

Chapter 15

New Biodosimetry Tools for Mental Health Support in Nuclear/Radiological Accidents or Terrorism

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Terrorist attacks or disasters involving radiological materials can cause severe stress. After an accidental release of radioactive material in Goiania, Brazil, the ratio of noncontaminated people to those actually contaminated reporting for voluntary radiological screening was about 500 to 1. This ratio was derived from a total of approximately 125,000 people seeking screening. The public health community would be overwhelmed in such incidents. Rapid biodosimetry tools may help distinguish those needing medical treatment for radiation injuries from those needing psychological support alone. The Armed Forces Radiobiology Research Institute (AFRRI) has prepared a rapid biodosimetry tool in a CD-ROM package entitled “Radiation Training and Assessment Tools” (4th edition, December 2007) that includes:

- Casualty Management Guidance, including the *Terrorism with Ionizing Radiation Guidance Pocket Guide* and *Medical Management of Radiological Casualties Handbook*
- Medical Data Forms, including the AFRRI Adult/Pediatric Medical Field Record and the AFRRI Biodosimetry Worksheet
- Exposure Assessment Software, including the Biodosimetry Assessment Tool (BAT), which was developed to record diagnostic information and estimated dose in suspected radiological exposures based on symptoms reported.

The First-responders Radiological Assessment Triage (FRAT), which will be available for a future edition of the AFRRI CD-ROM, is similar to the BAT but is intended for use on hand-held personal digital assistant (PDA) devices. With the beta version released August 2008, it will provide “triage” dose assessments and estimates of hospitalization

and mortality outcomes. The contents of the AFRRI CD-ROM are also available to download from AFRRI's Web site (www.afrrri.usuhs.mil).

Introduction

Although the world has not experienced nuclear warfare since 1945, there have been a large number of nuclear/radiological accidents over the years and a recent increase in the perceived threat of nuclear terrorism. Most people fear a nuclear/radiological threat even more than a conventional explosion due to their inability to perceive the presence of radiation with the ordinary human senses and their concerns about long-lasting radiation effects.

Public fears about radiation are often excessive, unrealistic, and persistent. Attitudes have been shaped over time by viewpoints expressed in the media and in the culture at large. While there was considerable American pride in nuclear weaponry after World War II, decades of exaggeration and misconceptions in books, movies, television, and other media led primarily to fear regarding anything related to radiation. Following Chernobyl, for instance, some people who actually had little exposure risk became obsessed with avoiding contamination. Some became so depressed due to their fears that they gave up hope entirely and committed suicide (Drottz-Sjoberg and Persson, 1993). Similarly, the 1979 Three Mile Island nuclear power plant accident in Pennsylvania—generally considered America's worst nuclear disaster to date—caused no actual radiation injuries or deaths and only a minor release of radioactive gas into the environment (Collins, 1991). Few people received a detectable dose of radiation above the general background level, and even of those, the largest possible exposures were roughly equivalent to the dose of an ordinary chest X-ray. Yet the concern and anxiety were very real. Psychophysiologic reactions were common among the citizens of the area, and many fled the region in the mistaken belief that a major nuclear detonation might occur at any moment.

More typical stress reactions may take many forms, including psychophysiologic reactions, adjustment disorders, acute stress disorder, and post-traumatic stress disorder. For example, data from the Hiroshima and Nagasaki attacks revealed widespread acute reactions such as psychic numbing, severe anxiety, and disorganized behavior, and there were later chronic effects including survivor guilt and psychosomatic reactions (Mickley, 1989).

Studies of severe radiological accidents have revealed that the number of people frightened and/or demonstrating psychophysiological symptoms may far outweigh the number of victims actually contaminated. The ratio of people with medically unexplained physical symptoms to radiation injured may be as high as 500 to 1, as occurred in the radiation accident in Goiania, Brazil, the worst radiological incident in the Western Hemisphere to date (Pettersen, 1988). A deliberate terrorist attack with a radiological dispersal device, such as a so-called dirty bomb, would use conventional explosives to spread radiological material. In such an event, the psychological impact may prove far worse than the medical effects. The potential for additional attacks might also contribute to the fear.

Providing early response diagnostic assessment information about radiation dose and injury received by each victim may help prevent or reduce anxiety and other adverse psychological reactions following a radiological incident. In addition, facilitating accurate exposure assessment would support medical triage and treatment of those actually exposed to significant levels of radiation and reassure minimally and non-exposed persons that they have not received medically significant doses.

