Personal Radiation Dose Monitors for the Public and Emergency Responders

Allen Brodsky, Sc.D.

ABSTRACT

The U.S. currently lacks a national program of preparedness for an attack involving nuclear weapons or radiation dispersal devices (RDDs). Local responders lack information, training, and appropriate instruments. The development of the self-indicating instant radiation alert dosimeter (SIRAD) is a vital addition to previously existing technology, greatly expanding affordability and accessibility. Dispersal of such personally worn or carried monitors provides both tools and motivation to establish life-saving programs, partly by dispelling the myth that such measures would be futile. It also has peacetime applications for enhancing the safety of the nuclear industry and medical interventions.

The State of Radiological Preparedness

Many methods[1-3] were developed by early civil defense agencies, at great cost to the public, for protection of Americans against harmful levels of ionizing radiation after a nuclear or radiological attack. However, as part of the "peace dividend" at the end of the Cold War, the national radiological defense program was discontinued in the mid 1990s. As any reader can ascertain by asking a local emergency responder, there are virtually no preparations for survival of an attack involving dispersal of radioactive material over a wide area.

Nine years after the attack on Sep 11, 2001, despite billions of dollars spent on homeland security, appropriately ranged instruments for nuclear or radiological attack are still not made available to the public or emergency responders. Authorities on homeland security acknowledge that such an attack is a matter of "when," not "if." Nuclear technology is in the hands of terrorists and "rogue" nations that have announced an intention to use it.

The fear of even insignificant levels of radiation or radioactivity, detected by the "pagers" that have been given to responders all over the nation, will likely cause panic. Citizens worried about insignificant exposures will inundate medical facilities, hindering aid to the truly injured, as well as blocking roads, impeding rescue efforts, and preventing work essential to community and national survival.

Such fears have long been promulgated by opponents of U.S. nuclear weapons programs, who argued that preparing the public would only increase the likelihood of an attack, and by opponents of nuclear energy.

Personal Dosimetry: Need and Availability

To support an effective response after a radiological attack, a dosimeter must be affordable, durable, portable, and easy to use with minimal training. It must give an instantaneous reading of exposure in the appropriate dose range, so that timely action can be taken.

Biodosimetry, which has long been funded, has been useful together with physical dosimetry, as in the medical management of a bone marrow transplant that saved the life of a worker exposed in a 1967 Van de Graaff accelerator facility accident at the Gulf Oil Corporation Research Laboratory in Pittsburgh, while at the same time planning and performing quadruple amputations. This is described in detail by Brodsky and Wald in chapter 20 of Brodsky et al.,[1] along with a number of cases of ingestion of plutonium, americium, and other radionuclides. The available methods of biodosimetry would, however, provide dose estimates only in ranges approaching and including those in which ill effects and death can occur, and only after many hours of tissue or other biological sampling sent for evaluation, perhaps days after an incident, and after radiation damage has already occurred. Biodosimetry cannot provide the immediate information needed to avoid panic among the large populations likely to be aware of the existence of radioactive contamination after an attack. Further, not many medical centers or physicians expert in interpreting information from biodosimetry currently exist in the United States.

Limited numbers of the ionization chambers for personal dose assessment, of civil defense program vintage, are still available. They are designed to be carried in a pocket. They require charging before use, and they must be calibrated. Also from the civil defense program are Geiger counters and survey meters employing an ionization chamber. These are dose-rate meters, so that cumulative personal exposure must be estimated by multiplying the dose-rate by the time exposed. They are moderately bulky, and like the pocket ionization chamber dosimeters are fairly expensive and require calibration and training for use.

The home-makeable Kearny Fallout Meter (KFM),[3] also a dose-rate meter employing an ionization chamber, is an expedient that is useful for education or in monitoring exposure within an otherwise unequipped shelter, but it is not rugged enough for field use. Considerable instruction is needed for making or using one.

An unfortunate recommendation of the otherwise excellent 2005 report of the National Council on Radiation Protection and Measurements (NCRP)[4] is that dosimeters that alarm at 10 mR (0.01 R) per hour or more should be given to responders who might enter areas with such radiation levels. Detection of such tiny doses may be suitable for interdiction or hazardous materials spills, but not for events that release large quantities of highly radioactive materials. Because of the public's limited ability to understand simple information about exposures and risks, such dosimeters would cause more public harm rather than less. Alarms could be set at such low levels that undue fear and panic could result. The military do not want alarming personal dosimeters that might reveal their presence at inopportune moments.

