To The Graduate Council:

I am submitting herewith a thesis written by Mike Henderson entitled "Evaluation of Radiation Exposure in Depleted Uranium Processing Areas". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

James E. Turner

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EVALUATION OF RADIATION EXPOSURE
IN DEPLETED URANIUM PROCESSING AREAS

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Mike Henderson

May 1991

ACKNOWLEDGEMENTS

Dr. Thomas Kerlin and Dr. L.F. Miller deserve an acknowledgement for bringing the Radiation Protection Engineering program to fruition. The program provides professional training sorely needed in the nuclear industry.

Dr. David Simpson and Dr. Paul Frame are to be commended for their Health Physics training programs. Their enthusiasm for the subject matter they teach generates an overall interest in the Health Physics field.

I would like to thank Rhonda S. Bogard for providing the dosimeter results used in this thesis. The fact that her counting lab is Department of Energy Accredited reinforces the validity of the results.

I would also like to thank B.F. Rutherford and Jerry Hunt for providing me the opportunity to work for them in the Y-12 Health Physics Department. Their friendship, however, is more important to me than the work-related opportunities they have provided me.

But most important, I would like to thank Dr. James E. Turner. Jim's rare combination of expertise and humility provides for an optimum learning environment. His caring and accessibility guarantees everyone a chance to learn. Both the academic and the industrial communities benefit when someone possesses these qualities.

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1. Introduction

Historically at plants where uranium is processed, most of the radiological emphasis has been directed toward uranium enriched in the U235 isotope. In comparison, very little research has been conducted in the depleted uranium operations. As a result of the recent Department of Energy (DOE) and Technical Safety Appraisal (TSA) directives, assessments of <u>all</u> radiological operations at the Y-12 Plant in Oak Ridge, Tennessee are now required.[1]

New standards found in the National Council on Radiation Protection and Measurements (NCRP) Report No. 91[2] and DOE Order No. 5480.11[3] state that there must not be a potential for high non-uniform or extremity beta and gamma doses to employees and that proper dosimetry techniques be employed. Compliance with these standards must be confirmed by data generated from particular work areas. Until now, thorough studies of this nature have not been done at Y-12, or industry-wide, in depleted uranium operations. As a result, there have been insufficient data to verify compliance to the aforementioned standards. Not only must dose regulations be met, but there must be a continuous effort to implement " as low as reasonably achievable" (ALARA) principles.[3]

This research provides the needed data to assess the magnitude of non-uniform and extremity exposures in the depleted uranium operations, to reduce such exposures in keeping with ALARA principles, and to design an optimum dosimetry protocol for assuring continued compliance. More important, as a result of the research, operational changes were made that lowered the dose equivalent to the employees.

2. Sources of Radiation Exposure

Uranium used in weapons production and as a fuel in power reactors must be enriched in the U235 isotope. As a result, large amounts of uranium depleted in the same isotope are produced as a byproduct. This depleted uranium (U238) has various uses. It is melted, molded into billets, rolled and machined for military, commercial, and research usage. These form-change operations require extensive handling of the uranium, and the end result is a potential for high non-uniform and extremity beta and gamma doses to the employees. Since U238 is an alpha radiation emitter, most of this beta and gamma dose results from the daughter products, thorium 234 and protactinium 234, associated with the depleted uranium.[4] Because form-change operations are mostly recycle and mixed batch operations, all types of depleted uranium are often treated as a single entity. This categorization is not necessarily true from a radiological standpoint.

During the casting operations, the daughter products float to the surface of the molten uranium metal and are left as residue on the top end of the billet. The residue can give surface beta radiation readings of hundreds of mrem per hour. The top end of the billet, where most of daughter products are virgin piece of uranium with a much lower beta and gamma dose rate. The radiological problem arises from the ultimate use of these top-end pieces.

As stated earlier, depleted uranium types are often treated operationally as a single entity. The operations people are concerned with hardness, brittleness, impurity content, and alloy percentage of the product being poured. These criteria determine whether a billet casting is successful or not. Therefore, the same radiation protection measures are used regardless of the type of depleted uranium being worked. When a batch of uranium has a disproportionately high number of the daughter product concentrated top end-pieces, the exposure potential to the worker is considerably higher than with normal depleted uranium batches. The increased exposure potential is a result of the high beta and gamma energies and large specific activity associated with the protactinium 234 daughter. Whereas the U238 parent is basically an alpha emitter with a specific activity of 3.3E-7 curies/gram, Pa234 emits a 2.29 Mev beta particle, a 1.00 Mev gamma ray, and has a specific activity of 6.8E8 curies/gram. By comparison, Pa234 has a specific activity that is 2E15 larger than the parent U238. Due to these disparities, there is now a categorizing of depleted uraniunm batches based on their concentration of top end pieces.

One type of concentrated top-end depleted uranium is used in the High Energy Physics Program (HEPP). The fact that this material poses a radiological problem was discovered during the initial investigative work of this thesis, and will be covered in Chapter 5, on Methods. Many of the dose reduction successes reviewed in this work are directly related to the handling of this particular type of depleted uranium. Any methods used to reduce exposures from this material will also work for the types of depleted uranium that contain a smaller percentage of the daughter products.

3. Job Categorization

Before any of the dose reduction goals could be accomplished, the jobs performed in the Y-12 depleted uranium melting operations had to be observed and categorized. Although the operations are continuous, the work is done in three different buildings: 9201-5 (A5), 9204-4 (B4), and 9998 (H1).

In the A5 area, depleted uranium billets are alloyed by electrical melting in consumable electrode arc melt furnaces and poured into molds. This process is called Skullcasting. Also, various uranium casting, cleaning, loading, sawing and welding jobs are performed. There is a lot of uranium both in billet and scrap form. These jobs have the potential to produce large amounts of uranium oxide, resulting in a large potential for contamination and employee exposures. Shielding, ventilation, proper protective clothing and good housekeeping are imperative when performing the operations. The largest contributor to employee doses received in A5, however, is not from these operations, but is related to work with the HEPP material cycle.

