REPORT OF

IN VIVO COUNTING

FOR

ATLAS MINERALS

DIVISION OF ATLAS CORPORATION

P.O. BOX 1207

MOAB, UTAH 84532

WORK PERFORMED ON

OCTOBER 4 THROUGH OCTOBER 6, 1976

BY

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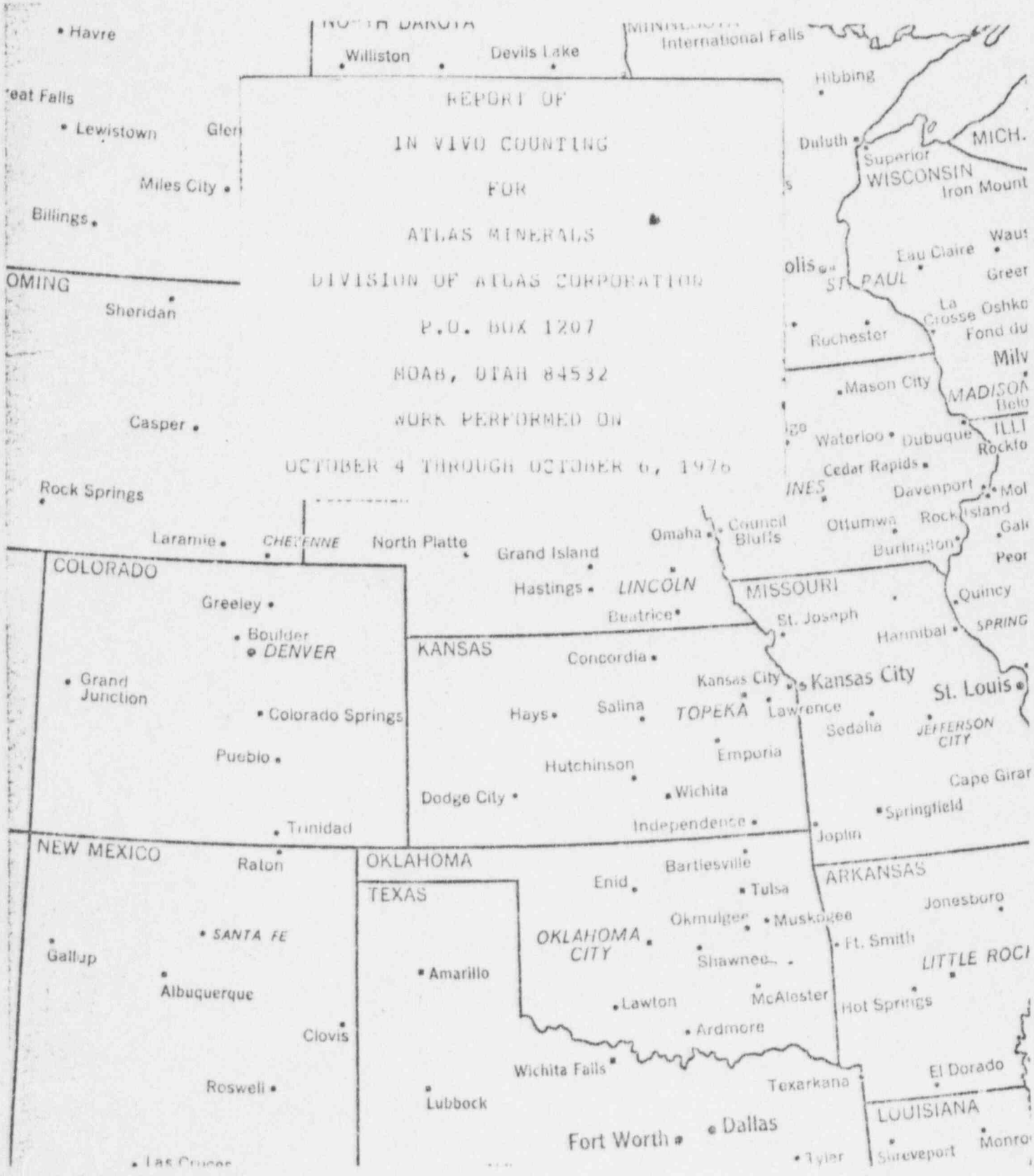


## SUMMARY

NINETY-NINE IN VIVO LUNG COUNTS FOR NATURAL URANIUM WERE PERFORMED ON NINETY-NINE PEOPLE DURING THE PERIOD OF OCTOBER 4 THROUGH OCTOBER 6, 1970.

EIGHT OF THE NINETY-NINE PEOPLE SHOWED POSITIVE RESULTS FOR URANIUM-235 WITH A MAXIMUM OF 82 $\pm$ 67 MICROGRAMS, COMPARED TO A MAXIMUM PERMISSIBLE LUNG BURDEN OF 180 MICROGRAMS. IN ANOTHER TEST OF THE SAME DATA IN WHICH ONE OBSERVES THE PHOTOPEAKS FROM PROTOACTINIUM-234 AND THORIUM-234 AT 63- AND 93-KEV A TOTAL OF 78 POSITIVE RESULTS WERE OBTAINED WITH A MAXIMUM OF 16 $\pm$ 2 MILLIGRAMS OF NATURAL URANIUM, ASSUMING EQUILIBRIUM CONDITIONS PREVAIL. THIS MAYBE COMPARED WITH A MAXIMUM PERMISSIBLE LUNG BURDEN OF 25.6 MILLIGRAMS OF NATURAL URANIUM. WE CAN NOT STATE AN OPINION ON WHETHER OR NOT EQUILIBRIUM CONDITIONS PREVAILED AT THE TIME OF MEASURMENT SINCE WE DO NOT KNOW THE TYPE OF WORK PERFORMED BY THE INDIVIDUALS AND THE RELATIONSHIP OF THEIR WORK TO THE PROBABILITY OF INHALING SEPARATED DAUGHTER PRODUCTS WHICH ARE NOT IN EQUILIBRIUM WITH URANIUM-238.