The Concept of Biodosimetry

Workers at nuclear facilities who may be exposed to radiological materials must wear physical dosimetry devices by regulation. These devices directly measure radiation received in the event of an accident. The public at large, however, does not typically have access to such devices. Thus, in the event of a surprise attack or accident, the vast majority of those affected will have no idea about their potential radiation exposure—whether it was minimal, enough to sicken but not kill them, or lethal. This uncertainty regarding exposure and its consequences adds to the victim's psychological distress.

Biodosimetry can provide a quantitative assessment of potential exposure. Years of research on the victims of past exposures have revealed a number of biological indicators of the dose received. Simply put, the greater the radiation dose, the greater the biomedical effect on the body. Therefore, the assessment of physiological effects in those present at an incident can be compared to historic data and the approximate radiation dose estimated. These biological indicators include a decline in lymphocytes with increasing dose, an increase in dicentric chromosomes,

and an increasing severity of various prodromal signs and symptoms such as nausea, vomiting, and erythema (Blakely, Brooks, Lofts, van der Schans, and Voisin, 2002; Waselenko, MacVittie, Blakely, Pesik, Wiley, Dickerson et al., 2004; Blakely, Salter, and Prasanna, 2005). Some of these dose indicators, such as the dicentric assay, require sophisticated equipment and too much time to be practical in a mass casualty situation where immediate triage is necessary. We have developed tools that can provide a reasonably accurate estimation of dose within a few minutes per victim, using only laptop computers or even hand-held computer devices.

A Dynamic Package of Biodosimetry Tools for First Responders

The fourth edition of the Radiation Training and Assessment Tools includes guidance for managing casualties, forms for recording medical information, and software tools for assessing exposure doses. This CD can be obtained by taking the Medical Effects of Ionizing Radiation course held routinely by the AFRRI's Military Medical Operations department. More information is available at the AFRRI Web site.

Casualty Management Guidance

The CD-ROM emphasizes what treatment providers should administer in the medical management of casualties, providing a complete handbook, an abbreviated summary for quick reference, and a brief overview. The *Medical Management of Radiological Casualties Handbook* (2^d edition, 2003) helps prepare medical care providers to treat injuries complicated by ionizing radiation exposure and radioactive contamination. The handbook provides concise reading material for health care professionals in the management of uncontrolled ionizing radiation exposure. The AFRRI *Emergency Radiation Medicine Response Pocket Guide* can be quickly consulted in a radiation emergency for assistance in assessing and controlling the situation. It includes such topics as diagnosis, treatment considerations, decontamination procedures, and public health reporting procedures. This document was originally developed by the U.S. Department of Veterans Affairs as a two-page pocket guide. Both the handbook and the pocket guide are available in print form or downloadable at the AFRRI Web site.

Medical Data Forms

The second subset of biodosimetry tools on the CD-ROM deals with the actual recording of medical data relevant to radioactive

contamination, exposure, and the resulting patient symptoms. Included are tools such as a brief field record and a more comprehensive biodosimetry worksheet. The AFRRRI Adult/Pediatric Field Medical Record is a convenient one-page form for recording emergency medical information in the field. It was adapted from the U.S. Army's Field Medical Card into an electronic form applicable to both military personnel and civilians, for adult and pediatric cases alike. For instance, it has both an adult and a pediatric body map for labeling areas of contamination or injury. It also includes sections on personal data, types of injury, other symptoms, treatments administered, and disposition of the case. The AFRRRI Biodosimetry Worksheet provides a six-page data entry worksheet for gathering facts about a case of radiation exposure, including the source and type of radiation, the extent of exposure, and the nature of the resulting injuries. It also is applicable to both adult and pediatric cases. This worksheet was adapted by AFRRRI from the North Atlantic Treaty Organization Standardization Agreement 2474 Appendix 1, "Medical Record of Ionising Radiation Dose and Contamination," and incorporates a version of the Medical Treatment Protocols for Radiation Accident (METREPOL) grading scale (Fliedner, Friesecke, and Beyrer, 2001). It includes the basic items from the one-page Field Medical Record, and quite a bit more as well. Additional features include a detailed section on types of radiation sources present, radioactive exposure, external and internal contamination, and consequent symptoms. There are two sets of adult and pediatric body maps, one for contamination distribution and the other for estimated dose distribution. There is also a section for tracking changes in counts of various blood cell lines over time. Using a modified METREPOL grading system, the Acute Radiation Syndrome Responses Assessment based on the neurovascular, cutaneous, gastrointestinal, and hematopoietic systems can be determined. Finally, there is an entire page for additional notes and comments. The Biodosimetry Worksheet is in PDF format and can be filled out on the computer, or printed to be filled out by hand. Information on this Biodosimetry Worksheet can be used to complete many sections of the BAT software program.

