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T.M. de Castro

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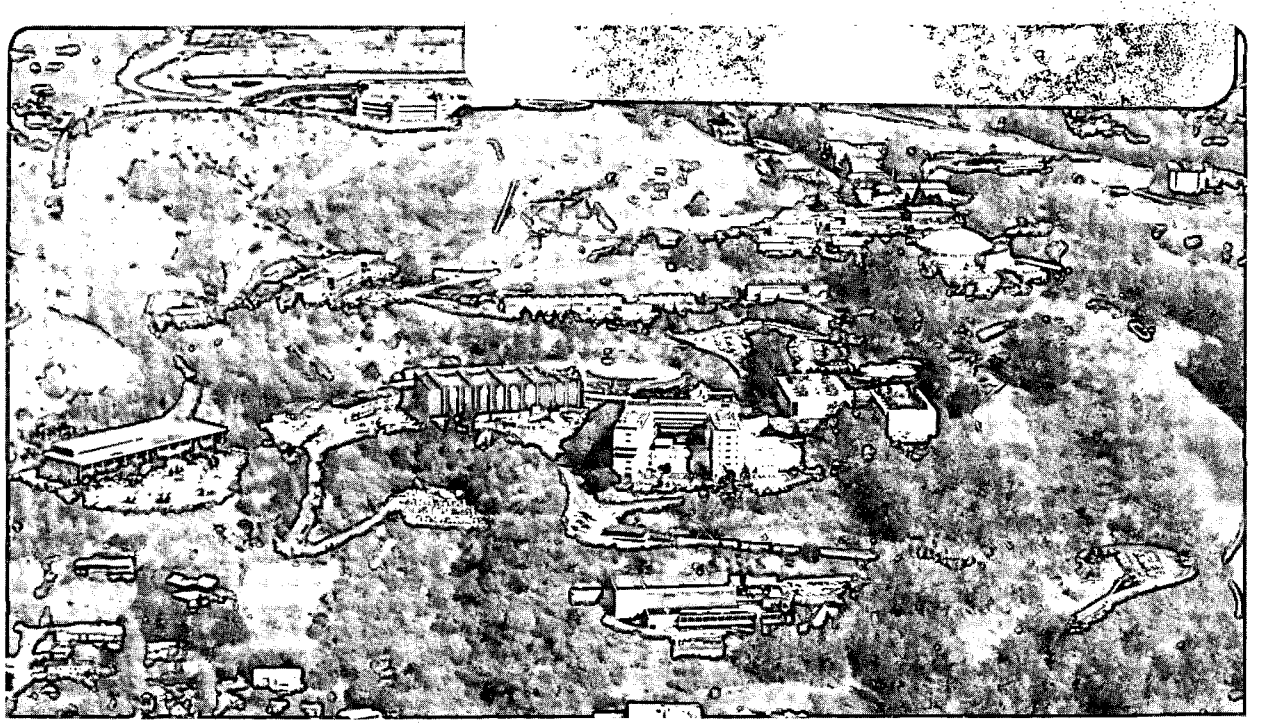

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DOSIMETRY OF X-RAY:
THE MEASURE OF THE PROBLEM

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While x-ray dosimetry is most definitely a "Measure of the Problem" in Analytical X-Ray Safety, there are additional factors which further enlarge the problem and are equally major considerations which must be taken into account when deciding upon the degree of action appropriate to prevent this problem.

Certainly, some idea of the nature of the typical levels of natural and man-made sources of radiation which surround us daily is useful to give us a perspective on the magnitude of radiation levels from analytical x-ray equipment. It is also important to know what levels of radiation exposure are considered unacceptable, either by regulatory limits or because of the potential for physiological damage.

The consequences of an exposure to radiation from analytical x-ray machines will often go beyond a report of an overexposure and investigation, or painful and lasting physiological damage. There are times when the matter will come before our courts in order to fix responsibility and decide compensation for injuries suffered.

Despite a knowledge of the levels of radiation involved and the possible consequences of exposure, the measure of the problem cannot be accurately assessed without an idea of the likelihood of occurrence of an accident. After all, having your house struck by lightning is equally destructive regardless of where that house is located. However, the degree of action taken by a homeowner to protect against this eventuality is highly correlated with the local probability of occurrence.