The initial processing of the HEPP cycle begins in the HEPP Reclamation Area where the smallest pieces of HEPP scrap arrive from an outside vendor. These pieces arrive in dedicated containers that must be returned as quickly as possible to the vendor. Consequently, the HEPP material must be removed from the containers and put into smaller tote pans for storage. When needed, the HEPP material is eventually removed from the tote pans and loaded into carbon melting crucibles for transportation to the H1 Foundry to be processed. Both of these loading/unloading processes are extensive hands-on operations. Ultimately, the operators spend many hours actually holding the HEPP material in their gloved hands. Most of the employee doses received can now be traced to this type of operation. When the scrap pieces are too large to easily fit into the crucibles, they must be sheared. The pieces going to the shear machine must also be handled. After shearing, some of the material goes into the melting crucible for transport. Any excess sheared material is stored in another tote pan, thus requiring another hands-on operation. Scrap requiring special cleaning is sent in pans to the H1 Foundry for acid cleaning.

The H1 Foundry takes huge quantities (thousands of kilograms) of depleted uranium scrap and reclaimed parts and turns them into various large sized billets and ingots, which eventually are rolled, cut, and machined into workable forms. These processes create more scrap; and by adding scrap from other uranium processing plants, the cycle is continuous.

Some of the pans arrive from A5 with scrap that requires acid cleaning. The scrap is dumped into a basket located by the acid bath. This procedure results in some oxide becoming airborne. Crucibles also arrive from A5; but due to the large weights involved and the shipping problems presented, these crucibles are only partially loaded. Upon arriving at H1, the crucible holding capacity is increased by using an extension ring, and additional scrap is added until the desired pre-pouring weight is achieved. This process is called Charge Make Up (CMU), and represents another extensive hands-on operation for the employee. In addition to handling the HEPP, the extension rings are also handled. Since they are reusable, many have been involved in the cycle hundreds of times. As a result, when surveyed for radiation, most of the rings show very high readings. Since the CMU operator hand rolls these extension rings from storage, loads the ring onto the crucible, and leans over the ring for an extended period of time while filling the crucible, the rings represent a potential radiation exposure to the CMU operator. It is not uncommon for the crucible filling operation to last one-half of a working day. Also, on many days, several crucibles are filled. The result is extensive uranium handling and large segments of time spent in the proximity of the uranium by the CMU operator.

The filled crucible is loaded with a graphite mold into a furnace can and placed into an induction type furnace where the uranium is melted and poured into the graphite mold. After cooling, the newly formed uranium ingots must be removed from the molds. The ingots are sampled by using a drill press and marked for identification.

In the B4 area various operations such as heat treating, forging and cleaning are performed. The main purpose, however, is the forming of weapons parts from depleted uranium billets and pre-formed uranium plates from the H1 Foundry. Most of this forming is done on huge 1500 ton presses. The heating of the uranium plates, banging of the presses, and constant handling of the plates, all present employee exposure potential. Perhaps the most exposure prone task performed is the Grit-Blasting operation where the small electrode ingots of depleted uranium and niobium received from the H1 Foundry undergo shot blast oxide removal. Although performed inside of an enclosed vessel, the operation provides large quantities of shot and fine uranium dust which sometimes become airborne. Many parts also must be handled before, during, and after the oxide removal. B4 also houses the Coordinate Machine Measurement, which is a very precise dimensional parts measuring operation.

4. Assessment of Doses

Instead of using historical beta and gamma surveys of the operating areas in an attempt to assess dose and potential dose, personal thermoluminescent dosimeter (TLDs) results were used. TLDs store radiation energy, which is emitted as light when they are heated. By calibrating the devices, the amount of light emitted is used as a measure of the dose. The Harshaw Beta and Gamma Dosimeter is the personal TLD used at the Y-12 Plant. It measures shallow dose equivalent at the basal-layer skin level, 7 mg/cm^2; at the depth of the lens of the eye, 300 mg/cm^2; and at a depth representing the whole body organs, 1000 mg/cm^2. The measurement is accomplished through the use of four lithium fluoride elements. Element number one uses a .015 inch thick chip with a 1000 mg/cm^2 plastic filter to measure deep dose equivalent. Element number two uses a .015 inch thick chip with a 300 mg/cm^2 plastic and copper filter for x-ray discrimination. Element number three uses a .0036 inch thick chip with a 7.5 mg/cm^2 Mylar filter to measure shallow dose equivalent. Element number four uses a .015 inch thick chip with a 300 mg/cm^2 plastic filter to measure the lens of the eye dose equivalent.[5]

Employee TLD dose results from the previous five years were used to assess the areas with the highest exposure potential. Each area was broken down on a job-specific individual basis to try and pinpoint the actual reason for the exposures received. In addition, TLDs not assigned to specific employees were used in various configurations to assess the whole-body, extremity, and non-uniform dose potential for the employees performing specific tasks.

To assess the potential for non-uniform exposures, stanchions were constructed to a height of six feet. From floor level, TLDs were placed at an extremity height of one foot, a mid-range height of three feet, and for normally worn TLDs, a height of five feet. The stanchions were then placed in an area where a particular type of work was performed. On several of the jobs performed, the TLD corresponding to the normally worn collar level TLD read approximately 50% less than the TLD representing the mid-range and extremity part of the stanchion. The jobs being performed at these two levels required additional dose assessment. In some cases, this assessment required the design of a dosimetry system using whole body, mid-range, and extremity dosimeters to measure non-uniform beta and gamma doses. This assessment would also give an indication if the present methods of inferring dose to one part of the body from a dosimeter placed on another part of the body are valid. When the dose field is very non-uniform, then changes must be made to ensure employee protection.

Dosimeter results used for the assessment were provided by the Y-12 Thermoluminescent Dosimeter Processing Center. The Center has been formally recognized for demonstrating compliance with Department of Energy performance criteria for personnel dosimetry systems. The type of results needed for the depleted uranium area dose assessment is included in the thirteen categories for which the Processing Center had received DOE Laboratory Accreditation. Thus, the beta and gamma external radiation numbers used as the basis for this study are valid and verifiable. The Processing Center's automated readout provides these quantities to the nearest mrem. Although this level of precision is beyond the capabilites of the measurement system, the dose equivalents have been retained in this thesis exactly as reported by the Processing Center. The category titled "Shallow" includes the beta plus gamma dose equivalent in mrem, while the category titled "Penetrating" represents only the gamma dose equivalent in mrem.

5. Methods

Since many of the directives contained in the Technical Safety Appraisal concerned the 9998 H1 Foundry, and since this area has traditionally been one of the highest external radiation exposure areas at Y-12, H1 was chosen as the first area for observation.[1] By categorizing the H1 Foundry TLD data for the previous five years on a job-specific basis, it was apparent that the employees performing certain tasks were receiving larger doses than the rest of the people in the area.

