

LARGE-SCALE PROCESSING OF PLUTONIUM:
RADIATION PROTECTION UNDER COMMERCIAL CONDITIONS

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(For Presentation Only)

Introduction

NUMEC broke ground for the world's first commercial plutonium laboratory on Monday, September 28, 1959. Just two years before, NUMEC had begun uranium operations in Apollo, Pennsylvania. So, the newly formed company displayed remarkable vision and courage to commit itself fully to the commercial exploitation of the most toxic material in the fuel cycle.

The facility was finished in May of the following year and plutonium received a month later in June. But it was March, 1961 before the USAEC granted a license and the plutonium could actually be handled. Since this was the first license ever granted for plutonium, the Commission was understandably cautious. They formed a review group, made up of health physicists and other safety professionals from USAEC plutonium facilities, to study the application and to inspect the finished facilities. What resulted was a consensus of the best safety practices in use at all of the USAEC plutonium plants.

Slide 1 - Overall View of Pu Plant

Today, the NUMEC Plutonium Plant is a complex of production and development facilities. It's situated on a site of 150 acres which NUMEC calls its Advanced Materials Center. The site is about 30 miles northeast of the city of Pittsburgh, Pennsylvania.

The original building was a 20,000 ft² research and development laboratory with 60 employees. After five separate expansions, it now has 61,000 ft² of space, mostly for production, and an employment of 300. The evolution isn't finished; two more additions of 14,000 and 4,000 ft² are planned. However, after these last two additions, future expansions will be separate buildings on the site. The first of these separated buildings will house a plutonium incinerator, expected to be in operation during 1970.

Several other facilities are also located at the Advanced Materials Center, including an Energy Conversion Laboratory, a Metals Plant, Machine Shops and a Hafnium Plant. The last large addition to the Plutonium Plant houses a core and bundle assembly facility. The Health and Safety group which services the Plutonium Plant also serves the entire Advanced Materials Center.

Slide 2 - Annual Inventory of Plutonium

The growth and the basic change from an R&D laboratory to a production plant is reflected by the annual inventory of plutonium reported each year on June 30. This is a log plot, so it's not misleading to say that the growth of the facility has been exponential over the past nine years. This inventory graph shows peaks connected with two major metal alloy contracts: ZPR III and ZPPR fuel wafers. Each job, when it was processed, was the largest plutonium fuel fabrication order ever given to a commercial plant.

Slide 3 - Overall View of Fab 1

Plutonium work was originally performed in gloveboxes designed after Argonne National Laboratory. They were quite satisfactory for the original R&D work done on small quantities of plutonium with low percentages of the 240 and 241 Pu isotopes. But with recycle plutonium the boxes had to be modified

for protection against gamma and neutron radiation. You can see the lead glass and lead impregnated vinyl shielding. The port covers and some gloves are also leaded. The slide also shows the principal features of the Argonne glovebox. It's made of stainless steel framing, gasketed homalite windows, bakelite glove ports with double O-rings, neoprene gloves and features High Efficiency Particulate Air filtered air intakes and exhausts. NUMEC innovation was the use of a ballast by-pass filter to allow reserve ventilation capacity in case of a gross glove failure. The relatively small inlet filter on the Argonne glovebox also limited the air sweep in the box.

Slide Off

Airborne radioactivity has always been recognized as the chief existing hazard in a nuclear fuels plant. Traditional monitoring for this hazard has been by fixed location air samplers and by analysis of urine samples for excreted radioactivity. Air sampling measures the concentrations of radioactivity in air to which operators are exposed and urine sampling is supposed to indicate how much radioactivity has accumulated in the operator.

It's been generally felt, up until recently at least, that permissible concentrations measured by fixed station air samplers and urine excretions below certain reference levels indicated acceptable working conditions for nuclear fuel handlers.

Experience we gained from evaluating accidental exposures to airborne radioactivity and developments in the radiation protection literature, particularly the publishing of a new ICRP Lung Model in February, 1966, led us to doubt the adequacy of these traditional monitoring methods. We noticed, for instance, very high fecal excretion following an accidental exposure to PuO_2 with hardly

any radioactivity excretion in the urine. In addition, high uptakes were often connected with relatively low fixed station air sampling data.