After learning the true magnitude of the problem and deciding to take preventative measures, you will find that you still don't have sufficient information to allow you to apply your resources in an efficient and effective manner. You need to know the relative levels of risk associated with the different operations performed on such equipment, and what types of equipment present more potential for harm. You then also need

to know what factors of the interaction between people and machine typically lead to an undesirable conclusion.

The X-Radiation is the energy which causes the injury and you need to know its nature, how to assess it, how to estimate it and how to record it's incursion into your workplace and your body. You may never need to apply many of the details discussed. You may find it more expedient to employ in-house safety personnel or outside consultants whenever such a need arises. But knowing what can be or is usually done will allow you to better determine the type of action warranted by a particular situation. Knowing how it is done will allow you to prepare for and assist in any dosimetry efforts required. Lastly, knowing the typical accuracy of dosimetry efforts will allow you to better utilize and understand the results.

The Radiation in Our Daily Lives

Throughout evolutionary history mankind has found himself in a sea of radiation from the world around him and the space beyond. These radiations have a different spectral nature or "Quality" than the x-rays you use in your laboratory, but their interaction with people is similar. Due to the higher energies involved, the effects from background radiations are more evenly distributed. Also the magnitude of natural radiation varies greatly from one location to another.

In our daily lives there is also an impact from man-made or enhanced sources of radiation. This could be from televisions or VDT devices (but that is highly unlikely), from medical/ dental procedures undergone to relieve or prevent other deleterious health effects, or from building or insulating techniques used in the structures you occupy.

Natural background radiation is composed of two main elements, terrestrial radiations from the elements in the soil and cosmic rays from the stellar processes in space. In the San Francisco Bay area the two components are close to equal with a total dose of about 85 mREM per year. The terrestrial component can vary significantly depending upon the particular geologic strata one is near, and on other factors like the fill used in the roadbed in front of your house. This may increase the level by about 50%. In locations at higher altitudes the extraterrestrial component increases because of less atmospheric shielding. An appropriate example is here in Denver where annual background is about 170 mREM per year. In some places high concentrations of naturally occurring radioisotopes in the soil can increase the background levels significantly. The most extreme example of this is Kerala, India, where the annual dose is 5000 mREM per year. The sands in that area are more radioactive than some laboratory spills which elicit significant activity for measurement, cleanup and future prevention.

The buildings you live and work in can add to your radiation exposure if they are of masonry construction since this, in effect, brings the terrestrial component closer to you. The degree to which this is so depends upon the formulation of the construction materials and is highly variable.

Another common source of radiation exposure is the medical or

dental x-ray. These, of course, are similar in spectral composition to the analytic x-rays in your laboratory, so the biological effects are likewise similar. The significant difference is that these are purposeful exposures without which the desired information could not be gained. Medical x-rays are prescribed in order to gain information which is used to provide the person exposed with some health benefit. By contrast, it is not necessary for you to be exposed to x-rays in order to gain information about the composition of a sample, nor would the benefits of such analysis be in any way enhanced by your exposure.

The magnitude of the dose received from medical procedures tends to be neatly proportional to the magnitude of the malady and inversely proportional to the frequency of the diagnosis. This is not coincidence. Just as more medication is prescribed for more severe illnesses, the radiologist is justified in giving more exposure for more serious problems. Also since the more frequent procedures receive more attention, there has been greater progress in dose reduction. These exposures can be as low as 5 to 10 mREM for a chest x-ray to as much as a few 10's of REM for a lengthy Cardiac Catheterization procedure. In between one could receive 50 to 300 mREM per exposure for dental x-rays, 500 to 2000 mREM for each Mammographic exposure and a few REM total for a G.I. examination. In the higher dose procedures it is interesting to note that accidents involving machine malfunction have given high enough exposures to cause dermatological symptoms.

In today's laboratory there has been a proliferation of Video Display Terminal (VDT) devices; in addition, we have the ubiquitous T.V set at home. X-ray exposure from these types of devices has been the subject of many heated controversies in recent years. While it is true that all the elements for x-ray production are present and some past instances of x-ray emissions have been documented, this problem is largely a paper tiger. Shunt regulator tube modifications in older technology T.V.s have greatly reduced the problem and the total replacement of this component in modern T.V.s and VDT's with solid state circuitry has eliminated it. Indeed if any radiations can be measured in VDT's, it is due to natural activity in the glass and occasionally some antireflective coatings. These type of devices have also received regulatory attention and exposure limits have been imposed.