THREE INDIVIDUALS WERE ANALYZED FOR RADIUM 226. NO ACTIVITY OTHER THAN THE NORMAL OCCURRING POTASSIUM WAS OBSERVED ON THESE INDIVIDUALS. RESULTS FOR EACH INDIVIDUAL ARE LISTED IN APPENDIX I.

1. EQUIPMENT

A. MOBILE IN VIVO COUNTING SYSTEMS FOR MIXED FISSION, ACTIVATION, AND CORROSION PRODUCTS (MFACP), RADIUM AND NATURAL THORIUM

THE DETECTORS USED FOR MEASURING IN VIVO DEPOSITIONS OF MFACP, RADIUM AND THORIUM ARE 8-INCHES IN DIAMETER BY 4-INCHES THICK AND ARE MADE FROM THALLIUM ACTIVATED SODIUM IODIDE, NAI(TL). SOME OF THESE DETECTORS USE 3 EACH THREE-INCH DIAMETER PHOTOMULTIPLIER TUBES FOR EACH CRYSTAL, OTHERS USE A SINGLE FIVE-INCH DIAMETER PHOTO TUBE. THE RESOLUTION OF THE DETECTORS IS 8.5% OR BETTER FOR CESIUM-137 WHEN MEASURED IN AN ESSENTIALLY SCATTER-FREE ENVIRONMENT. THE OUTPUT SIGNALS FROM THE DETECTOR ARE USUALLY FED TO A 256 CHANNEL PULSE-HEIGHT ANALYZER, ALTHOUGH IN SOME CASES A 128 CHANNEL ANALYZER IS USED. OUTPUT FROM THE ANALYZER MAY BE OBTAINED IN SEVERAL FORMS: IT MAY BE PUNCHED IN DIGITAL FORMAT ON PAPER TAPE BY A HIGH SPEED PAPER TAPE PUNCH, IT MAY BE TYPED AND PUNCHED BY THE HIGH SPEED PUNCH AND AN IBM COMPUTER TYPEWRITER, OR ON A TELETYPE. IT MAY ALSO BE RECORDED ON MAGNETIC TAPE, IT MAY BE DISPLAYED IN ANALOG FORMAT ON AN OSCILLOSCOPE, OR IT MAY BE GRAPHED IN ANALOG FORMAT ON AN X-Y RECORDER. THE DETECTOR SIGNALS ARE ALSO PASSED THROUGH A LOGARITHMIC COUNT RATE METER, THE OUTPUT OF WHICH IS FED TO THE Y AXIS OF AN X-Y RECORDER WHILE THE X AXIS RECEIVES A LINEAR VOLTAGE PROPORTIONAL TO THE LOCATION OF THE BED AND DETECTOR. THUS, ONE MAY OBTAIN A PLOT OF COUNTING RATE VERSUS DISTANCE ALONG THE BODY.

THE SHIELDING FOR MFACP COUNTING IS THE STANDARD HELGESON NUCLEAR SERVICES, INC. SHADOW SHIELD WHOLE BODY COUNTER. THE DETECTOR IS SURROUNDED BY 4-INCHES OF LEAD AND THE SUBJECT LIES ON A BLANKET OF LEAD WHICHHAS AN EQUIVALENCE OF 4-INCHES OF LEAD. THIS AND ALL THE ELECTRONICS PLUS NECESSARY ACCESSORIES SUCH AS MUSIC, LIGHTING, CARPETING, ETC. ARE CONTAINED IN AIR-CONDITIONED SEMI- TRAILER VANS. UNIT NO. 1 IS 24 FEET LONG BY 8-FEET WIDE AND UNIT NO. 2 IS 35-FEET LONG BY 8-FEET WIDE.

B. MOBILE IN VIVO LUNG COUNTING SYSTEM FOR URANIUM-235, AMERICIUM-241, PLUTONIUM-238,9, AND LEAD-210

THE DETECTORS USED FOR MEASURING LUNG DEPOSITIONS OF THESE MATERIALS ARE A PAIR OF 5-INCH DIAMETER "PHOS-WICH" DETECTORS. EACH DETECTOR CONSISTS OF A FRONT ENTRANCE WINDOW MADE OF 0.010-INCH THICK BERYLLIUM METAL, A NAI(TL) CRYSTAL WHICH IS 0.5-INCHES THICK TO WHICH IS OPTICALLY COUPLED A 1.5-INCH THICK CESIUM IODIDE (SODIUM ACTIVATED) CRYSTAL. A SINGLE 5-INCH DIAMETER ELEVEN DYNODE PHOTOMULTIPLIER VIEWS THE LIGHT PULSES FROM BOTH CRYSTALS. THE SIGNALS FROM A PAIR OF THESE DETECTORS ARE

FED IN PARALLEL TO A LOW-NOISE PREAMPLIFIER AND THEN TO A PULSE SHAPE DISCRIMINATION NET-WORK WHICH SEPARATES PURE NAI(TL) SIGNALS FROM ALL OTHER SIGNALS. A MEASURED REDUCTION OF A FACTOR OF 20 IN COMPTON SCATTERED BACKGROUND HAS BEEN OBTAINED IN THE URANIUM-235 PHOTOPEAK REGION THROUGH THE USE OF THIS SYSTEM.

