing a primary role in transducing the weak signals presented by induced ELF electrical currents in tissue. A growing body of experimental evidence suggests that electrochemical events initiated at the membrane surface by circulating pericellular currents can alter ion binding to membrane macromolecules and influence ligand-receptor interactions at the cell surface (e.g., the binding

of hormones, growth factors, etc.). These field interactions at the cell surface can trigger transmembrane phenomena involving alterations in ion transport and changes in the electroconformational states of membrane proteins.

Events initiated at the inner membrane surface in response to these transmembrane signals can, in turn, influence the cytoplasmic concentrations of biologically important "second messengers" such as calcium ions and cyclic nucleotide that regulate macromolecular synthesis and control cellular growth and functional states. The molecular details of this cascade of transduction events that carry ELF field signals from the extracellular milieu into a living cell remain to be revealed by careful experimentation. However, the present state of knowledge strongly implicates the cell membrane as a site of ELF field transduction and signal amplification (1).

The existence of intracellular responses to ELF field transduction is illustrated by several lines of experimental evidence. As shown in Figure 3, it has been demonstrated that ornithine decarboxylase levels are increased in several lines of cultured cells after exposure to a 60-Hz electric field (3). This enzyme is essential for polyamine biosynthesis, and is activated by a number of chemicals that bind to receptors at the cell surface and stimulate cell proliferation. One example is the class of tumor promoters known as phorbol esters, and the results of Byus et al. (3) suggest that ELF field interactions may alter cellular biochemistry in a manner similar to these compounds. Phorbol esters have been shown to produce large elevations in ornithine decarboxylase activity via their binding to membrane-associated

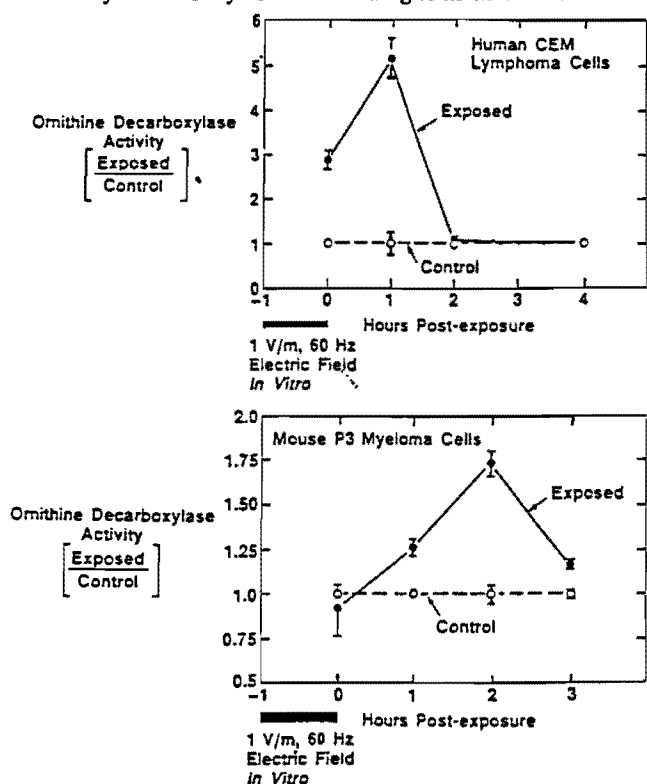


Figure 3. Changes in ornithine decarboxylase activity in cultured human and mouse cells exposed for 1 hour to a 1-V/m, 60-Hz electric field applied to the culture medium by electrodes. The increased enzyme activity was transient, and peaked 1 to 2 hours after termination of the electric field exposure. (Adapted from Figs. 1 and 2 of Ref. 3.)

phosphokinase C receptors and the subsequent production of new messenger RNA specific for ornithine decarboxylase (4).