A few other sources of daily radiation exposure would be from airline flights where the altitude allows around 1/2 mREM per hour (not including SST flights where it can be much higher), or even smoking where elements of terrestrial radiation are concentrated in the leaves of the tobacco plant and can cause significant exposure to the lungs. In the case of smoking, the radiation effects are probably outweighed by other health effects, but a synergism would not surprise me. Also there is a considerable controversy on the assessment of dose from smoking.

One last source of natural radiation enhanced by the efforts of man is Radon exposure. Radon accounts for 250 - 2500 mREM of equivalent whole body exposure per year in normal surroundings but levels 10 times this high are not unusual. Tight construction techniques for energy efficiency, and

elements in masonry building materials can significantly increase this exposure. The specific organ at risk is, of course, the lungs where the local dose may be 10 times the whole body equivalent. If you compound all these factors of 10 you can see that the dose from this pathway can be considerable.

Exposure Limits

Regulatory agencies have adopted limits for allowable exposures to radiation beyond those received from medical or natural sources. These limits are set low enough that prompt physical effects are not possible, and delayed effects are highly improbable. (At these levels, genetic effects in humans have not been demonstrated; it would be a difficult and lengthy study to achieve conclusive results.) The limits for occupational exposure and exposures to the general public are different. This is because the exposed individual is expected to gain some benefit from the operation which caused this exposure--if only a paycheck--which can provide definite health enhancement. Since occupational exposure is the topic of discussion here I will only mention those limits.

The limit for exposure to the whole body is 5 REM per year with not more than 3 REM in any one quarter. A former emergency limit of 5(AGE-18) REM of total lifetime accumulated dose has been pretty much discarded. Interestingly enough the 5 REM per year limit is the same as the natural background in Kerala, India as noted above.

Some portions of the body are considered to be more radio-resistant and are therefore allowed a higher exposure limit. Specifically the skin of the whole body is allowed 30 REM per year and the hands, forearms, feet and ankles 75 REM per year.

In the analytical x-ray environment, however, accidents usually involve much higher levels of exposure. They reach the thresholds for physical damage to the body. The next speaker will cover this facet of radiation exposure in detail.

Legal Matters

As much a measure of the problem as the dose rates themselves is the extent of legal liability and responsibility involved in the use of x-ray machines. Damage awards for radiation injuries are seldom settled under Workmans Compensation as are other occupational injuries.

X-ray machines come under the legal heading of Ultra Hazardous Equipment which invokes an element of the law known as "Strict Liability." Strict Liability applies mainly to manufacturers but can be applied to users, especially if the equipment is modified. In a loose interpretation, what Strict Liability means is that no matter what you do to prevent accidents, you are responsible for any injuries resulting from the use of this equipment. Frightening but true - this is a heavy responsibility!

A more relevant element of the law in a laboratory situation is Assumption of Risk. This means that the responsibility of the organization for the use of the x-ray machine may not be

delegated, transferred or assumed.

We all have confidence in our own capabilities. We do things that are not quite "according to Hoyle" with the absolute conviction that we will not be hurt and usually emerge justified in that assumption. At home this is merely "taking one's chances". In the occupational environment this is Assumption of Risk and legally you cannot do this and your employer cannot allow you to do so. The employer still is responsible and faces the legal consequences. Remember, however, as you listen to the next speaker, that you remain the recipient of the physical consequences of a radiation exposure accident and regardless of your legal outcome you will suffer the pain, disfigurement and disability - a very high price to pay.

Another significant aspect of assumption of risk is that the employer may not, for any reason, order you to work in an unsafe manner or with unsafe equipment. That only compounds his liability to a level of criminal involvement.

Primary Beam Dosimetry

The primary beam is the working tool of the analytical x-ray user, but it is also a VERY VERY powerful source of x-rays. The dose rate is so high that a factor of 2 error in its assessment is truly trivial and even factors of 10 do not make a large difference in assessing the consequences of, nor potential for, a serious accident or the type of protective actions appropriate. Indeed, at the distances usually involved in an analytical x-ray accident, the possible range of the position of exposure covers more than a factor of 10 difference in beam intensity. The consequences of the exposure of human tissue to the primary beam are dire!