THE SAME ANALYZERS AND OUTPUT DEVICES DESCRIBED ABOVE FOR MFACP COUNTING ARE AVAILABLE FOR THE LOW ENERGY COUNTING. THE SHIELDING FOR THIS WORK IS A TOTALLY ENCLOSED SHIELD WITH THE EQUIVALENT OF APPROXIMATELY 3-INCHES OF VIRGIN LEAD. THIS EQUIPMENT IS HOUSED IN UNIT NO. 2, WHICH IS A 35-FOOT LONG SEMI-TRAILER.

C. "DO-IT-YOURSELF WHOLE BODY COUNTERS" (TM) FOR MFACP

THE "DO-IT-YOURSELF WHOLE BODY COUNTER" (TM) IS BUILT QUITE SIMILARLY TO THE STANDARD HELGESON NUCLEAR SERVICES, INC. SHADOW SHIELD WHOLE BODY COUNTER, I.E., IT IS BUILT ON THE PRINCIPLE OF SHADOW SHIELDING. THE PRIMARY DIFFERENCE LIES IN THE FACT THAT THE "DO-IT-YOURSELF" DETECTOR MOVES OVER THE SUBJECT, WHILE IN THE STANDARD SHADOW SHIELD THE SUBJECT MOVES BENEATH A STATIONARY DETECTOR. OUTWARDLY, THE DETECTOR HOUSINGS OF EITHER SHIELD LOOK QUITE SIMILAR. THE BED OF THE "DO-IT-YOURSELF WHOLE BODY COUNTER" (TM) LOOKS LIKE A STAINLESS STEEL BATH TUB WHICH HAS TWO INCHES OF VIRGIN LEAD IN THE SIDES AND ON THE BOTTOM. FOUR INCHES OF LEAD ARE USED AROUND THE DETECTOR.

THE DETECTOR CONSISTS OF AN 8-INCH DIAMETER BY 4-INCH THICK NAI(TL) CRYSTAL AND, IN MOST SYSTEMS, A SINGLE 5-INCH DIAMETER PHOTOMULTIPLIER TUBE. THE ELECTRONICS ARE VERY SIMILAR IN FUNCTION BUT ARE DIFFERENT IN CONSTRUCTION. A MINI-COMPUTER IS USED BOTH AS A LOGIC CONTROL DEVICE AS WELL AS A MULTI-CHANNEL PULSE HEIGHT ANALYZER AND MULTI-SCALER. THE COMPUTER IS PROGRAMMED TO ASK THE SUBJECT FOR HIS NAME, SOCIAL SECURITY NUMBER, AND OTHER DATA FOR IDENTIFICATION OR PHYSICAL CHARACTERISTICS. IT ALSO GIVES HIM INSTRUCTIONS OF WHAT ACTIONS HE SHOULD TAKE TO COMPLETE THE COUNT AND TRANSMIT THE DATA TO THE HOME OFFICE AT THE END OF HIS COUNT. THE DATA TRANSMISSION IS ACCOMPLISHED BY STANDARD TELEPHONE LINES BETWEEN THE REMOTE SITE AND THE HOME OFFICE OF HELGESON NUCLEAR SERVICES, INC. IN PLEASANTON, CA.

D. HOME OFFICE EQUIPMENT

A NUMBER OF DIFFERENT COMPUTING SYSTEMS ARE USED IN THE HOME OFFICE. THE MAIN SYSTEMS ARE DIGITAL EQUIPMENT CORPORATION PDP-8 SERIES COMPUTERS WITH UP TO 32K OF CORE, DISK STORAGE IN EXCESS OF 3.2 MILLION WORDS, AND ESSENTIALLY UNLIMITED MAGNETIC TAPE STORAGE. INPUT MAY BE OBTAINED FROM PAPER TAPE, MAGNETIC TAPE, DISK,

TELEPHONE INPUT VIA A SEPARATE MESSAGE HANDLING COMPUTER OR BY MANUAL INPUT FROM THE FIVE TIME-SHARED TERMINALS WHICH ARE PART OF THIS SYSTEM. OUTPUT MAY BE OBTAINED IN THE FORM OF PAPER TAPE, MAGNETIC TAPE, DISK, OSCILLOSCOPE, INCREMENTAL PLOTTER, X-Y PLOTTER, HIGH SPEED LINE PRINTER, OR HARD AND SOFT COPY DATA TERMINALS.

DATA BEING RECEIVED OVER THE TELEPHONE LINES FROM THE "DO-IT-YOURSELF" COUNTERS ARE FORMATTED BY A SEPARATE MESSAGE HANDLING COMPUTER WHICH MAY BE CONNECTED BY DIRECT LINK TO THE MAIN COMPUTER SYSTEM OR WHOSE OUTPUT MAY BE OBTAINED IN PAPER TAPE, MAGNETIC TAPE, OR DISK FORMAT.

## II. CALIBRATION

### A. CALIBRATION FOR ENERGY VERSUS CHANNEL, "KEV/CHANNEL"

THE DETECTOR AND ANALYZER ARE CALIBRATED DAILY FOR CHANNEL VERSUS ENERGY USING THE TECHNIQUE OF HEATH DESCRIBED IN IDO-16880. FOR MIXED FISSION, ACTIVATION, AND CORROSION PRODUCTS, THE ENERGY CALIBRATION IS DETERMINED FOR EACH COUNT SINCE A SMALL AMERICIUM-241 SOURCE IS ATTACHED TO THE SIDE OF THE DETECTOR. THUS, BY USING THE 59.6-KEV X-RAY FROM AMERICIUM-241 AT THE LOW ENERGY END OF THE SCALE AND EITHER NATURAL POTASSIUM FROM THE SUBJECT ( OR DETECTOR ) WITH AN ENERGY OF 1460-KEV AT THE HIGH END OF THE SCALE, OR ANOTHER KNOWN PHOTOPEAK, SUCH AS THOSE FROM COBALT-60, ONE HAS TWO KNOWN ENERGIES WHICH MAY BE USED AS REFERENCES FOR A GAIN AND ZERO SHIFT OF THE DATA. THIS ASSURES THAT THE ENERGY-TO-PULSE HEIGHT CALIBRATION MATCHES THAT GIVEN BY HEATH. TYPICAL RESULTS SHOWED THAT THE ENERGY CALIBRATION WAS WITHIN AN AVERAGE OF 0.5 CHANNELS OVER THE ENERGY RANGE OF 0.06- TO 2.6-MEV.