These reservations about the value of urinalysis and fixed location air sampling motivated us to experiment with routine personal air sampling and fecal analysis. We also began in vivo gamma counting of our employees.

These methods of exposure evaluation uncovered a frequency and severity of exposures greater than urinalysis and fixed location air sampling had indicated.

We used the traditional monitoring methods to their best possible advantage. For instance, our fixed station air samplers were located at particular work stations where the airborne radioactivity was expected to be highest. Some radiation protection specialists feel that fixed station samplers should be located where average or "general" air concentrations might exist. However, we placed our fixed samplers on hoods and gloveboxes. The practice at some plutonium facilities is to put them on walls.

We had to search diligently to find a commercial vendor whose urinalysis technique for plutonium had enough sensitivity to measure below reference levels. Our cost more than doubled as a result of our insistence on quality analysis. We also collected true 24 hour samples, something not always done in a urine sampling program. We have also been able to make corrections to 24 hour values from a single sample by making specific gravity measurements. LASL data shows good correlation between basic metabolism and specific gravity of the urine.

We used the traditional evaluation techniques and practices but believe that

our personal air sampling, fecal analysis and in vivo counting supply an even superior analysis. Let us examine our rationale and some of our data.

Slide 4 - Metabolic Pathways

This chart is reproduced from ICRP publication 10 on bioassay. The principal route of entry for uranium and plutonium into the body is by inhalation. Entry through a wound is serious also, but is restricted to infrequent accidents. Plutonium and uranium is poorly absorbed through the skin or GI tract lining. So the original place of deposition of either element is in the lung. Only if the inhaled particles of nuclear fuel "dissolve" does any of the radioactivity cross the lung membrane and enter the circulating blood where it can be transported to various internal organs. Urine excretion can only indicate the presence of radioactive material which has "seen" the circulating blood. Thus, relatively insoluble oxides of plutonium and uranium tend to accumulate in the lung. Clearance is chiefly to the GI tract and, hence, appears in the feces. Even "soluble" forms of heavy metals are excreted principally in the feces, by way of the liver bile. Even just an elementary consideration of the metabolic pathways for radionuclides in the body dictated, to us at least, the importance of fecal sampling.

Slide 5 - Lung Model

When the ICRP lung model was revised, it became clearer to us how fecal excretion data could be used to estimate lung burdens of inhaled radioactivity. The model postulates deposition in three regions of the respiratory tract: the nasal-pharynx region, the trachea-bronchial region and the pulmonary portion of the lung. The relative deposition in the various parts of the respiratory tract is highly dependent on the particle size of the inhaled particles. This varies for deposition in the pulmonary lung as a function of mass median diameter.

For a one micron MAD distribution, pulmonary deposition is 24% of that inhaled. The rest is deposited in the upper parts of the respiratory tract or exhaled.

Slide 6 - PuO₂ Clearance

I've shown the clearance of nuclear fuel oxide from the lung in this slide. A partitioning occurs depending on particle solubility in the lung. A very small fraction enters the bloodstream early and late, while the much greater fraction is cleared via the GI tract in the feces. Lung clearance, and hence fecal clearance, occurs in two distinct phases. The first phase we designate early fecal clearance. This is made up of the particles cleared and swallowed within minutes from the nose, throat and ciliated portions of the lung and those cleared during the first few days from the unciliated pulmonary lung. Ciliated cells in the upper respiratory tract keep a mucous layer in constant motion, moving deposited particles to the GI tract. It's this basic mechanism that keeps us from drowning from all the ordinary dust we breathe.

Early fecal clearance data can be used to estimate the magnitude of single exposures. One merely estimates the fraction cleared and calculated the total activity inhaled. This procedure is complicated with the new lung model, because it is particle size dependent, but in our reported exposures, the calculation is very simple. We estimate 62.5% of inhaled activity appears in the early fecal clearance. This makes only the assumptions inherent in the existing MPC_a's.