This was particularly true for the Charge Make Up job (CMU). The data listed in Table I are a compilation representing all of the employees who performed a particular job, and served as a basis for prioritizing the methods used in the dose reduction.

Table I. Comparison of 1988 H1 Employee Dose Equivalent by Operation Performed.

OPERATION	YEAR	Shallow/Penetrating Dose Equivalent (mrem)
Charge Make-up	1988	4140/1272
Knockout-Acid Clean	1988	2808/ 804
Sampling	1988	1692/ 552
All Other Day Jobs	1988	1764/ 492

Although these numbers are within DOE radiation protection standard limits for shallow and penetrating exposure, additional measures need to be taken to meet ALARA principles and to verify compliance to extremity and non-uniform exposure standards.

The CMU operator works mainly with three types of depleted uranium. Consultation with the H1 General Foreman, along with timed observations of the job performed, revealed the maximum daily operational times the CMU operator spent handling the various materials. To give more relevancy, the tests were performed using these times for each respective uranium type. The three types of depleted uranium were isolated into separate storage arrays, and background radiation checks were made to ensure that the data from the tests would only represent the exposure from the material being tested. TLDs were used to obtain the initial data. As shown in Table II, the readings for all of the tests are in mrem, and represent the potential dose equivalent for the employee performing the listed job on a normal working day.

Table II. Potential Dose Equivalent Comparisons of Depleted Uranium Types.

TLD PLACEMENT	Shallow/Penetrating Dose Equivalent (mrem)
Directly on Derby material for one hour	285/10
Directly on 6% Niobium material for one hour	250/13
Directly on HEPP material for three hours	707/27

Based on the hourly rate, these data showed virtually no difference between the three types of material. Since distance is a known dose reduction method, tests were made to observe what impact, if any, removing the TLDs one foot from the material would have. Table III shows what the dose equivalent would be to the employee working this distance from the material.

Table III. Distance Related Dose Equivalent Comparison of Depleted Uranium Types.

TLD PLACEMENT	Shallow/Penetrating Dose Equivalent (mrem)
One-foot above Derby material for one hour	0/0
One-foot above 6% Niobium material for one hour	104/0
One-foot above HEPP material for three hours	226/16

These data showed that small changes in proximity of the employee to the material being worked with would have significant effects on the amount of exposure received. However, quite often this material must be handled by the employee. By putting a TLD inside the type of glove commonly worn, a general idea of the finger dose being received by the employee could be obtained. Table IV shows test results from the Neoprene synthetic glove that was worn during this time.

Table IV. Neoprene Glove Dose Equivalent Comparisons.

TLD PLACEMENT	Shallow/Penetrating Dose Equivalent (mrem)
Inside glove on Derby material for one hour	38/0
Inside glove on 6% Niobium material one hour	44/0
TLD inside of glove on HEPP for three hours	284/29

Although performing well in radiation protection on the Derby and the 6% Niobium depleted uranium material, the Neoprene glove was not providing adequate protection when the HEPP material was being handled. If these materials were handled 250 working days a year, the tests showed that the CMU had the potential for exceeding the extremity dose equivalent limits as set forth in DOE Order No. 5480.11.[3] Of this annual amount of dose received, 78% of the shallow exposure could be attributed to the three hour daily handling of the HEPP material. The HEPP program was new, and the HEPP material is not always handled that much per day. However, the program was expanding; and in actuality there was a potential for even longer daily handling times. There was also a chance that jobs in other operating areas could call for daily handling times in excess of those in the H1 Foundry. Table V gives an annual extremity dose to the CMU based on the present daily handling times and glove combinations .

Table V. Charge Make Up Annual Extremity Dose Equivalent.

Depleted Material	Shallow/ Penetrating (mrem per year)	Working Days Per Year		Shallow/ Penetrating (mrem per year)
Derby	38/0	250		9500/0
6% Niobium	44/0	250		11000/0
HEPP	284/29	250		71000/7250
			TOTAL:	91500/7250

The DOE limits for shallow and penetrating extremity exposures are 50,000 and 5,000 mrem, respectively.[3] The potential for exceeding the DOE limits was an unanticipated finding. Before this research, there was no indication that the problem existed. Obviously, the total exposure numbers were unacceptable. A solution needed to be found.

Lowering the exposure levels would require a combination of operational changes. In the short term, the quickest way to impact the problem would be to try to improve the radiation protection properties of the gloves being worn. Before spending a lot of time and money researching and testing glove combinations, a sample test needed to be conducted to see if changing gloves was a viable option for lowering the exposure numbers. Also, the validity of the dosimetry method being used needed to be verified. Since the HEPP material had the most dose producing potential, future tests would represent the three hour daily handling time for that material only. Any HEPP material exposure reduction properties the gloves possessed could be inferred for the other types of depleted uranium. The shallow dose would be the emphasis of the study. When reporting dosimeter results, the shallow dose includes the penetrating.

In the test a leather insert was added to the Neoprene glove. As shown in Table VI, as a method check, the test was run in duplicate. As in all of the glove tests, the three hour HEPP daily hands-on handling time was used.

Table VI. Methods Verification Leather Glove Tests Results.

Test	Daily Shallow (mrem)	Workdays Per Year	Annual Shallow (mrem)
1	188	250	47,000
2	196	250	49,000

Although this represented a lowering of the dose potential by 32% as compared to the Neoprene glove only, the readings were still unacceptable; and the problem would require further research. Test one and test two showed virtually the same results. For the results to be any closer, the TLDs would have had to be on the same piece of material in the exact same configuration. This showed that the readings being obtained were valid and, more important, reproducible.

As another form of verification, and to make sure that the TLDs were not being biased by other materials in the storage area, a test blank was run. A TLD was left uncovered in the center of the storage area for the same three hour period that the glove test was being run. Following are the shallow results in millirem for the test blank:

	mrem Per Day	Days Per Year	mrem Per Year
Three-hour blank	4	250	1000

The test showed that virtually all of the recorded exposure was coming from the material being tested. It also reinforced the validity of the tests. With the validity and the reproducibility of the tests proven, many glove combinations would have to be tested. Although many manufacturers list and rate their gloves according to performances on various tests, radiation protection properties are not included in these battery of tests. Therefore, many glove combinations needed to be tested with a goal of finding a combination that is safe, radiologically acceptable, and feasible from an operational standpoint.