FOR URANIUM-235 COUNTING THE ENERGY CALIBRATION WAS SET USING THE 60-KEV PHOTOPEAK FROM AMERICIUM AND THE 186-KEV PHOTOPEAK FROM URANIUM-235, WHILE FOR AMERICIUM-241, PLUTONIUM-238, PLUTONIUM-239, AND LEAD-210 THE GAIN IS SET USING THE 17- AND 60-KEV PHOTOPEAKS OF AMERICIUM-241 AS THE CALIBRATION STANDARD.

### B. CALIBRATIONS FOR DETERMINING CALIBRATION AND SCATTER FACTORS, "COUNTS PER MINUTE PER NANOCURIE, ETC."

FOR COUNTING OVER THE ENTIRE BODY THE SYSTEM WAS CALIBRATED FOR SENSITIVITY TO VARIOUS RADIOISOTOPES BY PLACING UP TO 240 SMALL UNIFORM ACTIVITY SOURCES IN SUGAR PHANTOMS WHICH RANGED IN WEIGHTS FROM 27 POUNDS TO 270 POUNDS. THE SOURCES WERE UNIFORMLY DISTRIBUTED IN THE PHANTOM SINCE IT HAS BEEN SHOWN BY PREVIOUS WORK THAT THIS DISTRIBUTION PROVIDES RESULTS WHICH ADEQUATELY REFLECT THE RESULTS OBTAINED WITH NON-UNIFORM DISTRIBU-

TION, SUCH AS MIGHT BE FOUND WITH INSOLUBLE PARTICULATES DEPOSITED IN THE LUNG. THE CALIBRATION FACTORS VARY WITH BODY WEIGHT AS DO THE COMPTON SCATTER FACTORS. IN MOST CASES THESE CALIBRATION FACTORS MAY BE REPRESENTED AS THE SUM OF TWO EXPONENTIAL COMPONENTS. APPENDIX II LISTS PERTINENT CALIBRATION DATA. ALL SOURCES WERE VERIFIED AS TO THEIR STRENGTH BY INDEPENDENT LABORATORIES WHO CAN REFERENCE THEIR SOURCES TO THE NATIONAL BUREAU OF STANDARDS.

CALIBRATIONS FOR URANIUM-235, AMERICIUM-241, PLUTONIUM-238, PLUTONIUM-239, THORIUM, AND URANIUM-233 (WITH URANIUM-232 CONTAMINATION) HAVE BEEN MADE BY DISTRIBUTING MANY SOURCES OF KNOWN ACTIVITIES IN A UNIFORM MANNER IN A MASONITE PHANTOM LUNG OF VARYING THICKNESSES. THE URANIUM-235 CALIBRATIONS HAVE ALSO BEEN CHECKED BY COUNTING THE LUNG AREA OF THE REMAB PHANTOM USED BY THE Y-12 PLANT, UNION CARBIDE CORPORATION, OAK RIDGE TENNESSEE. THESE RESULTS AGREE WELL WITH THE MASONITE CALIBRATION RESULTS. IF THESE TYPES OF MEASUREMENTS WERE PERFORMED AS A PART OF THIS REPORT, APPENDIX II CONTAINS THE APPROPRIATE CALIBRATION DATA.

AMERICIUM-241, PLUTONIUM-238, PLUTONIUM-239, THORIUM, AND URANIUM-233 CALIBRATIONS WERE PERFORMED IN THE SAME MANNER AS URANIUM-235 EXCEPT THAT NO CROSS-CHECK HAS BEEN DONE WITH THE Y-12 PHANTOM. PLUTONIUM-238, AND PLUTONIUM-239 CALIBRATION FACTORS WHICH HAVE BEEN PROVIDED BY P. N. DEAN, LOS ALAMOS SCIENTIFIC LABORATORIES, ARE ROUTINELY USED.

## III. COUNTING TECHNIQUES

### A. MIXED FISSION, ACTIVATION AND CORROSION PRODUCTS AND RADIUM-226

THE COUNTING TECHNIQUES FOR THE MOBILE COUNTERS ARE DESCRIBED IN THE FOLLOWING PARAGRAPH. THE COUNTING TECHNIQUES FOR THE "DO-IT-YOURSELF WHOLE BODY COUNTER" VARY ONLY SLIGHTLY FROM THAT DESCRIBED BELOW, THE PRINCIPAL DIFFERENCE BEING THAT THE DETECTOR MOVES OVER THE SUBJECT AS OPPOSED TO THE SUBJECT MOVING UNDER THE DETECTOR AS IN THE MOBILE SYSTEMS ANOTHER MINOR DIFFERENCE LIES IN THE FACT THAT THE DETECTOR MOVES THE SAME DISTANCE FOR EVERY SUBJECT REGARDLESS OF THE HEIGHT OF THE SUBJECT.