You know far more than I about the spectrum of the analytical x-ray beam. From a Health Physics perspective it suffices to characterize the spectral "Quality" as "Soft". This means that the beam is easily attenuated and thus does not penetrate deeply. But it is important to remember that photon radiation is attenuated exponentially, thus it is never truly attenuated to zero - only too low to measure. This means that even though attenuation in tissue is rapid, thus not deeply penetrating, it is really a matter of degree. Regardless of the amount of attenuation to a particular depth, the dose at that depth is still proportional to incident exposure. If that exposure is high enough, then damage can still occur. The exposure rate in the primary beam of these machines is definitely high enough for some deep tissue damage.

The size of a properly collimated primary beam on XRD equipment is quite small. This has a significant impact on x-ray dosimetry from the perspective of injury potential and on the difficulty of rate measurements, especially dose assessment. Fortunately, the impact on injury potential is good! The collimator itself provides separation from the tube port thus lowering the exposure rate. The small size is helpful since if an exposure occurs the movement involved spreads the beam out over the surface of the skin thus lessening the insult to any specific area. The consequences of an accident are less severe when then beam is collimated.

More serious accidents can occur when the beam size is large such as in a situation involving a loss of collimation or XRF units. These situations are easily detected however, and the operator can be alerted before exposure to the beam.

For many purposes an actual measurement of the primary x-ray beam is unnecessary. In the literature is cited an equation which can be used to estimate the beam intensity with sufficient accuracy:[1]

Exposure Rate:

$$50 \times \frac{(kV) \times (mA)}{(cm)^2} \frac{Z}{74} = R/sec$$

The original author claims an accuracy of 25% for 1 mm Be window tubes but later investigators claim factors of 2 to 3 accuracy, which is reasonable. This formula is inelegant and unsatisfying but has one saving grace--it works! It is not dimensionally correct and the linear relation to kV is crude. Typical relation of x-ray dose rate to kV is at least squared and often higher, depending upon filtration and characteristic radiations. The linear relation to Z and inverse square relation to distance are correct. Over the limited range of kV used to excite x-ray targets, however, this formula is very useful.

The intensity of the characteristic radiation can also be estimated as the difference between the kV applied and the kV of the characteristic excitation to the 1.6 power. This is a proportional formulation and does not provide a method for normalization to the bremsstrahlung curve.

For dosimetry purposes the first equation is all that is useful since the dose contribution from the white radiation usually predominates. As the spectroscopist is concerned with the x-ray tube target material and the characteristic radiations, the health physicist is more concerned with the applied voltage and the tube current.

In addition to the dose delivered by an x-ray beam the effective energy of that beam is also important. As mentioned above, these beams are not highly penetrating thus much of the dose is due to the lower energy photons. The addition of filtration will reduce these photons and thus cause a dose reduction of factors of 2 to 8. The characteristic radiation is made more prevalent by filtration, but since there is usually considerable overvoltage applied for additional intensity, there is a higher energy tail to the spectrum which imparts considerable dose. So although the target material changes the spectrum of the beam, the difference in depth dose or penetration is not as significant as for changes in applied potential.

In some calculated examples we can see the effect upon dose rate of various typical voltage/target combinations. These sample calculations are done for a distance of 5 cm from the port (7.5 cm from the target). This is a reasonable distance for an accident to occur. Calculations usually presented are for dose rates right against the tube port. While such calculations are useful for their "scare value" they are less

likely accident points and the figures at 5 cm are sobering enough! Also if interested in the "at port" estimate, the 5 cm figures can be multiplied by 10.

Cu Target 40 kV 20 mA

$$50 \times \frac{(40)x(20)}{(7.5)^2} \frac{29}{74} = 279 \text{ R/sec}$$

Mo Target 36 kV 20 mA

$$50 \times \frac{(36)x(20)}{(7.5)^2} \frac{42}{74} = 363 \text{ R/sec}$$

Ag Target 40 kV 20 mA

$$50 \times \frac{(40)x(20)}{(7.5)^2} \frac{47}{74} = 452 \text{ R/sec}$$

W Target 50 kV 20 mA

$$50 \times \frac{(50)x(20)}{(7.5)^2} \frac{74}{74} = 889 \text{ R/sec}$$

Scattered Beam/Leakage Dosimetry

Many people unfamiliar with the radiation environment around an analytical x-ray machine often express concern for the potential for whole body exposure or for genetic damage. This is the type of radiation they are asking about.