In other studies involving dipteran salivary gland cells, it has been demonstrated that exposure to either pulsed or sinusoidal electromagnetic fields leads to altered messenger RNA transcription patterns (5-7). This effect is accompanied by a significant change in the spectrum of cellular proteins synthesized by the exposed cells relative to control cells (8). A total of 248 polypeptides in the control cells were resolved by two-dimensional gel electrophoresis, while 326 were observed in cells exposed to a 72-Hz pulsed magnetic field. The polypeptides synthesized in the dipteran salivary gland cells were specific to the characteristics of the ELF field to which these cells were exposed, with various polypeptides being either enhanced in quantity or suppressed relative to those observed for unexposed cells.

Recent studies with cultured human cells have also demonstrated that an increased level of specific RNA transcripts occurs in response to ELF field exposure (9). Using the technique of dot blot hybridization, it was observed that exposure to pulsed or sinusoidal ELF fields increased the levels of RNA with specific homology for b-actin, histone H2B and c-myc DNA. As illustrated in Figure 4, the activation of protein biosynthetic pathways by ELF fields is frequency dependent (10). In addition, recent studies have demonstrated that the time course of ELF field effects on protein biosynthesis has a complex dependence on the amplitude of the applied field.

These recent experimental findings provide a useful set of clues regarding the biochemical events that occur in response to

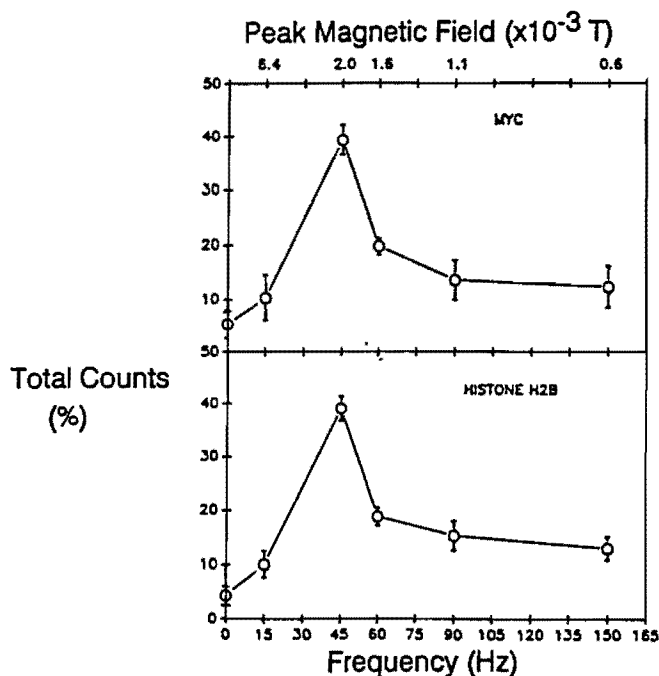


Figure 4. Effect of ELF field frequency on the quantity of RNA transcripts of *myc* and histone H2B genes in human HL60 cells. The peak magnetic field level was decreased as an inverse function of the field frequency in order to maintain the same value of the induced electric field and current density in the cell culture medium over the entire frequency range that was studied. The maximum stimulatory effect on transcription was observed at 45 Hz. (Adapted from Fig. 1 of Ref. 10.)

ELF field signals transmitted from the cell surface into the cytoplasm. The further elucidation of these signal transduction mechanisms constitutes a major challenge for future research on ELF field interactions with living systems.