THE SHADOW SHIELD WHOLE BODY COUNTER BUILT BY NELGESON NUCLEAR SERVICES, INC. FOLLOWS CLOSELY THE BASIC PRINCIPLES OF ITS ORIGINATORS, H.E. PALMER AND W.C. ROESCH. THEY HAVE SHOWN THAT IF A SUBJECT IS PLACED WITH HIS HEAD 4 INCHES TO ONE SIDE OF THE DETECTOR AND TRAVELS SO THAT HIS FEET ARE 4 INCHES ON THE OTHER SIDE OF THE DETECTOR AT THE END OF THE COUNT, 95-PERCENT OF ALL THE

COUNTING INFORMATION WHICH COULD HAVE BEEN OBTAINED BY TRAVELING AN INFINITE DISTANCE ON EITHER SIDE OF THE DETECTOR WILL HAVE BEEN OBTAINED. THUS, TAPES CALIBRATED IN FEET AND INCHES HAVE BEEN PLACED ON THE FLOOR OF THE COUNTER WITH THE ZERO INCH MARK LOCATED 8 INCHES FROM THE CENTER LINE OF THE CRYSTAL. TO POSITION A PERSON PROPERLY ONE NEED MERELY PLACE THE BOTTOM OF HIS FEET AT A DISTANCE WHICH CORRESPONDS TO HIS HEIGHT. THE BED SPEED IS THEN ADJUSTED SUCH THAT THE TOTAL TRAVEL TIME FOR A GIVEN INDIVIDUAL IS IN THE RANGE OF 5- TO 80-MINUTES, DEPENDING ON THE STATISTICAL PRECISION DESIRED AND ON THE DEGREE OF DIFFICULTY IN MEASURING CERTAIN RADIONUCLIDES. FOR EXAMPLE, A RADIUM-226 MEASUREMENT TAKES AT LEAST 40-MINUTES. IN THIS MANNER THE VARIOUS CRITICAL ORGANS ARE SCANNED BY THE DETECTOR FOR THE SAME PERCENTAGE OF THE TOTAL COUNTING TIME AS WERE THE CORRESPONDING ORGANS IN THE PHANTOM. MOST COUNTS FOR MFACP ARE FOR 6- TO 8-MINUTES.

ALL PERSONS WERE COUNTED IN THE SUPINE POSITION UNLESS OTHERWISE NOTED. THE HEAD WAS ALLOWED TO REST DIRECTLY ON THE BED OF THE COUNTER RATHER THAN BEING ELEVATED ON A PILLOW.

IN ONLY A FEW FACILITIES ARE PEOPLE COUNTED WHILE WEARING ALL OF THEIR STREET CLOTHING. THIS PRACTICE IS GENERALLY DISCOURAGED. AT OTHER FACILITIES, HOWEVER, WHERE THE PROBABILITY OF PERSONAL CLOTHING CONTAMINATION IS GREATER, PEOPLE WILL BE COUNTED IN PAPER LAB COATS ONLY. IF WOMEN ARE TO BE COUNTED IN OTHER THAN THEIR STREET CLOTHING, A SECOND WOMAN ATTENDANT WOULD BE REQUESTED. ALL DISROBING WOULD BE DONE IN PRIVACY.

ALL PERSONS WERE TO HAVE SHOWERED AFTER LEAVING A POTENTIALLY CONTAMINATED AREA.

B. URANIUM (ENRICHED, NATURAL, DEPLETED), PLUTONIUM-238 AND AMERICIUM-241

URANIUM-235, PLUTONIUM-238, 239, AND AMERICIUM-241 ARE COUNTED IN THE TOTALLY SHIELDED COUNTER CONTAINED IN UNIT 2. THE DETECTORS ARE PLACED DIRECTLY IN CONTACT WITH THE CHEST OF THE SUBJECT SUCH THAT THE DETECTORS WILL "SEE" MAJOR PORTIONS OF THE LUNG. FOR URANIUM-235 THEY ARE POSITIONED SUCH THAT THE DETECTOR IS CENTRALLY LOCATED BETWEEN THE BOTTOM OF THE CLAVICLE (COLLAR BONE) AND THE CENTER LINE OF THE NIPPLES AND ARE AT THE OUTER EDGES OF THE STERNUM. THIS USUALLY PLACES THE TOP EDGE OF THE DETECTOR ABOUT ONE INCH BELOW THE LOWER EDGE OF THE CLAVICLE. THE NORMAL COUNTING TIME FOR URANIUM-235 IS 20-MINUTES. NATURAL AND DEPLETED URANIUM ARE NORMALLY MEASURED BY THE SAME METHOD AS IS USED FOR URANIUM-235, I.E., THE 186-KEV PHOTOPEAK IS USED FOR CALCULATING THE LUNG BURDEN. IF INFORMATION IS DESIRED ON THE DAUGHTER

PRODUCTS PROTOACTINIUM-234 AND THORIUM-234, THE 63- AND 93-KEV PHOTOPEAKS ARE USED.

FOR PLUTONIUM AND AMERICIUM COUNTING THE DETECTORS ARE POSITIONED SUCH THAT THE TOP EDGE OF HE DETECTOR IS TANGENT TO THE BOTTOM OF THE CLAVICLE AND THE INNER EDGES OF THE DETECTOR ARE TANGENT TO THE OUTER EDGES OF THE STERNUM. THE COUNTING TIME FOR AMERICIUM-241 IS 40-MINUTES. THE COUNTING TIME FOR PLUTONIUM IS 40-MINUTES ON THE CHEST, WITH THIS DATA BEING TRANSFERRED ON PAPER TAPE, FOLLOWED BY A BACKGROUND OF 40-MINUTES WITH THE DETECTORS PLACED ON THE THIGHS. ADDITIONAL TIME IS REQUIRED FOR PLUTONIUM-238, 239 FOR MEASUREMENTS USING AN ECHOENCEPHAELOSCOPE TO DETERMINE THE CHEST WALL THICKNESS. THE LENGTH OF TIME FOR THESE MEASUREMENTS VARIES BETWEEN 10-TO 20-MINUTES. OTHER MEASUREMENTS REQUIRED FOR PLUTONIUM-238, 239, AMERICIUM-241 AND URANIUM-235 ARE THE HEIGHT, WEIGHT, AND CHEST CIRCUMFERENCE.