Diffuse scatter from an XRD unit is usually low. Rates of just a few mREM per hour are seen only very close to the more open camera types, such as the Back Scattered Laue. At the edge of the top surface of the x-ray unit or outside an enclosure barrier, even one without enhanced shielding characteristics, a radiation field is often unmeasurable with typical survey instruments. An exception would be a specular reflection, but this is very rare.

XRF units are usually well enclosed and scatter is unmeasurable at any normally accessible location.

Although x-rays do lose energy when scattered, at these low energies the scattered spectrum is not significantly different from the primary beam, at least in a manner which would make any difference for x-ray safety considerations.

As for tube head leakage - it should be unmeasurable. At these low energies adequate shielding is easily achieved. If it is otherwise, then there has been a serious error in the assembly of the tube head.

These low levels of x-ray exposure refer to a unit which is set up with proper collimation, beam stops and analysis devices attached. If there are leaks in the beam path, such as a mis-seated collimator, then the levels become much greater and an overexposure incident is possible.

It should also be noted that any exposure levels from leakage or scattered radiation subtends a large angle, very much in

contrast to the narrowly collimated primary beam.

Adventitious Radiation

This is another very rare form of low level x-ray exposure. Vacuum tube-type, high voltage rectifiers are very much like an x-ray tube. In fact an x-ray tube is a saturated diode, or a rectifier with the filament heat turned down so that its current flow is limited by the emission rate of the cathode. Of course there are differences in the construction of the electrode parts, but only to enhance the production of x-rays--not cause it. Both x-ray tubes and rectifiers pass current and standoff a high voltage across the terminals, the difference is that the rectifier does not do both at the same time. The electrons flowing must have dropped through a high potential to produce x-rays.

It is of course possible for a malfunction of some sort to occur which would cause the rectifier to act like an x-ray tube. However, in order to produce x-rays of any significance, this rectifier would have to drop at least 10 kV--most likely 15 kV. This amount of potential loss would not go unnoticed. There would be a large loss of beam intensity and maybe even the loss of characteristic radiations, depending upon the target material and the amount of overvoltage normally applied. For this reason routine surveys for adventitious radiation are unwarranted in the absence of other indications.

Measuring X-Ray Exposure

The measurement of exposure rates from an analytical x-ray machine does not require highly advanced measuring equipment nor knowledge of advanced concepts of nuclear interactions. The equipment used is based on very old principles and technologies and is given a hand in sensitivity and stability by modern circuitry and devices. The ion chamber and geiger counter are two very simple devices. The techniques used are quite straightforward.

What is required for x-ray measurements is a firm knowledge of the nature of the radiations to be measured and of the capabilities and limitations of the instrument used. It always seems that some parameter of the x-ray field is pushing some limit of the capabilities of whatever instrument is used. In other words, one must be very picky about all the little details.

One predominate consideration is the effective energy of the x-ray beam. As mentioned above these beams are not very penetrating, thus special thin window detectors must be used. This of course means that the response of this instrument will be directional too.

At these low energies air absorption is significant, as is self-absorption in the detector. These factors often may have to be corrected for, or at least be considered when choosing which instrument to use.

The size of the collimated beam is always a problem; even the size of the uncollimated beam can be troublesome. Few if any detectors are small enough to be entirely within the beam so corrections must be made. One method is to measure the size of

the beam with film and correct for the ratio of the exposed area to the total sensitive area of the detector. The problem here is the measurement of the beam size. It is very difficult not to grossly overexpose film in the primary beam thus making the beam appear much larger and better defined than it really is. Another technique is to back off to where the beam is large enough to cover the entire detector. Then the exposure rate must be corrected for distance to the position of interest and also for air absorption. This of course assumes that there is space to get far enough away from the beam to make this measurement.

Once one solves the problem of beam size, the problem of uniformity must be addressed. At close distances there is a large non-uniformity or gradient along the length of the detector. Instruments are seldom calibrated for this condition. At farther distances this becomes less of a problem but the problem of uniformity across the face of the detector becomes more noticeable.

Once one gets far enough away from the tube port to solve the uniformity problems the intensity decreases to where it is more difficult to localize the beam in order to ensure proper detector placement. Localization can also be a problem in finding the source of leaks.