By following the aforementioned methods to ensure the integrity of the tests and by using the same three hour daily handling of the HEPP material as a time frame basis, many glove combinations were tested. For the glove combination results that follow, a TLD was placed inside of the first material listed since this material is worn closest to the skin. Therefore, when the glove combinations were worn, the readings represent the radiation dose being received to the fingers. Since the tests only represent the HEPP material, the annual finger dose would be slightly higher when the other depleted uranium handling operations were included. The readings for the various glove combinations represent the potential annual dose equivalent to the employee performing the Charge Make Up (CMU) job.

Table VII. Glove Comparisons of Extremity Dose Equivalent.

Glove Combinations	Extremity Dose Equivalent (mrem Per Year)
Neoprene Only	71,000
Black Rubber Only	68,750
Welders Only	59,250
Thick Cotton - Black Rubber	59,250
Capeskin - Black Rubber	57,500
Surgeon - Capeskin - Black Rubber	50,750
Thin Leather - Neoprene	48,000
Thick Cotton - Orange Rubber- Black Rubber	47,000
Orange Rubber - Capeskin - Black Rubber	32,500
Capeskin - Used Kevlar - Welders	28,500
New Kevlar - Orange Rubber - Black Rubber	28,250
New Kevlar - Welders	20,500
Orange Rubber - Welders	17,750
Firefighters - Black Rubber	17,500
Lead Impregnated	15,750
Orange Rubber - Capeskin - Welders	14,250
Orange Rubber - New Kevlar - Welders	13,500
Firefighters - Neoprene	9,500

The glove combinations were then tested to see if the uranium handling jobs could be performed adequately. The firefighters and lead impregnated glove combinations allowed no flexibility; therefore, the uranium could not be adequately handled. The black rubber gloves proved to be too fragile, and some of the other combinations proved to be too cumbersome. The Kevlar gloves are preferred by the operators because they provide protection when handling sharp objects. However, since Kevlar is a metal stranded glove, it provides little radiation protection. The slightly used Kevlar, with the metal strands separated, was much inferior to the new

Kevlar. The most surprising finding from the tests is the ability of the orange rubber gloves to lower exposures, Although a basic commercial variety, Ansell AC-12, they made a significant difference in every combination they were part of. They are also cheap, abundant, and flexible. After reviewing all of the data, and giving consideration to the dexterity required to perform the various jobs, the following glove combination was recommended for all HEPP areas:

- Orange Rubber gloves worn next to the skin for radiation protection and the flexibility provided.
- Kevlar, with the metal strands as intact as possible, because the operators feel protected against cuts when wearing them.
- Welders gloves, worn on the outside, because they provide the best radiation protection of any of the gloves that were practical to wear.

Ideally, this combination will result in a 75% reduction in the exposure to the fingers for the applicable operators. The following memo was sent to the concerned parties apprising them of the findings and the suggested glove combination to be worn:

The recommended glove combination should result in a yearly extremity exposure from a three hour daily HEPP operation of between 13,500 and 17,500 mrem per year. By interpolating this glove combination's exposure reduction ability to the other, less dose producing material handled daily in H1, the overall extremity exposure to the Charge Make-Up operator will be between 18,000 and 22,000 mrem per year maximum. This is one-fourth of the amount that would have been received by the CMU if the glove changes had not been implemented. While these numbers are well within the new DOE limit of 50,000 mrem per year, any more exposure reduction will have to be accomplished through lower handling times, proximity changes, and different methods of making up charges.

One of these method changes for making up charges is the removal of one of the crucible filling handling steps. Originally, when the larger pieces of HEPP being processed in the A5 had to be sheared, the uranium coming out of the shear was placed in pans and stored for future use. At a later time, the uranium was taken out of the pans and placed into a crucible to be sent to the H1 Foundry. This represented two uranium handling steps for the operator.

As shown in the Figure 1, provided by the Metal Preparation Division, an operational change was proposed and eventually implemented. The uranium is loaded automatically into the crucible after being sheared, thus saving two hands-on uranium handling steps by the operator.