EFFECTIVE CHEST WALL THICKNESS IS DETERMINED BY MEASUREMENT OF THE CHEST WALL THICKNESS IN AT LEAST 12 DIFFERENT LOCATIONS USING AN ECHOENCEPHALSCOPE AND IS CALCULATED BY THE METHOD OF RUNDO ET AL (HEALTH PHYSICS, VOL. 17, PP 155-157, 1969) AND BY DEAN'S EMPIRICAL FORMULA.

C. THORIUM

THORIUM IS COUNTED BY POSITIONING THE CHEST OF THE SUBJECT BENEATH THE 8-INCH BY 4-INCH DETECTOR WITH A BED-TO-DETECTOR DISTANCE OF 10.5-INCHES OR 12.5-INCHES. THE SUBJECT IS COUNTED FOR 40-MINUTES WITHOUT CHANGING THE COUNTING GEOMETRY OF THE CHEST AND THE DETECTOR.

IV. SENSITIVITY

A. MIXED FISSION, ACTIVATION, AND CORROSION PRODUCTS AND RADIUM-226

THE SENSITIVITY OF THE SYSTEM IS A FUNCTION OF THE BACKGROUND RADIATION LEVELS, THE SIZE AND EFFICIENCY OF THE DETECTOR, THE DETECTOR-SUBJECT GEOMETRY, AND THE COUNTING TIME. THE BACKGROUND IN THE MOBILE SYSTEMS IS CAREFULLY MONITORED AT VARIOUS INTERVALS DURING THE COUNTING PERIOD. THE DETECTOR-SUBJECT RELATIONSHIP IS NORMALLY CONSTANT AT AT 12.5-INCHES BETWEEN THE FACE OF THE CRYSTAL AND THE TOP OF THE BED, ALTHOUGH IT MAY BE CHANGED TO 10.5-INCHES OR 14.5-INCHES AS THE NEED WARRANTS. SINCE THE PRESENCE OF RADIOISOTOPES OTHER THAN FALLOUT CESIUM-137 OR NATURALLY OCCURRING POTASSIUM WILL CAUSE A RISE IN THE APARENT "BACKGROUND" DUE TO COMPTON SCATTER, THE ACTUAL SENSITIVITY VARIES SOMEWHAT.

APPENDIX III PRESENTS A TABLE OF MINIMUM SENSITIVITIES. IF A RADIONUCLIDE LISTED IN APPENDIX III IS NOT LISTED IN APPENDIX I, THEN IT IS NOT PRESENT IN AN AMOUNT EQUAL TO OR GREATER THAN THAT LISTED IN THE COLUMN LABELED "MIN. SEN., NCI".

THE BACKGROUND OF THE "DO-IT-YOURSELF WHOLE BODY COUNTER" IS CONTINUOUSLY BEING DETERMINED WHEN A SUBJECT COUNT IS NOT BEING MADE. EVERY 16-MINUTES THE CURRENT BACKGROUND JUST COMPLETED IS TRANSFERRED TO A DIFFERENT MEMORY LOCATION AND A NEW BACKGROUND IS STARTED. THIS CYCLE IS CONTINUOUS. IF A SUBJECT COUNT SHOULD BE STARTED BEFORE THE CURRENT 16-MINUTE PERIOD HAS BEEN COMPLETED, BUT AFTER 8-MINUTES HAS ELAPSED SINCE THE START OF THE CURRENT BACKGROUND, THE SHORTER BACKGROUND WILL BE SAVED. IF LESS THAN 8-MINUTES HAS ELAPSED IN THE CURRENT BACKGROUND, THE DATA ARE ABORTED AND THE PREVIOUS BACKGROUND IS USED. THUS, ONE WILL ALWAYS HAVE A CURRENT AND STATISTICALLY REPRESENTATIVE BACKGROUND.

B. OTHER RADIONUCLIDES

THE SENSITIVITIES FOR URANIUM-235, PLUTONIUM-238, 239, AMERICIUM-241 AND THORIUM ARE LIKEWISE A FUNCTION OF THE BACKGROUND, DETECTOR SIZE, DETECTOR-SUBJECT GEOMETRY AND THE COUNTING TIME. THE TOTAL CHEST THICKNESS AS WELL AS THE CHEST WALL THICKNESS ALSO AFFECT THE SENSITIVITY FOR LOW ENERGY RADIONUCLIDES. SEE THE CALIBRATION DATA IN APPENDIX II FOR THE VARIATION OF THE CALIBRATION FACTORS AS A FUNCTION OF THESE PARAMETERS. TYPICAL NUMERICAL VALUES FOR MINIMUM SENSITIVITIES ARE 30 - 60 MICROGRAMS OF U-235, 4 - 50 NANOCURIES OF PU-238 AND 239 (HIGHLY DEPENDENT ON CHEST WALL THICKNESS), 0.05 - 0.1 NANOCURIES OF AM-241 AND 6 - 8 MILLIGRAMS OF NATURAL THORIUM.