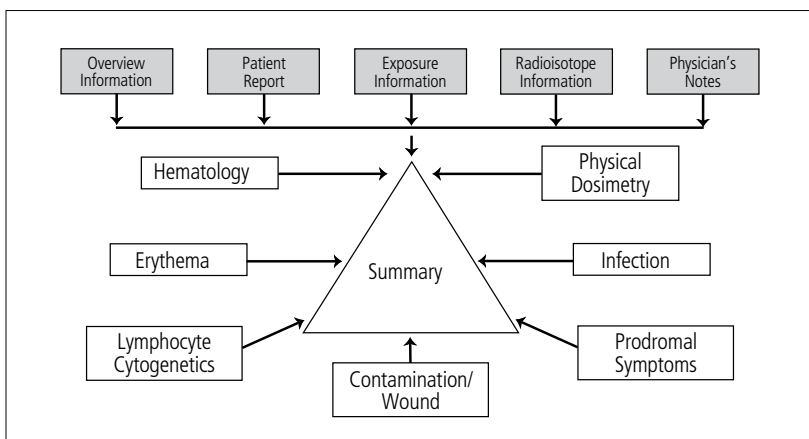
Exposure Assessment Software

The current edition of the CD-ROM includes one complete software program and will soon include a hand-held application that is currently in beta testing phase.

Biodosimetry assessment tool. The BAT software program was developed by AFRRI in collaboration with the Radiation Emergency Assistance Center/Training Site for recording diagnostic information in suspected radiological exposures. Version 1.03 is included on the CD-ROM and information on downloading BAT is also available on the AFRRI Web site. The minimum system requirements for BAT are Microsoft Windows XP SP2 operating system and a Pentium 200 with 256 MB of RAM and 10 MB of free disk space. A typical patient's complete record will require about 1 MB of disk space.

The BAT software equips health care providers with diagnostic information (for example, physical dosimetry and clinical signs and symptoms) germane to the management of human radiation casualties. Designed primarily for prompt use after a radiation incident, the user-friendly program facilitates collection, integration, and archiving of data obtained from exposed persons. Data collected in templates are compared with established radiation dose responses obtained from the literature to provide multiparameter dose assessments. The program archives clinical information (such as the extent of contamination, wounds, and infection) that is useful for casualty management, displays relevant diagnostic information in a concise format, and can be used to manage both military and civilian radiation accidents (see figure 15–1). In addition, the use of this program to monitor individual patient diagnostic information could minimize the severity of psychological casualties to

Figure 15–1. **Biodosimetry Assessment Tool Flowchart**



radiation victims and the concerned public by influencing how they view their exposure, dose, and potential risk for the development of disease.

Background information about the patient and the circumstances of the suspected radiological incident (date of exposure, time of exposure, location) are entered first. Next, medical data on various symptom categories are entered under the appropriate tabs (physical dosimetry, contamination/wound, prodromal symptoms, hematology, lymphocyte cytogenetics, erythema, infection) on the master screen. Only the categories for which data are available would be used for a given patient. In some cases, that may mean only two or three sections would be used, and the other tabs could be ignored.

Clinical signs and symptoms associated with radiation exposure are varied and numerous (see table 15-1) (Anno et al., 1989). The BAT's prodromal symptom screen allows data entry of this diagnostic information. While all the symptom categories for which data are available would be useful in treating a patient, three are especially relevant to estimating dose received. These are latency to vomiting in the prodromal symptoms category and the absolute number of lymphocytes and rate of lymphocyte depletion in the hematology category. These data are used by the BAT program to estimate exposure dose based on human accident databases and algorithms (see table 15-2). In the BAT prodromal symptom screen there are cells for entry of vomiting data, including time of onset and duration, while an "Obtain Dose Assessment" button can then be clicked to display an estimated dose from onset of emesis.