The NukAlert is a dose-rate meter of moderate cost, small enough to be carried on a keychain, that emits audible "chirps" indicating dose levels in the range of 0.1 R/hr to >50 R/hr, levels that could be expected from a nuclear detonation or radiation dispersal device (RDD or "dirty bomb"). It is always on and is simple for untrained personnel to use. More information is available at www.nukalert.com and www.ki4u.com; the latter offers the other described devices as well.

Note that dose-rate meters will not show how much radiation was received in the initial, very short burst of gamma radiation from a nuclear detonation. For this purpose, members of the public need an inexpensive and reliable pocket or handbag dosimeter that can be read at any moment and interpreted immediately by visual inspection, like the colorimetric devices described below.

The Self-Indicating Instant Radiation Alert Dosimeter (SIRAD)

I have followed the development of the family of colorimetric (color changing) dosimeters, the self-indicating instant radiation alert dosimeter (SIRAD), over many years. I have worn them and examined the production facilities. I have inadvertently tested one by leaving it in a pocket of a shirt that was washed and dried through a laundry cycle. The dosimeter was still in good condition, my confirmation of the excellent ruggedness shown in formal testing.[5]

The technology has been extensively tested with funds from the Departments of Defense and of Homeland Security, and SIRAD cards are approved for purchase, with grant funds provided to States by the Department of Homeland Security and other agencies, for emergency responders, members of the public, and radiation workers.[2] Information on testing and use is available from JP Laboratories (www.jplabs.com), and on grantwriting and purchase from Crowe and Company (www.croweandcompany.com).

The SIRAD has been shown to be dependable, quality-controlled, sufficiently accurate, and stable up to years of wear in varied climates, if properly protected and not abused. The built-in false-positive-false-negative, inactivation, tamper (FIT) indicator, which would detect any abuse, is standard in most models or can be provided at nominal additional cost. It cannot itself be tampered with or removed without detection. The FIT indicator also detects any exposures to interfering ultraviolet radiation. An "expiration date" of one year from the issue date is given; in fact, the indicator remains stable for many years, but one should make a note that radiation exposure is accumulating over that period, at least from background.

The SIRAD is self-developing, and it requires no reading equipment and no individual calibration.

The size of a credit card, the SIRAD can be carried unobtrusively in a wallet or handbag, so it can go wherever the user goes. It is best not to send it through the x-ray screening at airports, as a detectable color change will develop after about five such exposures. One can put it in a pocket and carry it through the magnetometer (S. Jones, personal communication, 2010).

The sensor material that develops blue color upon polymerization by radiation is a proprietary diacetylene compound, which contains attached hydrocarbon groups; thus, the thin sensor and surrounding plastic card and envelope are of a low effective atomic number close to human soft tissue for dosimetry purposes.

The dosimeters are not electronic, and so are not susceptible to interfering electric or magnetic fields, intense radio signals, or the electromagnetic pulse (EMP) from an atomic bomb, which might destroy or annul other electronic dosimeters or communication equipment.[2] They do not need a power source.

The SIRAD card comes in a small envelope containing easily understood descriptions of the meaning of its color changes relative to radiation levels in dose ranges that might indicate significant health risks. It does *not* respond with color changes in the decades of lower ranges of more sensitive detectors, used for peacetime monitoring or for sensitive detection of orphan sources, which will not lead to a cumulative exposure likely to cause ill effects. The range of dose covered is about the same as that which biomedical dosimetry is able to span, except that SIRAD dose indications are immediate, rather than many hours or days after exposure to dangerously high doses.[1,2]

With this card, a person could assess immediately the degree of exposure from a terrorist or nuclear attack. If significant doses were seen to be accumulating, it would signal the need for actions to reduce risk, such as evacuation or shelter. Perhaps even more important, this assessment would avoid panic for the vast majority who would be in areas where radioactivity would be detectable but within a range that would not likely cause short- or long-term health effects.

The SIRAD is useful in peacetime also. It can be placed within security badges for persons working in nuclear plants or other facilities, and can serve as emergency dosimeters for employees in situations where accidents that could involve life-threatening exposures might be possible. They may be used as backup dosimeters worn by workers at NRC-licensed facilities to confirm that regulatory annual limits of exposure are not exceeded. Annual dose limits of 2 or 5 rem can easily be observed in the colorimetric sensors. Because they can be worn continuously on the job, perhaps contained or incorporated in the usual security badges that are routinely required in such facilities, they can make up for any lost readings that might occur from inadvertent misuse or loss of the usual monthly or quarterly personal monitoring badges. The color change is irreversible, permanent, and cumulative, so the badge can be saved if needed for accident investigations. It can be shielded to protect it from additional exposure.