As the energy of the beam presses against the lower limit of the response of most available instruments, the intensity of the beam presses the limit of exposure rate linearity. At typical exposure rates a geiger detector may go dead, and an ionization detector may go out of saturation. Also if an integrating detector is used, and its volume is small enough to lessen the effects of nonuniformity and high rate losses, it may be difficult to accurately produce a short enough exposure of known duration which will not exceed its capacity. An exception to this would be a solid state integrating detector such as TLD, but then internal absorption would cause other problems.

The answer, of course, is compromise. For that one must consider the purpose of the measurement and therefore the requisite accuracy. In the case of accident dosimetry many other factors regarding uncertainty in movements and positions can produce far larger error limits than even crude measurements or mathematical estimates. In a brief leakage survey, accuracy is even less important. Usually the only question is whether there is a leak and where. In few cases is precision as high as 25% ever required or useful.

After considering all the above factors you may now choose an appropriate instrument. You will probably never make a direct beam measurement or need to know stray fields with any degree of accuracy. What you will need to do is survey a setup for leaks from mis-seated components. For this purpose the end window GM detector type instrument is well suited. A unit with audio response is preferred since this will allow more rapid scanning than with the typical meter response. If, however, you do need to know accurate radiation levels from stray fields, then a portable ion chamber type instrument is a good choice. One of these two instruments should always be available to the analytical x-ray user so that setup surveys may be made quickly, easily and frequently.

Personal Dosimetry

Many arguments can be advanced to claim that personal dosimeters cannot be useful around analytical x-ray equipment, especially the body badge dosimeter worn at breast pocket level. Those who have been involved in many accident investigations, however, claim that the body badge is often the first indication that something has occurred. Since we have not had any accidents involving this type of equipment at LBL I cannot lend my opinion to this controversy.

Some have suggested that dosimetry for personnel who perform alignment operations or service operations is highly indicated but that for routine users it may be unnecessary. If this were modified to say routine use on units with interlocked enclosures, then I would be inclined to agree. In any event it is certainly expected that exposures recorded for persons using analytical x-ray equipment should always show zero unless some sort of incident has occurred. These x-rays are just to easy too shield and control, to allow routine exposure at any measurable levels.

Extremity dosimetry can be useful since it is the extremities which are most at risk with this type of x-ray equipment. Often, however, the user feels discomfort and a loss of dexterity when using such devices. For those who perform operations for which there is the greater risk of exposure, such irritation and feelings could be sufficiently distracting to contribute to an accident. There are other ways to monitor accident situations and to estimate dose in case of an exposure. In fact in an exposure investigation the extremity dosimeter would not be the sole method of dose assessment or even the most believable. For these reasons I feel that extremity dosimeters should be made available but used as an individual option.

What type of dosimeter is best? At LBL we use, and I prefer, the film badge.

Many people avoid the film badge around x-ray fields because it does not have a linear energy response. In fact it is the x-ray region where the response differs most from the typical calibration. This only because the typical calibration is done with ^{137}Cs. Actually film is much more sensitive to these low energy x-rays than it is to Cesium gamma rays so what we actually have is an enhanced sensitivity dosimeter. The accurate use of film in this energy range is then merely a matter of correct calibration.

The advantage of film is that it gives a pictorial image of an exposure. This can be quite helpful around x-ray machines. From this "picture" it is possible to tell if the film was moving during the exposure or relatively still. When still it can show if the exposure was a single event or several. These are just the most obvious circumstances which can be inferred from the nonuniformities of the exposures on a film badge. At LBL this kind of information has enabled us to separate the high energy exposures from the low and to detect instances of radioisotope contamination. It has also enabled us to separate out from exposures attributable to laboratory operations, those due to lab coats hung in unfortunate places, airport x-ray

machines, medical x-rays, being kept in a drawer with a Radium dial watch and, in one case, when an employee wanted to test the system with the help of his dentist's x-ray machine.

Other dosimeters which can be used are TLD's and pocket ion chambers. TLD's offer a well-behaved energy response and reasonable sensitivity. Also the processing of TLD's is simple but unfortunately is also a Read Once situation; if something goes wrong the information is lost. If extruded TLD chips are used, it is also necessary to correct for attenuation within the chip. There is, of course, no way to separate out the various bogus exposures mentioned above.