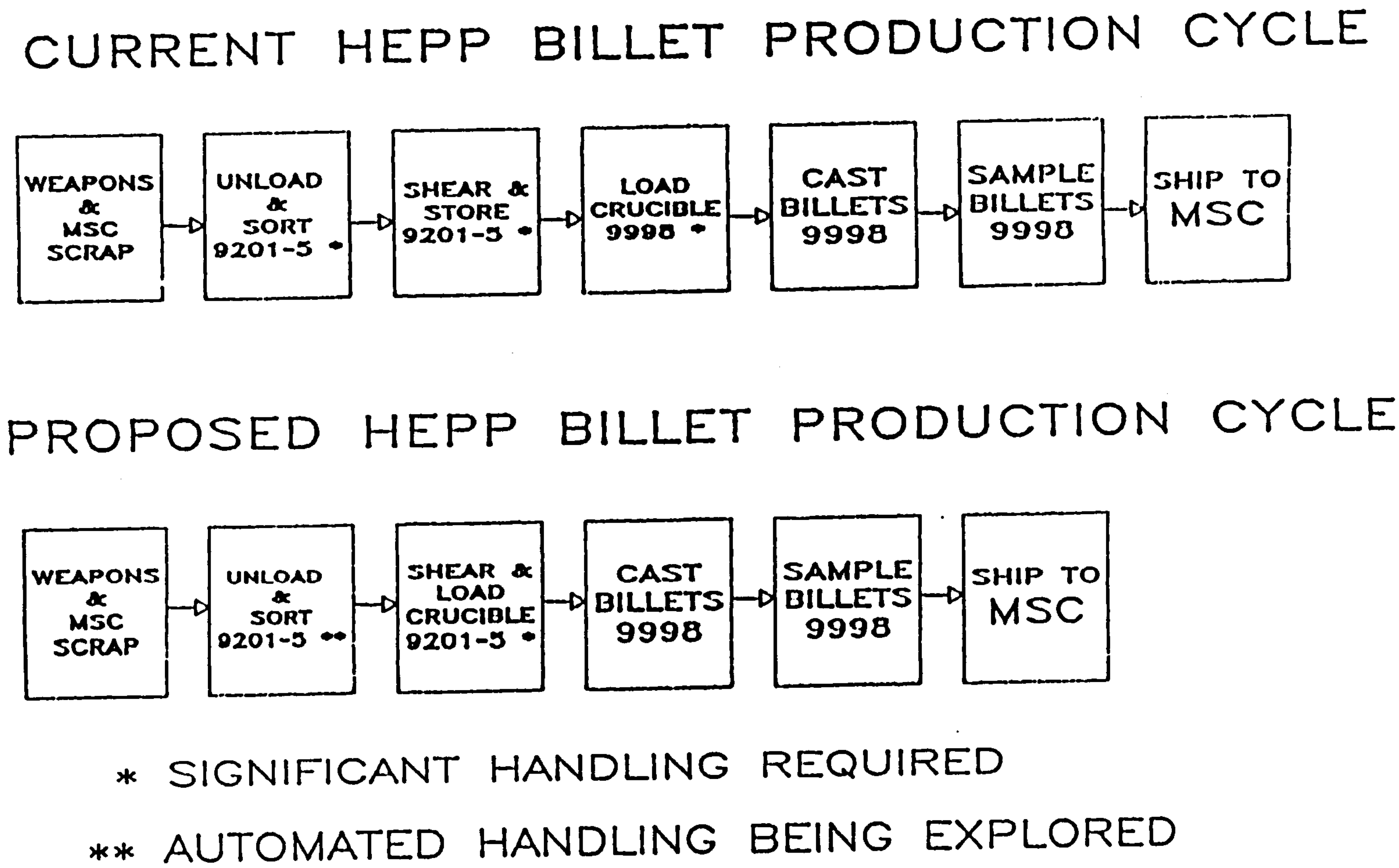

Figure 1. Uranium Handling Operational Change.

Comparing the exposure results for H1 workers to A5 workers revealed many similarities. It reinforced the hypothesis that the common cause of the exposures was the HEPP material. The same exposure per-job-performed categorization was used in A5 as in H1. The A5 HEPP Reclamation operation was initially observed. Although the HEPP program is in its infancy, and the gap in the exposure range would become more pronounced, the A5 HEPP Reclamation operators were receiving more exposure than the other A5 operators.

The collar-level TLD data listed in Table VIII show that the HEPP Reclamation operators were receiving 24% more shallow dose and 17% more penetrating dose than the A5 operators performing non-HEPP operations. The newly recommended glove combination was applied to the Reclamation workers, and further observation was planned.

Table VIII. Comparison of A5 Operator Dose Equivalent.

Operation	Year	Shallow/Penetrating Dose Equivalent (mrem)
HEPP Reclaim	1988	2712/520
Non-HEPP Jobs	1988	2068/432

The 9204-4 (B4) Forming Area presented a particular challenge in methodology. Not only were the jobs diverse, but some of the areas had twenty-four hour operations where the employees constantly changed job assignments. Through the use of shift logs, data for six months were compiled. The data showed that for the collar worn TLDs, the projected annual readings given in Table IX would be received by the operator performing the various jobs:

Table IX. Comparison of B4 Dose Equivalent by Operation Performed.

Operation	Shallow/ Penetrating Dose Equivalent (mrem)
Grit Blaster	5200/768
CMM	2352/272
Heat Treat	2216/336
Press	2144/324

Since money had already been appropriated for a new wet slurry grit blasting operation, the dose reduction methods were directed to the other jobs. The Coordinate Machine Measurement (CMM) job is in a room with controlled access and environment. The readings seemed too high for the amount of material being handled. In an effort to see if the CMM operator was getting the exposure while substituting on other jobs, dedicated TLDs were worn only while working in the CMM room. The data from the dedicated TLDs showed that the exposure received in the CMM room was indeed minimal, and the doses were being received elsewhere. The results projected annually are shown in Table X.

Table X. CMM Room Dose Equivalent Data Verification.

Location	Shallow/Penetrating Dose Equivalent (mrem)
CMM Room Only	692/260
Compiled CMM Data	2352/272

Only 30% of the shallow dose originally compiled for the CMM operator was actually being received while working the CMM job.

The Press Area was the hardest place in B4 to pinpoint the exposure producing tasks. There are five distinct jobs done in the area, with five different operators doing each job one day per week. Also, the area operates three shifts per day, five days per week. A TLD was dedicated to each of the five specific jobs and was relayed to the person performing the job on each particular shift. This method allowed the jobs with the most exposure potential to be identified.

The readings, projected annually, from these dedicated TLDs are shown in Table XI.

Table XI. Comparison of Press Job Annual Dose Equivalents.

Press Job	Shallow/Penetrating Dose Equivalent (mrem)
Dagman	2028/528
Doorman	2028/480
Haul Up	1452/308
Haul Back	1452/ 40
Operator	360/180

The results showed that the dose reduction efforts would mainly be directed toward the Dagman and the Doorman jobs. Dag is an oil mixture that is used to help lubricate some of the moving parts on the presses. The Dagman applies this mixture. The Doorman operates the furnace doors.

6. Dose Reduction Suggestions

Employee exposure can always be lowered by handling less uranium. The objective here, however, is to lower the exposure to the employees without reducing the production levels. Also, employees will not be rotated on jobs in order to "split" doses. Suggestions were made to implement cost-effective ways to lower exposure based on the ALARA principles. Following is a brief explanation of some of the main dose reduction suggestions that were made, beginning with the H1 Foundry.

Since the composition and the handling of the uranium on Charge Make UP (CMU) could not be altered, the program changes to lower radiation exposures on this job deal with the vessels containing the uranium. Although the crucibles are cleaned after each use, the extension rings that are placed on them are not. When metered, most of these extension rings had very high readings; and material is visible on the older rings. Since the operator hand-rolls these rings from storage, and eventually leans over the ring for an extended period of time, cleaning of these rings should lower the dose to the operator. Shielding should be installed between the crucible and the CMU operator. A long-term suggestion was made to make the task an enclosed or glovebox operation. On the sampling job, a portable shield should be available for placement between the operator and the drill press during uranium billet drilling operations. In the Knockout/ Acid Cleaning job, there are uranium slabs that come from the rolling mill in tote pans. These slabs are put into an acid bath to be cleaned, but before cleaning, the slabs are dumped into a basket at the acid bath. This dumping causes uranium oxide to become airborne. Stainless steel pans need to be placed at the end of the rolling mills where the uranium slabs can fall into the pans. These tote pans could then be taken to H1 and placed directly into the acid bath. Not only would this prevent inhalation exposures from the airborne oxide, but it would eliminate the double handling of the uranium slabs. More roped-off areas, radiation sign installation, covering of billets, chock replacement, and an evaluation of the billet stenciling procedures were also requested. The back side of the crucible cleaning station also needs to be covered.