When material is cleared from the lung, it still must traverse the GI tract. This can take 18 hours or more. So depending on when the last bowel movement

occurred, the first radioactive material won't begin coming out of the "pipeline" immediately after the inhalation, but sometime later. Often the second fecal sample after a special bioassay sampling has been initiated is the highest. Sometimes it is the first, but we've seen cases where it takes five days to appear.

Later fecal clearance is much slower and consequently, the amount of material cleared each day is much smaller than during early clearance. Theoretically, the late fecal clearance should be a straight exponential function representing a monotonically decreasing single compartment. This would allow calculation of an individual's lung burden from late fecal clearance data. We've done this on occasion, but it's difficult, because early fecal clearance from even permissible exposure can mask the late clearance. We've learned that individuals must be kept away from any possible exposure 5-7 days in order to get late clearance data, unperturbed by early clearance. Another difficulty is the unsimple power function form which late fecal data often take. Late clearance from the lung may be more complicated than the ICRP task force had imagined.

But in any case, fecal clearance follows a pattern of high early fecal excretion which decreases rapidly in a few days to the late fecal clearance. Late clearance falls off very slowly with half time running up to months and years.

Slide 7 - Phase I and II Clearance

An example from our own data shows bioassay data from an exposure to uranium oxide.

The fecal data clearly show the two phase characteristic. With a biological half time of a day and a half, the early fecal clearance drops off in 5 days and merges into the slower second phase. The urine data, on the other hand, do not follow any clear pattern and, furthermore, are not even remarkable, even though the fecal data demonstrate a sizeable lung burden.

Perhaps a word about how these bioassay data are presented would be useful. One needs to know how the excretion rate changes with time to be able to calculate body burdens. So bioassay samples are collected over a period of time, long enough to allow the pattern to develop. This is one of the drawbacks of estimating body depositions from excreta data. One is guessing how much water is in the pail by observing the rate of a slow leak. Conventionally, the time unit is taken as a 24-hour day. Thus, to be completely accurate, total excretion must be collected and analyzed for the entire 24-hour period being measured. The activity excreted per day is then plotted against time in days.

Slide 8 - Acute Exposure Data

The real value of fecal analysis and in vivo counting is vividly demonstrated here. This exposure occurred when the gloves blew out of a glovebox from a propane torch gas leak. When urine samples were just collected, they were negative. However, the early fecal clearance, and the in vivo counting showed an overexposure. Based on the fecal and in vivo data, the consulting physicians decided to subject the patient to chelation therapy. Immediately, the formerly negative urine excretion jumped to substantial levels. Over the next few months levels in both urine and feces were elevated, but slowly decreased. The total radioactivity excreted as a result of the chelation therapy was a substantial fraction of a permissible lung burden. The actual

lung burden, measured long afterwards, was less than two nanocuries. If fecal analysis and in vivo counting had not been performed, it would have been decided, based on the negative urine data, that no uptake had occurred. No chelation therapy would have been performed, and the patient would have carried around an appreciable lung burden for a long time afterwards.

Slide 9 - Late Excretion Data

This is an example of how late fecal clearance enabled us to estimate a lung burden too small for the in vivo counting technology at the time to detect. The positive fecal excretion was discovered some time after the exposure had occurred, during a period when we were routinely screening for exposures by doing random sampling. We no longer use fecal sampling for any purpose other than evaluating exposure. We followed this individual for 200 days, during which the fecal excretion fell off exponentially. This allowed us to estimate a lung burden at time zero of seven nanocuries. The biological half time was 100 days, very close to the 90 days predicted for "soluble" plutonium by the ICRP lung model. The urine excretion, during the whole period never exceeded any applicable reference level. For example, the UKAEA reference level is .44 d/m/day. The urine excretion in this case remained well below reference levels throughout the entire period. The urine data would not have caused any particular concern even though it was positive. The University of Pittsburgh Graduate School of Public Health has since increased the sensitivity of their counter for plutonium, and the burden would now be detectable on their machine.