Pocket ion chambers, usually called pencil dosimeters, can be quite useful when used properly. They should never be used alone as a primary dosimeter. They should always be "backed up" by a film or TLD dosimeter for the official exposure record. What pencil dosimeters offer is immediacy. The other dosimeters mentioned are usually processed in cycles so there can be a substantial delay between an accidental exposure and its indication on the dosimeter. With the pencil dosimeter, the user can know immediately IF THE CHAMBER WAS EXPOSED. This can initiate an investigation to determine if any accident has actually occurred. There are better ways to deal with immediacy and I will discuss that in the third part of this morning's workshop.

Accident/Injury Rates

Why all the fuss? Have you been a victim of an exposure from an analytical x-ray machine? Do you know someone who has? Probably not! And, of course, you are a very careful and competent worker.

Actually tracking down the true frequency of incidents is not that easy since, unless there is an overexposure or injury, it will most likely go unreported. The rate of "near misses" would be even more telling but, of course, these are even less documented. From my experience at LBL I know that, prior to our total enclosure policy, such near misses were relatively common--about 1 to 2 per quarter among our 20 or so machines. Most of our users have been very conscientious about reporting when they think they may have gotten into the beam; we try to give them little reason to "sweep it under the carpet." In all these cases, we found that for one reason or another no exposure had occurred - fortunately!

Some 1968 statistics[1] show that the accident rate for analytical x-ray machines ran about one per one-hundred units per year. At a rate of about one per two- or three-hundred units per year an injury occurs, and at one per thousand there is a severe injury. There is a suspicion that the simple accident rate may be underestimated but the serious injury rate was probably fairly accurate. More recent information (1974)[2] suggests little change and the same suspicion of underreporting of low consequence incidents. More recent data does not seem to be available.

Of interest is the type of machine the accident occurs on. Seventy-five percent of analytical accidents happen with XRD units. This is hardly surprising since they tend to be more

prevalent, and in the open beam configuration there are many ways to inadvertently get into the primary beam. Another factor which would contribute to the higher accident rate would be the amount of "fussing" which must be done with these instruments, and the poor engineering often found in the controls with which one "fusses," and illconsidered warning indicators.

It is also not surprising that the more serious accidents occur on the XRF units. The higher energy spectrum from the Tungsten target, and the broad beam used both contribute to the potential for injury. Another factor is that there is not much room in the sample chamber so exposures are close to the port where the rates are highest.

From accident reports I have read, an interesting observation arises. While XRD accidents are often inadvertent or due to inattention, the XRF accidents are usually due to violation of hardware constraints. In other words, to get into an accident with a fluorescence unit someone had to work hard at it and do it deliberately, with the help of tools. For the purposes of punitive action which may be taken against an employee who violates the rules, or for increasing the liability of an employer who allows such practices, the "use of tools" is a significant indication of the deliberacy of an act.

Relative Use Risk

This rather cryptic heading, for lack of imagination to come up with anything better, is to indicate a discussion of the relative risk associated with various operations involved in the use of analytical x-ray equipment.

The routine user is the safest. Just changing samples, making minor adjustments and recording data presents reduced opportunity for primary beam exposure. Even this risk can be reduced by allowing the necessary adjustments to be made without the use of x-rays. Light alignments or lasers, sighting devices and alignment jigs can all help reduce the potential for accident here.

The more advanced user, by virtue of his greater involvement in machine adjustments, which cannot be as easily done without x-rays, is exposed to a greater risk. In addition, these tend to be your more experienced personnel and the ones you would least like to be without as a result of a disability suffered from an accident.

Service is of necessity the more invasive operation with any piece of equipment. Safety features usually have to be overridden and the majority of the safety protection is in the competence and experience of the individual. Also these are usually the cases when the beam is the least collimated and times spent in high dose rate positions is greatest. Some of the most severe accidents recorded have arisen from service operations. The biggest help for the service person is the area monitor. More about that in the third part of this workshop.

Typical Causes of Accidents

I have already touched upon most elements of typical accident scenarios so this will be somewhat abbreviated.

Reviewing reports of accidents with analytical x-ray equipment is about like watching sitcoms on T.V. (a low x-ray emission one, of course); they are all the same. Only a few factors are responsible for most accidents. By addressing these few factors a great deal of safety can be gained. Of course, highly imaginative users can cause problems here but nobody really wants to get hurt.

There is often discussion of tight controls upon casual users and lesser controls upon experienced ones. Well both have accidents, just for different reasons. While inexperience may get the casual user into trouble, complacency and overconfidence will do the same for the experienced user. The controls applied should be only as flexible and loose as is necessary for the operations to be performed, allowing reasonable latitude for unusual circumstances.