## V. STATISTICAL EVALUATIONS

### A. GENERAL DISCUSSION

STATISTICAL ANALYSES OF THE DATA USE STANDARD TECHNIQUES. RANDOM COUNTS OBSERVED FROM NUCLEAR DISINTEGRATIONS HAVE BEEN SHOWN TO FOLLO THE POISSON DISTRIBUTION. HOWEVER, FOR THE NUMBER OF COUNTS OBSERVED OVER THE TYPICAL COUNTING TIMES, THE POISSON DISTRIBUTION MAY BE EVALUATED WITH A HIGH DEGREE OF CONFIDENCE BY USING THE CHARACTERISTICS OF THE NORMAL (GAUSSIAN) DISTRIBUTION. THUS, THE AVERAGE GROSS COUNTING RATE FOR POTASSIUM, FOR EXAMPLE, IS TYPICALLY FOUND BY DIVIDING THE TOTAL OF THE COUNTS OBSERVED IN CHANNELS 132 THROUGH 155, INCLUSIVE, BY THE COUNTING TIME IN MINUTES, OF,

$$G = (\text{SUM OF CHANNELS } 132 - 155) / T.$$

THE VARIANCE OF THE COUNTING RATE IS EQUAL TO THE LONG TERM EXPECTED COUNTING RATE DIVIDED BY THE SQUARE ROOT OF THE COUNTING TIME, OR,

VAR(G) = G/T

NET COUNTING RATES ARE FOUND FROM THE RELATIONSHIP

N = G - B,

WHERE G = GROSS COUNTING RATE OBTAINED IN T MINUTES AND
B = BACKGROUND COUNTING RATE OBTAINED IN T(B) MINUTES.

THE VARIANCE OF THE NET COUNTING RATE IS FOUND FROM

VAR(N) = VAR(G) + VAR(B),

WHILE THE STANDARD DEVIATION OF THE NET COUNTING RATE IS THE SQUARE ROOT OF THE VARIANCE OF N.

THE ACTUAL AMOUNT OF ACTIVITY, A, FOUND IN THE SUBJECT IS THEREFORE OBTAINED BY DIVIDING THE NET COUNTING RATE, AFTER CORRECTING FOR COMPTON SCATTER WHERE NECESSARY, BY THE CALIBRATION FACTOR, F.

A = N/F

THE VARIANCE OF A IS FOUND FROM THE RELATIONSHIP

VAR(A) / (A*A) = VAR(N) / (N*N) + VAR(F) / (F*F)

[THE ASTERISK, (*) IS USED HERE TO SIGNIFY MULTIPLICATION WHILE THE SLASH, (/), SIGNIFIES DIVISION.]

IN MOST CASES THE VARIANCE OF THE CALIBRATION FACTOR, VAR(F), IS SMALL COMPARED TO THE VARIANCE OF THE SUBJECT DATA, VAR(G), AND WHEN THE FORTRAN PROGRAM IS LARGE, VAR(F) IS ASSUMED TO BE NEGLIGIBLE. THE STATISTICAL ERROR DUE TO COMPTON SCATTER FROM ISOTOPES WHICH ARE ACTUALLY PRESENT IS INCLUDED IN THE CALCULATION OF THE VAR(A).

B. EVALUATION OF DATA FOR U-235, PU-238,9, AM-241

PRIOR TO ANY DATA REDUCTION THE ORIGINAL DATA FOR THESE RADIONUCLIDES ARE PLOTTED FOR INSPECTION BY THE ANALYST. THE DATA MAY BE SMOOTHED ACCORDING TO THE METHODS OF SAVITZKY AND GOLAY (ANALYTICAL CHEMISTRY, 36, #8, JULY '64, PP 1627 - 1639) FOR THE PURPOSE OF MINIMIZING RANDOM STATISTICAL VARIATIONS BUT PRESERVING PHOTOPEAK STRUCTURE. THIS HELPS SIGNIFICANTLY IN FURTHER EVALUATION OF THE DATA.

MOST OF THE DATA REDUCTION FOR U-235, NATURAL URANIUM, AND DEPLETED URANIUM UTILIZES THE COMPTON CONTINUUM SUBTRACTION TECHNIQUE. IN SOME CIRCUMSTANCES A NON-LINEAR CURVE-FITTING ROUTINE MAY BE USED.

DATA REDUCTION FROM PU-238, PU-239, AND AM-241 ANALYSES IS MUCH MORE INVOLVED THAN THAT FOR URANIUM ANALYSES. THE BACKGROUND FROM THE THIGH COUNT IS ASSUMED TO BE REPRESENTATIVE OF THE BACKGROUND WHICH WOULD HAVE BEEN OBTAINED OVER THE CHEST IF ONE COULD HAVE BEEN ASSURED THAT NO PLUTONIUM OR AMERICIUM HAD BEEN PRESENT IN THE CHEST. THIS IS A REASONABLE ASSUMPTION FOR MOST SITUATIONS. SEVERAL OTHER RADIONUCLIDES HAVE BEEN SEEN IN THE LUNGS OF SEVERAL INDIVIDUALS, PRINCIPALLY COBALT-60. THESE REQUIRE SPECIAL TECHNIQUES, THE DESCRIPTION OF WHICH IS BEYOND THE SCOPE OF THIS DOCUMENT. THE LUNG AND THIGH DATA ARE SMOOTHED BY THE METHOD OF SAVITZKY AND GOLAY AND ARE DISPLAYED ON THE OSCILLOSCOPE SCREEN. THE ANALYST MAY SUBTRACT FRACTIONS OF THE THIGH DATA AND DISPLAY THE NET COUNTING RATE. NORMALLY, 100-PERCENT OF THE THIGH DATA ARE SUBTRACTED FROM THE LUNG DATA. IN THOSE INSTANCES WHERE THE NET COUNTING RATE IS ENTIRELY NEGATIVE AFTER SUBTRACTING 100 PERCENT OF THE THIGH DATA, SMALL AMOUNTS OF THE DATA ARE ADDED BACK TO THE NET COUNTS TO OBTAIN A GRAPH IN WHICH APPROXIMATELY HALF OF THE NET COUNTS ARE POSITIVE AND HALF ARE NEGATIVE IN THE BACKGROUND REGIONS ADJACENT TO THE PHOTOPEAKS OF INTEREST. THESE DATA ARE THEN USED IN THE COMPTON CONTINUUM SUBTRACTION PROGRAM TO OBTAIN THE ACTUAL NET COUNTING RATE UNDER THE PHOTOPEAKS OF INTEREST.