Slide 10 - Urine Versus Fecal Data

The value of routine fecal sampling in a plutonium plant is demonstrated in this slide. The excretion rates via feces and urine are plotted against each

other for cases where samples were collected the same day. The horizontal dotted line represents expected urine excretion from a maximum permissible body burden of plutonium. As you can see, most of the urine data are less than this value and would be considered evidence of permissible exposure, if that's all the information which was available. But the fecal data give an entirely different impression. Almost all the data exceeds a fecal excretion rate of 50 d/m/day, which represents the excretion from a permissible lung burden. Many of the fecal data may represent early clearance and thus would not be necessarily unpermissible. However, it is obvious that urine data by itself gives a false impression of actual exposure. The information presented here caused us to investigate and correct conditions of which we had been unaware. It is likely that personal air sampling, fecal analysis and in vivo counting would result in vastly different exposure levels for any nuclear fuel facility which is depending entirely on urine and fixed station air monitoring.

Slide 11 - Fraction of Inhaled PuO₂ in Early Fecal Clearance

As mentioned earlier, it's possible to use the very simple 1959 model to calculate how much PuO₂ has been inhaled by assuming that 62.5% of the inhaled activity appears in the early fecal clearance. All current MPC_a's are based on the 1959 lung model. However, the 1966 lung model is particle size dependent. The fraction of the inhaled PuO₂, appearing in the early fecal clearance, is drawn here as a function of the particle size distribution. The recommendation when the particle size is unknown is to assume a 1.0 micron AMAD distribution. The fraction of the inhaled activity then appearing in the early fecal clearance is 42.5%. Whether you choose 62.5 or 42.5%, it's interesting to note that you can only over or underestimate the activity inhaled

by about a factor of 2, no matter what the particle size. This makes fecal sampling at least as accurate as air sampling exposure.

Slide 12 - Pulmonary Deposition Shown by EFC

Of course, the health physicist is more interested in what the actual long term lung burden will be than in how much radioactivity is inhaled. Here significant errors can be generated by using early fecal clearance to estimate pulmonary deposition. For instance, only 0.02 nanocuries of PuO_2 are deposited from a 50 micron AMAD distribution for every nanocurie in the early fecal clearance. About 0.3 nanocuries is deposited per nanocurie for 1.0 micron AMAD. But more than a micron is deposited in the deep lung for every nanocurie in the early fecal clearance when the size distribution is 0.05 microns. Thus an underestimate of a factor of three and an overestimate of a factor of 15 are possible, if early fecal data is used to estimate pulmonary deposition without particle size data. This is one of basic weaknesses of the use of fecal sampling in exposure evaluation. Otherwise, it is superior to urinalysis.

Slide 13 - Urine Data in Pu-238 Exposure

The potential danger in relying solely on urinalysis is clearly illustrated in this slide. This is not NUMEC data, but is from an individual exposed to $^{238}\text{PuO}_2$ at another laboratory. The initial urine levels after the accidental exposure were quite low, and it was thought that no uptake had occurred. However, beginning some 50 days after the exposure had occurred, the urine levels began to increase and rose until they peaked out several hundred days after the exposure. What was happening was the slow transfer of ^{238}Pu from the lung to the bone. Finally after several hundred days, the plutonium excreted in the urine fell off, following Langham's classic power function.

Only then was the true extent of the man's deposition known. He had inhaled a lung burden of more than 0.12 microcuries, 3 times the permissible skeletal burden and eight times the permissible lung burden. Had fecal analysis or in vivo counting been employed, chelation therapy would have been indicated and, possibly, a large fraction of the final body burden could have been removed. Furthermore, the man's lungs were subjected to an average annual dose of 120 rems without any realization until 2 or 3 years had elapsed. As it is the man will be restricted from radiation work for the rest of his life.