This brings us to non-routine use. This is often a factor in accidents. It is usually argued that protection cannot be applied to analytical machines because, by their very nature all use is non-routine and a great deal of flexibility is required. If degrees of flexibility are honestly evaluated it can often be found that the vast majority of operations can be done with adequate protection.

Three factors almost always seem to come together in an accident. The first is various combinations of haste or hurry as deadlines draw near, late hours to accomplish the urgent tasks and a zeal that distracts attention and throws caution to the wind. The other factors are the overriding of interlocks, obscuring of indicators or generally disabling safety features to meet the requirements of the first factor or for non-routine use mentioned previously.

Rather than belabor the human tendency to engage in all of the above operations one should ask oneself why it was necessary to do these things to begin with. Safety cannot address the problem of deadlines and workloads nor should it squelch the zeal from which progress and innovation are born. But the problem of disabling safety features is usually due to poor or unimaginative engineering of the safety devices, or often an effort to keep costs down. Sorry, but adequate design with good safety is always more costly than just getting by! In light of the degree of potential injury and legal liability, is the less costly approach really less expensive?

At LBL we are very fortunate to have had very innovative in-house engineers to help solve many of our design problems, but an open dialogue between the user and the engineer has always been the most important factor in coming up with workable, and not too expensive, solutions.

Another factor in x-ray accidents is multiple users. One user sets up the machine for his use, then another alters that setup before the first user gets back to his work. The first does not know that any changes have been made and proceeds as though the machine has not been touched. This is often the case with multiple tube machines. Another time that this is true is a permutation of the previous situation when safety devices were disabled and not restored. Then a later user suffers for the mistakes of the previous one. Both of these problems can have

design solutions.

The use of fingers where manipulative devices such a tweezers, forceps or hook devices can be used is sometimes a causal factor in an accident. This is usually involved with operations such as the placement of beam tubes and the manipulation of manual shutters. Often the use of such tools will allow adequate use of the x-ray machine from outside a full enclosure.

The last factor is one I have dubbed "Attitude Accumulation". I think this is something we all do everyday. This is a matter of a violation of safety rules being reinforced by the lack of untoward consequences. The greater the accumulation of such positive feedback the greater the attitude of complacency and the confidence to go on to bigger and better things. If it was unnecessary to violate the rules to begin with, then this problem would not have arisen.

Post Accident Dosimetry

This is the last element of the measure of the problem. All the other discussion of dosimetry eventually comes down to here. You already know what can be done to measure x-ray intensities and how to consider the effects of beam size and energy. You also know what factors to look for which may have contributed to the accident. What you need to understand now are some of the factors which complicate this kind of dosimetry. If you as an x-ray user are involved in an accident you can be more aware of the kind of information needed from you to assist in dose determination.

Time delays from dosimeters or physiological effects can be one of the biggest problems in delaying proper action to abate the situation or, when necessary, in providing prompt medical care. This can be remedied with immediate warning devices, such as alarming area monitors, but when these are unavailable recollection may be necessary to reconstruct the situation with what is called a "time and motion study".

Recollection can be especially difficult for routine operations. It is often difficult to try to recall what you may have done differently 2 weeks to a month ago in an operation you do several times a day. Trying the best you can is often all that can be done.

Also information can be gained from sleuthing out some clues.

For machine malfunctions, anomalous results from recent analyses can indicate the onset of failure. Also anything different in workloads, time constraints, and personnel could help.

What this all comes down to is that the human factors are by far the largest variables effecting the accuracy of post accident dosimetry and attempting to apply advanced measurement techniques may be an attempt to fix precision where none can be gotten.

Sometimes as a result of such investigation it is necessary to decide if there has in fact been an exposure accident or if the dose estimates are in alignment with physiological symptoms. In some cases you may even find that other agents are responsible

for the effects noted.

It is appropriate that the next speaker will discuss the effects of acute exposure since in an accident situation this is where the reconciliation of exposure calculations would lead us.

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[1]B. Lindell, "Occupational Hazards in X-Ray Analytical Work," Health Physics Vol. 15, pp. 481-486 (1968).

[2]R. Jenkins and D. J. Haas, "Incidence, Detection and Monitoring of Radiation from X-Ray Analytical Instrumentation," X-Ray Spectrometry Vol. 4, pp. 33 to 42 (1975)

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