The SIRAD is inexpensive to manufacture. Cards can be purchased for less than $10 each, depending on quantity, compared to hundreds or thousands of dollars for electronic instruments. And there are no maintenance costs.

An even smaller and less expensive colorimetric indicator called a RadSticker, which uses radiosensitive ink, is under development and has been distributed to thousands of police officers and firefighters[6] through the efforts of Stephen Jones, who previously equipped rural fire districts throughout Arizona with KFMs, NukAlerts, and the *Nuclear War Survival Skills* manual.[7]

Once people recognize that radiation is an easily measured entity, not a mysterious force that is lethal in the tiniest dose and beyond their ability to comprehend or manage, they are much more likely to prepare for early action that could save many lives after an attack, even one using weapons of mass destruction (WMD). Life-saving methods were developed and tested with tens of millions of dollars of civil defense research in the pre-1963 days of above-ground atomic tests. It seems that much of this early information and experience has been forgotten in the development of today's homeland security programs—or deliberately withheld as a matter of policy, on the theory that an unprepared, vulnerable population is less likely to be attacked. Yet the information is still available,[1-3] and the SIRAD marks a great advance in affordability and feasibility.

The distribution of SIRAD creates a "teachable moment" for providing rudimentary information[8] about initial response to an incident involving a WMD or RDD. Jones provides wallet-sized yellow cards with the most essential information on protection from blast and the thermal pulse ("drop and cover") and fallout,[9] along with RadStickers. He reports that first responders who work in the field acknowledge that they have no knowledge or training about nuclear weapons or radiological attack. They are, however, eager to learn, and quite capable of understanding the concepts.[6,7]

Technical Notes on Dosimetry

For a person in a fallout field where gamma radiation is coming from all directions on the ground, a pocket chamber or SIRAD reading in roentgens (R) or rads always produces a reading on the safe (high) side whenever it is substantially in error at all. For most gamma energies likely to be encountered, the reading in R multiplied by 0.95 would give the absorbed dose in rads near the surface of the body where the dosimeter is worn, and thus the same dose in rem from gamma radiation, for a small volume of tissue in the vicinity of the chamber. However, because gamma rays would be attenuated before reaching the internal tissues of the body, the mean dose to body tissue would be less than that indicated for unattenuated gamma radiation striking the dosimeter.

Studies of the average dose to the body from a surrounding field of incident gamma rays from nuclear bomb fallout indicate the effective body dose may be taken as approximately 0.7 (70 percent) of the reading in R or rads by a dosimeter worn on the chest. However, for lower-energy gamma photons, such as the 60-keV gamma rays from americium-241, the attenuation would be greater and the mean body dose would be much less than that indicated by a dosimeter worn on the body. Therefore, the reading in R or rads on a dosimeter worn near the waist or chest would tend to always be on the safe side (high-sided) for fallout either from a nuclear device or RDD, so the wearer would tend to seek even greater shielding protection.

With the SIRAD, materials used for the card and wrapper are close enough to tissue equivalent that they indicate close to the actual radiation absorbed dose (rad) at the surface of the body where the dosimeter is worn, over a wide range of gamma-ray, x-ray, and beta-ray energies.

In the unusual event that a person has a large amount of beta-emitting contamination on or near the skin, the skin beta dose as well as the entrance gamma dose can be determined by wearing two dosimeters in a packet between which is sandwiched about 1 cm of paper or other low atomic number material close to that of tissue. In any event, if a SIRAD dosimeter is worn in a pocket without other absorbers in front, it will at least overestimate the total body dose and warn of serious skin doses.

Radiation dosimetry rests on the Bragg-Gray principle that the amount of ionization produced in a gas cavity serves as a measure of the energy dissipated in the surrounding material. Because the sensitive colorimetric indicator and its surrounding materials of plastic and paper are of low atomic number material, the indicator approximates a Bragg-Gray cavity, and thus the beta dose in rads at the surface of the body would be about equal to the indicated reading on the dosimeter.

Another potential application, considering the low atomic number of the materials, is that the hydrogenous plastic and paper surrounding the indicator could provide neutron detection for criticality accidents, with proper calibrations.