The main trouble with using excretion data to estimate body burdens is that it takes time to establish the excretion pattern. Time can't be afforded whenever action, be it a medical decision or a decision to correct an exposure problem, is needed promptly. In addition, these excretion models really only represent single acute exposures. They're good for evaluating accidental exposures. But, we're also interested in evaluating chronic exposures, where body depositions accumulate from many small exposures. These dual necessities, prompt evaluation and unambiguous interpretation of chronic exposure, have led us to consider in vivo counting as the method of choice for evaluating internal deposition of radioactivity.

Slide 14 - Whole Body Count Spectrum

This shows the spectrum for the first individual we ever body counted. It's the same person we showed earlier whose bioassay data showed the effect of chelation therapy after originally negative urine and positive fecal data. The 60 KeV peak of Am-241 is very prominent and easily measured. This success led us to count many of our plutonium workers with equal success.

Also, other data raised questions in our minds about the validity of using late fecal clearance to estimate lung burdens. Sometimes both the fecal and urine excretion rates fall off faster than the lung burden. In vivo chest burden falls off exponentially, but not the excretion data. Another interesting aspect of this sort of data is that excretion does not always account for all the radioactivity leaving the lung. The amount excreted per day is less than the daily decrease in the lung burden. This can only mean that translocation from the lung to other organs is taking place.

Slide 15 - Comparison of Urine, Fecal and In Vivo Counting Sensitivities

To assist you in understanding the relative value, of the three ways of evaluating internal radioactivity, I've prepared this slide. It shows the calculated minimum lung burdens of PuO_2 which can be detected by urinalysis, in vivo counting and fecal analysis. The calculations are for a single exposure and give the minimum lung burden detectable as a function of time after the exposure. As you might expect, the sensitivity of both fecal sampling and in vivo counting decreases with time since the lung burden clears with time; note that the urine sensitivity gets better the longer you wait before sampling. This occurs because plutonium transfers slowly from the lung to the circulating blood until finally, at several hundred days, urinalysis is the most sensitive indicator.

The extreme sensitivity of early fecal clearance for detecting and estimating single small exposures is truly remarkable. Even a single days' exposure to the soluble plutonium permissible concentration is easily measured.

Urinalysis doesn't even detect a permissible lung burden until the second day. Even then detection won't enable you to really know whether the individual

has an important lung burden. You'll just know it's detectable.

In vivo counting is intermediate in sensitivity, at least for the first several days. But that fact doesn't tell the whole story. When a lung burden is detected by in vivo counting, it is also directly measured.

The importance of this advantage cannot be over stressed. Excreta numbers are always delayed because of the time required for analysis, may be ambiguous, and repeated measurements are always necessary.

I made the following assumptions to make these calculations. First, the minimum detectable PuO_2 lung burden is 3 nanocuries. This assumes that 10% of the alpha activity is ^{241}Am and that the counting system can detect 0.3 nanocuries of ^{241}Am in the lung. Both assumptions are conservative for our situation. Secondly, 0.08 d/m per 24 hour sample can be detected in the urine. This actually is very difficult. I know only one commercial vendor who can do it. It can't be done reliably, except by using ^{236}Pu tracer and low level alpha spectroscopy. I've put a less stringent limit of detection for fecal analysis of 1 d/m per sample. This is easy with good technique.

Slide 16 - Urine Excretion From Continuous Exposure to Plutonium

Urine excretion from continuous exposure to plutonium is a very poor method on which to base control. For instance, only after 90 days of continuous exposure to 10 times the maximum permissible concentration does the urine level reach a reference level. This reference level is not the permissible level, but only the level at which the urine excretion begins to be followed by the health physicist. So, if urinalysis is the sole indicator of hazard, you wouldn't begin to suspect that operators were even being exposed until 900 MPC-days or 7200 MPC-hours of exposure had occurred. A lifetime of

exposure to MPC_a is necessary before the urine excretion reaches the reference level.