The following dose reduction recommendations were made in the A5 area. The Skullcaster operation involves working with a lot of uranium both in the billet and oxide form. The operator's face and head are in proximity to these materials during part of the operation. Face shields and aprons should be worn during this part of the operation. During cleaning operations, oxide can become airborne due to impacting with tools, and due to sweeping operations. This operation needs to be modified or some form of ventilation installed. The welding area requires better shielding practices. Parts awaiting loading and unloading assistance from the crane operators need to be shielded, and inaccessible to nonessential persons through better use of roped off areas. Tools used in the various stages of the operations are contaminated, and require appropriate storage to ensure they will be dedicated to contaminated operations only. Electrode hanger plates should be handled and stored more in keeping with ALARA concepts.

Containers that transport uranium from B4 and arrive at the HEPP Reclamation area should have pans under them so that no oxide can be dropped during shipment. The shearing operation needs to have better ventilation. Also, some alteration to the shear should be made so the roller works better. This alteration will allow the operator to spend less time standing next to the uranium. Shielding at the shear should also be added. Leather aprons, instead of plastic, should be worn at all times. Extremity monitoring and multi-dosimetry need to be implemented for the operators performing HEPP Reclamation duties.

The following dose reduction suggestions were made in the B4 area. As stated earlier, the Grit Blasting machines are going to be replaced. Therefore, the suggestions deal with uranium billet handling. The billets need to be stored in an area away from the operators until time for the grit blasting to be done. When handling the billets, the same glove combinations recommended for the HEPP material should be worn. Many of the shields used to cover the billets and parts are in need of replacement, and some are cumbersome and unwieldy. This area needs containers that are practical, properly shielded, and dedicated to a particular part size. The Heat Treat area needs to use better storage practices. The skids of uranium parts are presently located for long periods of time in a location where operators, maintenance workers, and visitors sit. During operations that require extensive part handling, leather aprons need to be worn. This is especially true for the operations involving all U-Ti parts. During thermocouple hooking and unhooking operations, when the operator's face is close to the uranium, face shields need to be worn. In the Press Area, the shield located on the 1500 ton press operator's desk is not presently being used because it blocks out light. A more workable shield needs to be installed. Also, the Dagman takes scrap generated by the press and throws it into a scrap pan sitting on the raised tines of a forklift. Not only is the scrap pan located in proximity to both the Dagman and the Operator, but oxide becomes airborne when scrap is thrown into the pan. The scrap pan and the tines need to be lowered to the ground, and an enclosed chute installed to drop the scrap into. While the pan can remain on the forklift, this chute would physically remove the uranium from the two workers and prevent the oxide from becoming airborne. There needs to be a small retractable shield installed west of B1011 furnace so the Doorman can stand behind it when the furnace switches are being operated. In the CMM room, parts are being stored too close to the operator's desk while awaiting measurement. A storage array needs to be set up along the distant wall for these parts.

The following is a summary of the exposure-reducing suggestions made in the various depleted uranium processing areas:

H1 Foundry

1. Cleaning of extension rings
2. Crucible shielding
3. Shielding between operator and drill press
4. Stainless steel tote pans at acid baths
5. More roped-off areas
6. Installation of radiation signs
7. Billet covering
8. Chock replacement
9. Backside installation at crucible cleaning station
10. Evaluation of stenciling process
11. Make immediate changes in HEPP operations

B4 Forming

1. Improve uranium billet and part storage containers
2. Make a storage array away from the CMM operator's desk
3. Use leather aprons and face shields in Heat Treat area
4. Remove unworked skids of parts from the Press area
5. Install shielding at the B1011 furnace
6. Modify scrap operation at the 1500 ton press
7. Install shielding on the operator's desk at the 1500 ton press

A5 Arc Melt

1. Use face shields and leather aprons in the Skullcasting area
2. Modify cleaning operations
3. Additional shielding and storage in Welding area
4. Dedicate tools to contamination producing jobs
5. Improve transport containers
6. Make alteration and add shielding to shear
7. Implement extremity and multi-dosimetry in HEPP Reclamation

7. Extremity Dose Estimates

After finding the potential for high annual extremity doses associated with the HEPP project, the most important radiological protection question to be answered was whether an individual actually received an extremity exposure larger than the annual DOE limit of 50,000 mrem shallow or 5000 mrem penetrating radiation.[3] An accurate, and defensible, extremity dose estimate was the only way to provide this information.

Although HEPP material is also handled in the B4 and A5 areas, the H1 Foundry workers perform the largest amount of hands-on operations. By estimating the H1 workers' extremity exposures, a maximum extremity exposure for all depleted uranium workers could be determined. After consultation with the two CMU operators who performed the most hands-on operations and going through the yearly shift logs, the actual daily uranium handling times were slightly altered. The estimate still represents the maximum extremity exposure received by any worker in the depleted uranium operations at Y-12. The following data were used to make the annual extremity dose equivalent estimates.

CHARGES:

HEPP- During the year, 376 HEPP charges were made. Employee # 1 was the dayshift CMU from January through April when 104 of these charges were made. Employee # 2 was the dayshift CMU from May through December when the other 272 charges were made. Of these 272, 94 were made on the non-dayshift hours, thus leaving a total of 178 charges made by the dayshift CMU. Some of these charges were made jointly by Employees # 1 and # 2. For the year, Employee # 2 was the CMU for 168 working days, and Employee # 1 was the CMU for 82 working days. Considering all of the above, with a correction factor for jointly made charges, of the 282 charges made on the dayshift, Employee # 2 made 169 charges (60%), and Employee # 1 made 113 charges (40%).

Non-HEPP- In addition to the HEPP charges, non-HEPP work is also performed on a daily basis. On these charges, a lifting fixture can be used during most of the operation, thus reducing hands-on handling times.

HANDLING TIMES:

HEPP- Approximately 90% of the HEPP charges are made from small sized material requiring a maximum hands-on handling time of two hours. The other 10% of the charges are made from larger sized material requiring one hour hands-on time.

Non-HEPP- For the non-HEPP work, there is approximately one hour of hands-on time spent per day.