References

1. T.S. Tenforde and W.T. Kaune, *Health Phys.* Vol. 53, pp. 585-606 (1987).
2. T.S. Tenforde, in *Extremely-Low-Frequency Electromagnetic Fields: The Question of Cancer*, pp. 291-318, edited by B.W. Wilson, R.G. Stevens, and L.E. Anderson (Battelle Press, Columbus, OH, 1990).
3. C.V. Byus, S.E. Pieper, and W.R. Adey, *Carcinogenesis* Vol. 8, pp. 1385-1394 (1987).
4. A.R. Verma, R.-C. Pong, and D. Ericksen, *Cancer Res.* Vol. 46, pp. 6149-6155 (1986).
5. R. Goodman, C.A.L. Bassett, and A.S. Henderson, *Science* Vol. 220, pp. 1283-1285 (1983).
6. R. Goodman, J. Abbot, and A.S. Henderson, *Bioelectromagnetics* Vol. 8, pp. 1-7 (1987).
7. R. Goodman and A.S. Henderson, *Bioelectromagnetics* Vol. 7, pp. 23-29 (1986).
8. R. Goodman and A.S. Henderson, *Proc. Natl. Acad. Sci. (USA)* Vol. 85, pp. 3928-3932 (1988).
9. R. Goodman, L.-X. Wei, J.-C. Xu, and A. Henderson, *Biochim. Biophys. Acta* Vol. 1009, pp. 216-220 (1990).
10. L.-X. Wei, R. Goodman, and A. Henderson, *Bioelectromagnetics* Vol. 11, in press.

60 Hz Electromagnetic Fields: Problems in risk assessment and policy response

M. Granger Morgan

I will talk about five things:

- Why this topic is so controversial.
- Insights from experience to date.
- Limits to risk analysis and the importance of public understanding and public perceptions.
- The need for utilities and public health organizations to think strategically about their policy responses.
- The need to work on what comes "after the smoking gun".

Why is this topic so controversial?

- In his classic book *The Structure of Scientific Revolutions*, Thomas Kuhn argued that science does not advance in a smooth and continuous way, but rather through a series of discontinuous "paradigm shifts".
- Over the past couple of decades we have been witnessing such a shift in scientific thinking about biological effects from electric and magnetic fields.

The conventional paradigm

ELF fields can *not* produce biological effects since:

- Joule heating and h , v are both vanishingly small
- ambient cellular fields and naturally induced currents are larger than externally imposed fields.

Counter evidence and paradigm shift

- Over the past several years evidence has mounted that indicates effects *do* occur.
- The validity of specific individual studies may be open to question, but in my mind the many positive studies in the refereed literature affirmatively resolve any question of *whether* effects exist.
- In the face of this evidence it has taken time for scientists to readjust their thinking... i.e., to "shift their paradigm".
- It remains unclear whether there are risks to public health, but as I will explain, there is a basis for concern.

Sources of evidence

- Cellular level studies.
- Whole animal studies.
- Epidemiological studies.

Evidence to date

- Clearly indicates that there are biological effects but leaves unresolved the question of whether exposure to fields presents public health risks.
- Suggests that if there is a risk, dose may not be measured by a simple time integral of field strength, i.e., that is at least in some circumstances across common exposures "more may not be worse".

- In short, we have only some pieces of what appears to be a complex puzzle. We are still struggling to put the full picture together.

The problem is *not* cover up

It is important to note that while parties with economic and other interests play roles in the public debate, interest group obfuscation is a secondary, not a prime cause of the uncertainty and scientific controversy.

Insights from experience to date

Four insights related to research:

- It is important to define "the problem" too narrowly.
- It is important to maintain a mix of cellular studies, laboratory-based animal and human studies, and human epidemiological studies.
- We need more flexible and adaptive research management with heavy emphasis on quality control.
- We need substantially expanded and more diverse sources of research support. In the United States, EPRI can not do it all alone.

Four insights related to policy:

- Risk assessment poses great challenges. Today only approximate bounding is possible.
- Public perceptions are likely to play a major not a minor role.
- Utilities and public health organizations need to think strategically about the strategies they should adopt. Incremental extrapolations from business-as-usual may not be adequate.
- It is not too soon to start working on what comes "after the smoking gun."

Problems in risk analysis

- Dose is not defined. If there are risks, the effects function may not be a monotonically increasing function of the time integral of field strength.
- This makes it very difficult to perform conventional risk analysis. Parameterized approaches lead to a combinatorial explosion.
- Attempts we have made at bounding analysis have led to bounds that are too large to be very useful.

Standards

- There is growing public pressure for standards.

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