Slide 17 - In Vivo Counting Sensitivity for Chronic Exposure

A similar treatment for in vivo counting of PuO_2 lung burdens shows the great advantage it has over urinalysis. At its limit of detection, it can warn the health physicist when as low as 240 MPC-hours of exposure has occurred. This allows detection of $10 MPC_a$ in 3 days or MPC_a in 30 or even a tenth of MPC_a in several hundred days. The added advantage of an immediate estimate without ambiguity adds to the case for in vivo counting.

Slide Off

Because airborne radioactivity is the chief hazard in a nuclear fuel plant, air sampling is an important part of any health program. Although air sampling accomplishes many ends, its primary purpose is the determination of personnel exposure to airborne radioactivity. In fact, since Part 20 of the US-CFR is written in terms of individual exposure, the law compels the health physicist to estimate the radioactivity which each radiation worker inhales.

The problem is, does the air sample represent what the worker is breathing? Some vague ideas about the nature of industrial airborne activity have led to elaborate fixed station air monitoring systems. One common notion is that air activity takes the form of a rather large cloud which disperses throughout a room. Another concept is that, except in accident conditions, air activity consists of isolated particles randomly distributed in the room air.

Slide 18 - Local Exposure Concept

Our experience presents a completely different picture. We believe almost all

industrial radioaerosol exposures are extremely localized in space. This is a training slide we posed to illustrate the wrong way to work with a hood. Of course, work should be done inside the hood. The smoke was made with an MSA smoke tube, and the bottle is painted yellow to look like uranium. But the slide is a clear example of what we mean by a local cloud.

Slide 19 - Personal Air Samplers

To detect the small localized releases, we began using personal air samplers in 1965. These are battery operated air pumps worn on a belt with a sampling head attached to the lapel. Hence, the sometimes used term -- lapel samplers. The samplers will operate for 8 hours before recharging. The air flow is small -- about 2-4 lpm -- but enough to allow easy detection even for the soluble MPC_a for plutonium, if it's worn the entire shift. Shorter wearing periods are possible for uranium and insoluble plutonium.

Slide 20 - Local Releases in Plutonium Glovebox Work

Plutonium glovebox releases, especially, follow steep concentration gradients. In this posed example the operator is coming out of the gloves to check his hands on the alpha meter. He will find them contaminated because a hole developed in the left glove. As soon as he is aware of the contamination, he will put on a respirator, cover the port, survey the area and change the glove. But he will have already been exposed to the small cloud generated when the glove was inverted. We have found that fixed station samplers, like the one in the background, rarely detect these local releases, even though we place them close to work stations.

Although these photographs were staged with MSA smoke tubes, NUMEC experience with lapel samplers strongly suggests that uranium and plutonium aerosol clouds, although invisible, take exactly the same shape. The typical

airborne release is a small cloud which quickly disperses to unmeasurable concentrations with relatively little surface contamination. In our experience floor contamination does not necessarily mean you have an air inhalation problem now, but it surely means you had one earlier.

Slide 21 - Ratio of Lapel Sampler Concentrations to Fixed Air Sampler Concentrations

NUMEC uranium and plutonium workers have worn lapel samplers for several years. We find these samplers usually indicate higher concentrations than stationary samplers. Often the difference is orders of magnitude.

This slide gives a two year comparison of lapel samplers with fixed station air samplers. It shows the lapel to fixed station ratio distribution for 594 BZ samples at our plutonium laboratory and 459 at our uranium plant. The sample durations were for single shifts, an eight hour workday. The fixed station concentration is either the average of those in the worker's area or the one closest to his work station. Actually we found little difference between fixed station "breathing zone" samplers and those intended to cover general area. The interval of general BZ - GA agreement (+ 100%, - 50%) covered 27% of the plutonium BZ samples and about 19% of uranium plant BZ samples. Notice that almost 9% of Pu BZs are less than 50% lower than the GAs. Sixty-four percent of Pu BZ's exceeded the GA concentration by a factor of 2 or more, 23% by more than a factor of ten. The highest ratio we've ever detected was 9,870. Thirty-five percent of uranium plant BZ concentrations exceeded 10 times the fixed station concentrations. While the median of these ratios is less than 10 for both plants, the very skewed distribution makes high level exposures very important in computing the average exposures.