EXPOSURE RATES:

Test results using the type of Neoprene glove that was worn during the year by the CMU, as shown in Chapter 5 on Methods, resulted in the following exposure rates, in mrem per hour handling time, to be assigned to each type of charge:

	HEPP	Non-HEPP
shallow:	95 mrem/hr	44 mrem/hr
penetrating:	10 mrem/hr	0 mrem/hr

The previous data resulted in the following dose equivalents being assigned to the two employees who did the most uranium handling. The results shown in Table XII and Table XIII represent the maximum extremity dose equivalent that could have been received by any employee at the Y-12 Plant during the year.

Table XII. Annual Extremity Dose Equivalent Estimate for Employee # 1.

EMPLOYEE # 1

Charge	Size	# Made	Hours/Charge	Hours/Year
HEPP	Small	102	2	204
	Large	11	1	11
			Total:	215 hrs/yr

Non-HEPP-One hour per day for 82 working days equals: 82hrs/yr

Charge Type	Radiation Dose	mrem/hr	Hrs/yr	Total mrem
HEPP	Shallow	95	215	20425
HEPP	Penetrating	10	215	2150
Non-HEPP	Shallow	44	82	3680
Non-HEPP	Penetrating	0	82	0

** Annual Extremity Dose Equivalent Estimate:
24105 mrem Shallow
2150 mrem Penetrating

Table XIII. Annual Extremity Dose Equivalent Estimate for Employee # 2.

Employee # 2

Charge	Size	# Made	Hours/Charge	Hours/Year
HEPP	Small	152	2	304
	Large	17	1	17
			Total:	321 hrs/yr

Non-HEPP-One hour per day for 168 working days: 168 hrs/yr

Charge Type	Radiation Dose	mrem/hr	Hrs/yr	Total mrem
HEPP	Shallow	95	321	30495
HEPP	Penetrating	10	321	3210
Non-HEPP	Shallow	44	168	7392
Non-HEPP	Penetrating	0	168	0

** Annual Extremity Dose Equivalent Estimate:
37887 mrem Shallow
3210 mrem Penetrating

The dose estimates showed that for the year in question no employee had exceeded the DOE limits of 50,000 mrem shallow or 5,000 mrem penetrating radiation.[3]

8. Multi-Dosimetry

DOE directives require that multi-dosimetry be performed if there is a potential for non-uniform exposures to any part of the employee's body.[3] After determining that the fingers of the employees performing the HEPP handling were receiving a much larger dose than the collar TLD was recording, extremity monitoring was implemented for these employees. This was made logistically possible by the fact that by this time the Y-12 Dosimeter Processing Center had worked out the proper algorithms and could supply a limited number of ring dosimeters for the employees. The ring dosimeters issued were Teledyne RB-4 Finger Sachets with one 7 mg/cm^2 lithium fluoride element to measure the extremity dose equivalent.

The operational change involving some automatic crucible filling had been implemented by this time. This resulted in greatly reduced HEPP handling times for the H1 Charge Make Up job. However, the workers in the A5 HEPP Reclamation area were still handling the material approximately three hours daily. The data in Table XIV are the results from ten months of ring dosimeter wearing by three employees in this area. Temporary budgetary and program requirements prevented the acquisition of a full year's data.

Therefore, the dose equivalents shown in Table XIV have been projected for a twelve month period so that an annual dose equivalent could be obtained.

Table XIV. Extremity Dose Equivalent in HEPP Area.

Employee	Ten Month Total (mrem)	Projected Annually (mrem)
A	12339	14808
B	8268	9924
C	11341	13608

These results verified that Y-12 was in compliance with the DOE standards for extremity exposures. Since the employees were wearing the new recommended glove combinations, the readings also showed the validity of the dose methodology used. As shown in Chapter 5 on Methods, the effectiveness of the research methods was borne out by the fact that two of the employees had received dose equivalents in the range of 13,500 to 17,500 mrem, as predicted in the inner-plant memo dated three months before the ring dosimeter program started. Also, the consistency of the dosimetry program was demonstrated, since one type of dosimeter could predict the dose equivalent from another type, if the proper algorithms were employed.

With the program's credibility and need established, ring dosimetry has now become a vital part of the Y-12

Radiation Protection Program. During 1990, extremity monitoring was named the number one radiological priority in the plant. Currently, fifty-five employees in twelve depleted uranium handling areas are being monitored.

In addition to extremity monitoring, multi-dosimetry also pertains to other parts of the body which might receive a non-uniform radiation dose. Many times this non-uniform dose is received in the mid-range section of the body. Observations of the various uranium handling jobs had shown that, during most of the time that the work was being done, the uranium was in the vicinity of the employee's waist. Due to the low energy and penetrating power of the beta and gamma radiation associated with depleted uranium, there was a strong possibility that the middle parts of the employee's body were receiving dose equivalents not accurately reflected by the dose numbers generated at the collar worn TLD. In an effort to ascertain if this were true, the six employees performing the most uranium handling were assigned TLDs to be worn on their waists. These TLDs were to be placed under any aprons worn so the amount of radiation the body received, after passing through any protective clothing, could be recorded. After seven months of monitoring, the average monthly dose equivalents given in Table XV had been recorded for the six employees.

Table XV. Comparison of Dose Equivalent by TLD Location.

TLD Location	Shallow/Penetrating Dose Equivalent (mrem)
Collar	135/41
Waist	231/55

The shallow dose equivalent being received in the waist area was 71% larger than the dose equivalent recorded by the collar worn TLD. The penetrating dose equivalent was 34% larger. Due to these results, mid-range, or waist, monitoring became a routine part of the Y-12 Radiation Protection Program; and six additional employees performing waist-level uranium handling jobs were added to the program.

To reduce the differential between the amount of radiation received in the mid-range area as opposed to the rest of the body, some protective clothing and operational changes needed to be made. The same type of tests that had been used in determining glove radiation protection properties were used on various types of aprons. A more protective leather apron, as compared to the plastic apron that was being worn, was eventually chosen. A lead impregnated apron actually provided the best radiological protection, but it proved too cumbersome to wear continually . An operational change to provide additional waist-area protection was made by adding aluminum shielding to the crucible-filling job. These changes should be able to lower the ratio of the shallow dose equivalent recorded by the collar TLD and the shallow dose equivalent recorded by the waist TLD.

As a result of the above changes, during the next six month monitoring period, the waist level shallow dose for the original six employees that had been monitored went from a 71% collar-to-waist ratio, to a 23% ratio. When all twelve employees' data were included, the waist level TLD doses were only 16% higher than the dose being reported by the collar worn TLD. The penetrating level, as might be expected for gamma radiation, was not significantly reduced by the leather and aluminum materials.