The hematology data entry screen has room for up to 13 serial measures of lymphocytes over time (see figure 15-2). Note that in this screen, dose can be estimated from a single lymphocyte count simply by clicking on the "SHOW DOSE" button after entering the number. A better estimate, however, can be derived from lymphocyte kinetics showing changes over time as revealed by multiple measurements. A click on "Get Multi-Sample Dose Estimate" will reveal a feedback screen estimating dose and 95 percent confidence level. The dose estimate based on lymphocyte kinetics is determined by one of two methods based primarily on data from Goans, Holloway, Berger, and Ricks (1997, 2001) and Goans (2001) or Guskova, Barabanova, Baranov, Gruszdev, Pyatkin, Nadezhina et al. (1988) (see table 15-2). While other patient data like cytogenetics can be used to calculate dose later, the advantage of the onset of vomiting and lymphocyte counts or depletion kinetics is that the physician or other user of the BAT program can get immediate

Table 15-1. Early Clinical Responses Following Radiation Exposure

Nausea	Fatigue
Vomiting	Weakness
Headache	Abdominal pain
Fever	Parotid pain
Tachycardia	Erythema

Table 15-2. Human Databases Used in BAT Dose Assessment Algorithms

Onset of Vomiting	Hematology	Radiation Quality	References
X	X	Photon	Anno et al., 1989 Dr. George Anno (personal communication)
X	X	Photon, Mixed Photon, and Neutron	Goans et al., 1997; 2001; Goans, 2001 Dr. R.E. Goans (personal communication)
X	X	Photon, Mixed Photon, and Neutron	REAC/TS Registry
	X	Photon, Mixed Photon, and Neutron	Guskova et al., 1988 Dr. A.K. Guskova (personal communication)
	X	N/A (control)	AFRR1 studies (BD-02)

feedback on estimated dose, bound by error bars or upper and lower confidence limits.

The BAT summary screen captures all the most relevant information entered or computed earlier for the given patient (see figure 15-3). In this screen the various symptom categories present are displayed, along with information on dose estimates. Note in this example

Figure 15–2. Hematology Data Entry Screen

Jones, Sally M -- AFRRRI BAT Data Entry Screen 10

File Window Help

Hematology Data Entry

Patient: Jones, Sally M

Blood Count [Help on this screen](#)

Date Collected	Time Collected	Hrs. Post Exposure	Lymphocytes (L#) (E+09)/liter	Single Sample Dose Estimate	Monocytes (M0#) (E+09)/liter	Gr (GR) (E+)
12/21/2000	06:00	27	001.500	SHOW DOSE		
12/23/2000	03:00	72	001.100	SHOW DOSE		
12/24/2000	03:00	96	000.900	SHOW DOSE		

[Instructions for scheduling lymphocyte measurements](#)

Get Multi-Sample Dose Estimate

[Help on blood cell unit conversion](#)

Therapy

#	Date	Therapy	Dosage
1			
2			
3			

Comments (Include address of lab performing analysis.):

The most critical information is BLUE

Hematology
Lymphocyte Cytogenetics
Erythema/Wound
Infection

Summary
Physical Dosimetry
Contamination
Prodromal Symptoms

Back to Radioisotope Information
STOP

that the dose estimated by onset of vomiting is slightly different from that estimated using hematology. An expert can view the information and assign a dose in the specified box. If more information or additional diagnostic indices became available later, of course, the operator could add that at any time.

First-responders radiological assessment triage. A beta version FRAT was released in August 2008, and the final version will be available in a later edition of the CD-ROM. While the two programs are somewhat related, BAT requires a desktop or laptop computer, while FRAT works on a hand-held PDA device using the Palm operating system. BAT computers could be used in a far-forward command post, but the size and portability of FRAT make it ideal for first responders or others who will enter a radiological incident zone and need to make patient data entry or dose estimates while operations are under way.

The FRAT was developed by surveying experts in radiobiology and medical effects of ionizing radiation. A group of experts responded to a questionnaire asking them to provide their judgments about the possible contributions of several diagnostic factors to predict radiation dose received. First, they were asked to estimate how useful each factor

Figure 15–3. Summary Screen

Summary of Entered Data Screen 14

File Window Help

SUMMARY

Dose estimates and measurements are shown in Red

Patient: Jones, Sally M
Military unit or organization:
Filename: sally.jones.mdb

[Help on this screen](#)

Prodromal (Gy)

Symptoms Onset of vomiting (h): 3.00

Estimated dose: 2.7 Antiemesis therapy prior to initial vomiting

95% CL: 2.2-3.2

[About prodromal estimates](#)