Slide 22 - Log Probability Plot of Personal/Fixed Station Ratios

This presentation gives the same two year comparison of personal air sample concentrations with fixed station air samplers. The UKAEA data is from Fraser. These log-normal distributions tell an alarming story. When the BZ/GA ratio equals one, the personal air samples agree with the fixed position air samples. This happens less than 10% of the time. The rest of the time, the personal air sampler shows higher concentrations than the stationary sampler. Observe that at NUMEC more than 10% of the personal air samplers were greater than 20 times the fixed location samples. (X10 for the UKAEA data).

Slide 23 - High Level PuO₂ Personal Air Sample Data

This presents a clearer idea of how important personal samplers are when high level exposures occur. The BZ/GA ratio data for all plutonium exposures exceeding 10 MPC for an eight hour shift is plotted against the breathing zone concentration.

The first impression from this graph is the extreme variability of the BZ/GA ratio for a given BZ concentration. As an example, for those BZs between 40-50 d/m/m³ the fixed station concentration varied from one half to one eight hundredth of the BZ concentration. It is difficult from this data to pick out a suitable factor (such as the UKAEA has done) by which to multiply the GA concentrations to obtain individual exposure.

Another thing to notice is the upward trend in the BZ/GA ratio as the BZ concentration increases. Basically this means the worse the problem is the more incorrect the fixed station data.

We have drawn in the line where the fixed station air sample would indicate the soluble MPC_a for plutonium. For all data above the line the GA was less than MPC. Only those GA's below the line even indicated that a hazard existed. This is an important point. Many industrial radioaerosol exposures are going unnoticed because the nuclear industry is depending on fixed station air sampling.

Slide 24 - Correlation of Personal Air Sampling and Early Fecal Clearance

The lapel sampler data would not be relevant, if it did not represent true exposure. For this reason, whenever an exposure occurred, the operator was removed from radiation work and both fecal and urine samples were collected. Figure 7 gives the correlation between BZ sampling and early fecal clearance for plutonium exposures. The eight cases shown were selected from almost a hundred exposures because total fecal and urine data was available for the first seven days post exposure and because there was no recent prior exposure to complicate interpretation. Early fecal clearance was chosen as the exposure criteria because of earlier experience with urine and fecal sampling at our Plutonium Laboratory.

There is remarkable agreement between the proposed ICRP lung model and the lapel sampler data. The line represents expected 72 hour lung clearance for insoluble one micron MAD PuO₂ particles.

The failure of fixed station samplers could not be more graphic. We might also add that urine sampling did not demonstrate these exposures. Except for the highest plutonium exposures, no perturbation in urine excretion could be detected.

Slide 25 - Local Cloud Gradient Concept

Many radiation protection workers feel that breathing zone sampling is too difficult for routine evaluation. We believe it is absolutely necessary and can be easily done successfully with personal air samplers. This figure demonstrates our concept. Nearly all radioaerosol sources are small; generally the worker's hands are the major aerosol generator. In static room air conditions concentrations will fall off with the inverse cube of the distance. If the distance from the hands is doubled, the concentration will be lower by a factor of eight. We have verified this by experiment.

The usual turbulent condition is more complicated. Still, the concentration gradient will be steep and any fixed station air sampler a few feet away will underestimate the man's exposure.

Breathing zone sampling is usually recommended on the vague intuition that the closer the sampler is to the nose the better. NUMEC and UKAEA experience provides a more convincing basis for personal air sampling. The worker handling radioactive materials lives in a "micro-climate" which must be sampled if the health physicist is to detect industrial radioaerosol exposure.

Slide Off

In summary then, the best exposure evaluation technology available must be used. We've found a greater incidence of exposure in plutonium plants than has been suspected, because we're using personal air sampling, fecal analysis and in vivo counting. If we had relied on the more traditional methods, more design and procedural changes we've instituted in our plants would not have been made and our employees would still be unknowingly receiving excessive exposures. Instead, with the utmost cooperation of our management, we've

Thank you.