For comparison reasons, and to have verification whether a person is receiving a non-uniform radiation dose or not, the data shown in Table XVI were compiled. The data are for the twelve employees who are wearing multi-dosimeters on three parts of the body. The readings are in mrem and are a four- month shallow dose equivalent total.

Table XVI. Comparison of Multi-Dosimeter Four Month Total for Shallow Dose Equivalent.

	TLD Location			
Employee	Collar (mrem)	Waist (mrem)	Ring (mrem)	Approximate Ratio Ring:Collar
A	230	269	1255	5:1
B	542	733	4925	9:1
C	565	741	922	2:1
D	596	368	3125	5:1
E	529	555	1000	2:1
F	305	433	407	1:1
G	300	205	790	3:1
H	165	351	1035	6:1
I	566	483	2101	4:1
J	316	853	1314	4:1
K	323	259	1888	6:1
L	504	509	4964	10:1

As anticipated from the research, there is quite a large range in the dose equivalent ratios, depending on the job being performed and the amount of uranium being handled. As a group, the TLDs located at the waist level recorded dose equivalents that were 16% larger than the collar dose equivalents. Also as a group, the ring-to-collar ratio is approximately five to one. These data can thus be used on a job-specific basis as a guideline for employing additional radiation protection practices. The group average, although not job-specific, was compiled to give an indication of the dose equivalent ratios that could be expected for an employee working multiple jobs in the depleted uranium areas.

9. Lessons Learned

The diversity and magnitude of the depleted uranium operations at the Y-12 Plant are probably unique in the world. To the author's knowledge, no study of the kind and scope reported in this thesis has been conducted before. The new DOE Orders pertaining to extremity dose equivalent and large non-uniform exposures provided the impetus for conducting the present study. The study, in turn, has led to increased attention to extremity dosimetry and its documentation in a variety of operations at the Y-12 facilitiy. Although other facilities have their own particular radiological protection problems, some conclusions can be drawn from the research presented in the study. The lessons learned, as detailed in the following text, will generally apply to other operations that entail extremity doses from beta particle emitters.

First, a study of existing records can provide a good deal of vital information. Using readily available information such as operational logbooks, shift records, existing radiological surveys, and production schedules, can give a basic direction to the research. This method prevents unnecessary wasting of time and resources before the more sophisticated methods are employed.

Second, because dose distributions from beta and beta-gamma emitters are non-uniform, it is useful to be able to estimate the dose equivalent at one location on the body from a measurement made at another location. When employees are performing jobs involving the handling of depleted uranium, this study shows that it is common for the fingers to be receiving dose equivalents five times larger than the dose being recorded on the upper body dosimeter. If the job requires extensive handling of depleted uranium, the finger dose equivalent can be ten times larger than the recorded upper body dose. Most uranium handling jobs are performed at waist level. Consequently, unless shielding is provided, the mid-range portion of the body can receive dose equivalents that are double what is being recorded by the upper body dosimeter. By taking the values recorded for the upper body dosimeter and multiplying by the appropriate ratios listed above, one can determine if multi-dosimeters should be employed to ensure proper monitoring of the employees. For sources other than depleted uranium, these figures can serve as a rule of thumb. One should still verify, however, by employing multi-dosimetry on a trial basis, whether a single dosimeter will provide adequate dose equivalent assessment.

Third, when designing radiological protection practices to meet a particular radiation standard, one should keep in mind the fact that these standards are contiually being downsized. As an example, the DOE annual limits of 50,000 mrem shallow and 5000 mrem penetrating dose equivalent may be changed in the near future to 20,000 and 2000 mrem respectively. Programs designed to simply meet current standards might soon require further restrictions. Anticipation of greater restrictions in making current designs is also consistent with the ALARA principle.

Fourth, the present study proves that when it is not possible to employ optimum dose reduction controls such as automated material handling and gloveboxes, dose reduction can still be accomplished. Before the addition of a one-eighth inch aluminum shield to the Charge Make Up job, the waist area of the employees performing that particular job was receiving 71% more shallow dose equivalent than the upper body was receiving. After the shielding was added, this ratio fell to 23%. The ratio was further reduced by using leather aprons instead of plastic. Also, changing to a more protective glove combination reduced the extremity shallow dose equivalent on the most extensive uranium handling jobs by a factor of five. These changes represented a significant dose reduction, and can be employed in a variety of radiological settings.

Finally, human resources should not be overlooked. By taking time to talk to operators, technicians, and front line supervision, one can gather various kinds of valuable information. These people know when operational changes and the implementation of new procedures have occurred. They can indicate when new source materials have been introduced into the area, and if production levels have varied. Their ideas are very important when making workable operational changes, but they are rarely asked for their input. Including them at the start of the project also makes them more receptive to changes and gives them an overview of what the radiological protection project is attempting to accomplish.

10. Conclusion

Although this evaluation of radiation exposure in the Y-12 Metal Preparation Depleted Uranium Process Areas began as a way to show compliance to Department of Energy and Technical Safety Appraisal directives, the most significant result was the identification of the potential for high employee dose equivalents encountered in processes involving the High Energy Physics Project type of depleted uranium. This discovery led to operational and protective equipment changes which resulted in a five fold reduction in the level of extremity doses being received by the employees performing the more extensive hands-on uranium handling tasks. Normally, a reduction of this magnitude would require lowering the production levels. However, it was accomplished while the production levels were actually increasing.

Another significant accomplishment was showing that the dosimetry methods being used were successful in accurately recording the dose equivalent being received by the employees. This was proven when the predicted annual dose equivalent for the workers performing tasks with the greatest exposure potential were verified by ten months of actual dosimeter data. A guideline was also established where, on a job-specific basis, the dose equivalent received at one part of the body could be inferred from the dose equivalent received at other parts of the body. This information has been incorporated into plant procedures, and is used as a criterion for issuing extremity and multi-dosimeters. The net result has been an overall lowering of the radiation dose equivalent received by the employees, thus providing a safer working environment.

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REFERENCES

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VITA

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Mike worked as a process operator at the Oak Ridge Gaseous Diffusion Plant from 1976 until 1981. Since 1982, he has been employed in the Health Physics Department at the Y-12 Nuclear Weapons Plant. In 1988, he received a B.A. in Biology from the University of Tennessee. He has one daughter, Lori, who was born in 1976.