Radioactive Contamination

Internal Sampling
 External Sampling
 Chelation/Blocking Therapy

Infection

Infection
 Therapy

Eryth/Wound

Erythema
 Wound

Hematology (Photon Equivalent Gy)

Hours	Dose (Gy)	N	95%CL
Multiple:	1.4	3	1.1-1.7
Individual 1st:			
Individual 2nd:			

Cytokine therapy

[About hematology estimates](#)

Lymphocyte Cytogenetics

#	Dose (Gy)	95%CL
1		
2		
3		

Physical Dosimetry (Sv)

#	Shallow Dose Equiv	Deep Dose Eq Photon	Deep Dose Eq Neutron	Comm Eff Dose Equiv	Total Eff Dose Equiv
1					
2					
3					

Expert's Assigned Individual Dose

Set 1.5 Gy

Print this form Return To Data Entry Form

Note: All dose estimates are in sieverts (Sv) or gray (Gy).

would be in predicting whether radiation exposure had occurred. Then they were asked to rate how reliable that factor might be in estimating the dose if exposure had indeed occurred. Answers were to be provided on a 100-point scale with 0 indicating that the item had no value in such judgments. Ratings on each item were ranked and then the median score was used to weigh each sign and symptom factor in the multiparameter-based determination of a triage dose.

The FRAT software allows first responders to triage suspected radiation casualties based on the initial or prodromal features as listed in the AFRRRI *Emergency Radiation Medicine Response Pocket Guide*. An additional feature of FRAT is the inclusion of a digital version of the AFRRRI Pocket Guide that can be accessed quickly from the help menu. FRAT was developed initially to use the Palm operating system due to the portability of PDA devices. The program was written using NS Basic Palm and is compatible with Palm OS3 or higher.

The FRAT program permits convenient entry of signs and symptoms, blood lymphocyte counts, and dosimetry data, all with minimum text entry requirements (see figure 15–4 for a schematic of possible

inputs to FRAT). As with BAT, only the program components for which data are available are used. Otherwise, they can be ignored until such time as pertinent data are gathered.

Figure 15–4. Schematic Outline for First-responder Radiological Assessment Triage

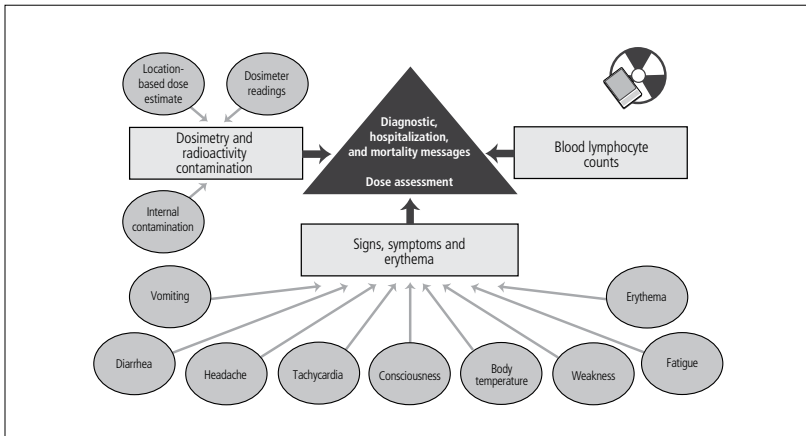
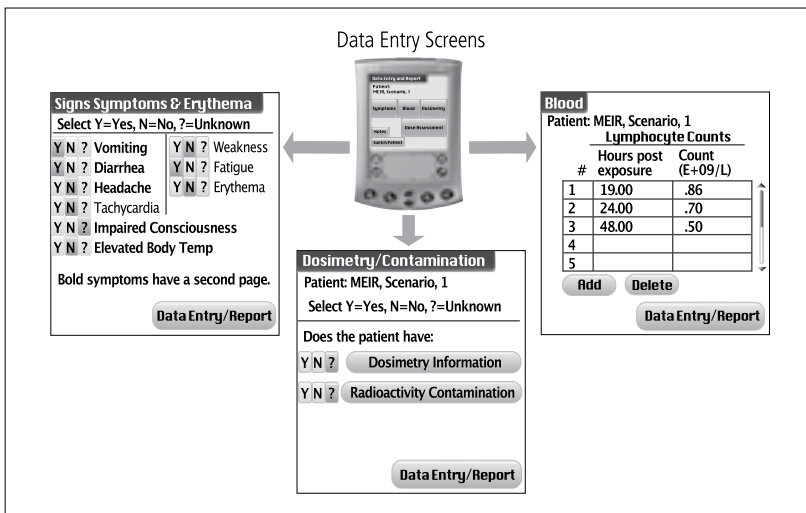