The SIRAD can also be fabricated into rings or smaller sizes, with appropriate dose ranges, that can monitor extremity exposures, such as in the Gulf Oil Corporation Research Laboratory incident. In that incident, I needed to perform a phantom mockup with many types of dosimeters attached around the phantom in order to estimate body and extremity doses for physician planning of a bone marrow transplant and eventual limb amputations.[1,2] If SIRADs had been available and worn by those who were harmed in this incident, an earlier alert might have been issued, and some suffering might have been avoided. Also, the availability of SIRADs after this accident would have helped to determine marrow doses, and enabled the easier measurement of the extremity doses.

Currently available SIRADs are suitable for prevention of serious overdoses related to radiation therapy and CT scanning with modern computerized equipment[10,11] as recently reported in the press. In radiation treatments to cure cancer, the routine use of the smaller versions of SIRAD on or behind patients for first radiation therapy sessions could, with negligible cost or staff time, reduce the frequency of disastrous cases of serious harm and death to zero. Even the relatively low frequency of such misadministrations is receiving bad press and tends to induce many patients to avoid necessary examinations and therapeutic treatments. Biodosimetry is useless in preventing such misadministrations; it can only be used after serious tissue injury has occurred.

SIRAD cards currently have a dose range of 2 rad to 1,000 rad, but can be fabricated for special purposes to have ranges less than 1 rad to above 1,000 rad. Their response in indicating biological doses over the range 1 rad to 1,000 rad to gamma, x-ray, and beta radiation is relatively independent of quantum energy from about 0.03 MeV to 18 MeV, adequate for almost any routine or emergency monitoring of radiation. It is thus suited to be at least a back-up monitor for routine or emergency exposures in medical institutions for patients and workers, in nuclear power plants, and in any other facility where higher doses than those routinely allowed might be inadvertently received.

In addition to distribution to personnel, SIRADs could be posted on wooden poles, and with global positioning satellite (GPS) localization could serve the purposes of real-time intelligence about radioactivity dispersion and dose that could be relayed to homeland security command centers in the event of a radiological attack. This could be much faster and more accurate than the radiation isodose plotting that was required in the earlier days of civil defense operations, in which human monitors were needed to go into radiation fields and radio back their readings as they walked through designated areas. Having been involved in these tasks as radiological defense officer at the Region II command center of the Federal Civil Defense Administration in 1956-1957, I can testify to the difficulties and time lags of such isodose plotting compared to what could be accomplished with appropriately distributed SIRADs and modern computers and electronic data receivers today.

A Note on Units

The early radiation protection literature used rads and rems, and SIRADs are calibrated in these units. Today, radiation therapy physics uses "special" SI units, which were proposed in 1973 for adoption 10 years later. While SI units have advantages in certain scientific contexts, there are dangers. If a reading of an instrument in sieverts (Sv) is thought to be in rems, and 1 Sv is taken for 1 rem instead of 100 rem, the potential for serious biological harm might be overlooked. There are also inconveniences.[2] An NCRP commentary evidently recognizes that the original units are better for emergency responders, as it gives the newer units in parentheses if used at all.[4]

Appropriate Responses to Exposure

SIRAD wearers should know that exposures below 50 rad are unlikely to cause symptoms or immediate threat to life or health. Because of potential long-term health effects, e.g. late cancers, experts have long recommended that first responders limit exposures to less than 25 rad except to save lives. Avoidable higher exposures should be incurred only with knowledge and consent. Exposures of around 100 rad are likely to cause symptoms of radiation sickness. Members of the public should consider staying indoors and surrounding themselves with shielding materials to diminish exposure when their SIRADs begin to show color in the range of 1 to 2 rad.

Conclusions

Widespread dispersal of personal dosimetry enables proper response to radiological accidents or emergencies of all types, and is also vital to prevent panic. It highlights the need for providing the public and first responders with understandable, accurate information about radiation effects and protective measures. SIRAD is a technologic breakthrough that could enable the initiation of affordable homeland defense against WMDs and RDDs.

Allen Brodsky, Sc.D., has worked in radiation physics for decades, beginning with the first hydrogen bomb explosions. He has been radiation safety officer at three medical institutions, has written regulations for the Atomic Energy Commission and the Nuclear Regulatory Commission, and has taught graduate students at the University of Pittsburgh, Duquesne University, and Georgetown University.

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