Figure 15–5. Sample First-responder Radiological Assessment Triage Entry Screens



The program comes equipped with a variety of input screens (see figure 15–5). The main input screen allows the user to link to the three subsections mentioned above. The “Signs Symptoms and Erythema” screen allows the responder to select from the nine symptomatic conditions indicated in the input schematic. The symptoms highlighted in bold, such as vomiting, have a sub-screen where additional information on time of onset and duration can be logged. The “Blood” screen is capable of saving up to 10 lymphocyte counts. The “Dosimetry/Contamination” screen allows the responder to store exposure information. Note that no writing is required for most data entry since in most cases the options are built in and one must simply touch the on-screen menus with a stylus to proceed. Once familiarity with the program has been achieved, it is possible to enter all the known facts about a given case quite rapidly.

At the conclusion of data entry, the user taps the “Dose Assessment” button on the main screen to get immediate feedback in the form of five triage dose assessment screens to advise the first responder about triage and prognosis on the case (see figure 15–6). “Triage Dose Assessment 1” indicates whether the patient has received no dose, a dose of inestimable magnitude, or a measurable degree of overexposure. The second dose assessment screen supplies messages related to hematology, such as warnings related to dose estimate or to draw serial blood samples.

Figure 15–6. First-responder Radiological Assessment Triage Dose Assessment Screens

Triage Dose Assessment-1
Patient: MEIR, Scenario, 1
Radiation **OVEREXPOSURE--** potentially **SEVERE** medical effect.
All results are based on acute whole body photon exposures of healthy subjects without medical treatment.
POOR Reliability [Next]

Triage Dose Assessment-2
Patient: MEIR, Scenario, 1
Lymphocyte Message:
Draw serial blood samples and make additional lymphocyte measurements. Determination of []
POOR Reliability [Previous] [Next]

Triage Dose Assessment-3
Patient: MEIR, Scenario, 1
CATEGORY Est. Dose (cGy)
Signs and Symptoms 160.00
Dosimetry _____
Blood Lymphocyte Counts 465.7
Pooled 408.4
95% Confidence 239.7-577.1
POOR Reliability [Previous] [Next]

Triage Dose Assessment-4
Patient: MEIR, Scenario, 1
Reliability/Diagnostic Message:
The multiparameter triage exposure or dose estimate has **POOR** reliability based on the FRAT triage parameters. Additional patient signs and symptoms, blood cell counts, and []
POOR Reliability [Previous] [Next]

Triage Dose Assessment-5
Patient: MEIR, Scenario, 1
Hospitalization & Mortality Msg
Hospitalization (90%) for 60-90 days with 0-80% fatality risk in 3-12 weeks without extensive treatment.
POOR Reliability [Previous] [Next]

The third assessment screen provides a dose estimate for each of the three categories (if available) as well as a weighted multiparameter triage dose in centi-Gray (cGy), along with confidence limits. The fourth assessment screen provides reliability and diagnostic information. Finally, the fifth screen reports hospitalization estimations and mortality projections. All this information has great utility for triage in a mass casualty situation as well as for treatment.

Conclusion

The tools included on AFRRI's CD-ROM can greatly assist first responders at the scene of a nuclear/radiological mass casualty accident or attack and medical treatment providers at all subsequent echelons back to tertiary care. The doctrinal guidelines and articles provided offer an enormous amount of useful information pertaining to both radiation and casualty care management. The medical data forms offer a means to collect the necessary information that physicians can use to help triage a patient and decide on the best course of treatment. The BAT and FRAT software can provide almost immediate radiation received dose estimates for each individual with a tremendous potential to triage large groups of victims rapidly. Such expedited triage can differentiate patients who actually have been exposed from those showing psychosomatic symptoms, thereby allowing medical treatments to be rapidly focused where they are needed most. With the truly exposed being taken care of, the likely hundreds of non-seriously exposed persons can be reassured that they are in no medical danger from radiation. The psychodynamics causing persons to be less likely to trust such "government/official pronouncements" are beyond the scope of this chapter, as is the interaction between such distrust and continuing psychological distress. Not everyone will be reassured, but many might experience a significant relief of stress and impetus toward sustained mental health through the use of biodosimetry tools to assess radiation exposure.

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