THE CHEST WALL THICKNESS IS DETERMINED BY THREE METHODS AS DESCRIBED IN SECTION III. AT LEAST 12 CHEST WALL THICKNESS MEASUREMENTS ARE MADE USING AN ECHOENCEPHALOSCOPE. SINCE THE TRANSMISSION OF LOW ENERGY X-RAYS IS AN EXPONENTIAL FUNCTION OF THE CHEST WALL THICKNESS, A CALCULATION IS MADE TO DETERMINE THE AVERAGE TRANSMISSION. THE AVERAGE CHEST WALL THICKNESS IS BACK-CALCULATED FROM THIS INFORMATION. THUS, THE 2 SIGMA STANDARD DEVIATION IS SKEWED DUE TO THE USE OF THE LOG-NORMAL DISTRIBUTION. A LINEAR ABSORPTION COEFICIENT OF 1.15 PER CENTIMETER IS USED FOR HUMAN TISSUE AT 17-KEV. THE CHEST WALL THICKNESS IS ALSO CALCULATED BY THE METHOD FROM DEAN OF LOS ALAMOS:

THICKNESS, CM = 0.007 + 5.12* (WEIGHT, KG) / (HEIGHT, CM)

THE WALL THICKNESS IS ALSO CALCULATED BY THE METHOD OF RUNDO:

THICKNESS, CM = 15.3 * (WEIGHT, KG) / (HEIGHT, CM) - 0.01 * CIRCUMFERENCE, CM - 3.55

THE CHEST WALL THICKNESS AS DETERMINED BY THE ECHOENCEPHALOSCOPE IS NORMALLY USED IN THE CALCULATION OF THE CALIBRATION FACTORS UNLESS IT IS SIGNIFICANTLY DIFFERENT FROM THOSE OBTAINED BY THOSE OBTAINED FROM THE METHODS OF DEAN AND RUNDO. THE CALIBRATION FACTORS FOR PU-239 AND AM-241 ARE IDENTICALLY THE SAME VALUES AS USED AT LOS ALAMOS AND ARE:

CALIBRATION FACTOR, PU-235 = 39.48897 *EXP(0.836646 * CT)

RATIO, AM-241 SCATTER IN PU-239 CHANNELS TO AM-241 COUNTS=

0.2 * EXP(-0.039*CT) + 0.8 * EXP(-1.09*CT)

CALIBRATION FACTOR, AM-241 = 1.396 * EXP(0.143655 * CT)

WHERE CT = CHEST THICKNESS, CENTIMETERS.

## VI Discussion of Results

The purpose of these measurements is multi-fold. The first goal is to determine if any uranium may be observed in the lungs of the individuals being counted. This may be done in two ways, by measuring the 186-keV gamma ray from uranium-235, and by measuring the 63- and 93-keV x-rays from thorium-234, the second daughter product of the uranium-238. Since natural uranium contains only approximately 0.7 weight percent of uranium-235, the 186-keV photopeak is more difficult to observe in than in enriched uranium. The maximum permissible body burden for uranium-235 in natural uranium contained in the lungs is 180 micrograms. This would correspond to 25.6 milligrams of natural uranium. If the protoactinium-234 and thorium-234 are in equilibrium with uranium-238, one would theoretically be able to see both of these x-rays as well as a small amount of uranium-235. Unfortunately, because of the varying chest thicknesses of individuals counted, it is difficult to establish a ratio between these two different types of signals.

The results found in Appendix I show only a few individuals who have positive results for both uranium-235 and natural uranium. These persons and the ratio of micrograms of uranium-235 to milligrams of natural are given in the following table:

| Name | U-235 Micrograms | Natural U Milligrams | Ratio U-235/Nat. U. |
|---|---|---|---|
| Gibby, Duane R | 78 ± 35 | 6 ± 1 | 13 : 1 |
| Nelson, James L | 72 ± 57 | 6 ± 1 | 12 : 1 |
| Nowak, Jeffery H | 32 ± 34 | 3 ± 1 | 11 : 1 |
| Price, William F | 67 ± 38 | 2 ± 1 | 34 : 1 |
| Shields, Darvin H | 82 ± 67 | 5 ± 1 | 16 : 1 |
| Tso, Amos | 57 ± 34 | 1 ± 1 | 57 : 1 |
| White, Douglas E | 73 ± 46 | 5 ± 1 | 15 : 1 |

These individuals may be contrasted with, for example, Richard L. Griffith and Joseph P. Morgan, who show no uranium-235 but show an apparent 12 ± 2 and 16 ± 2 milligrams of natural uranium, repectively. It is quite likely that these results represent unsupported daughters of uranium-238 which, if the subject be removed from exposure to these daughters for several weeks, would probably be significantly reduced or eliminated as evidenced by a later lung count.

Thorium-230 is a daughter product in the uranium decay chain and is the precursor of radium-226. It has a half life of 80,000 years and emits a 68-keV x-ray only 0.6% of the time and a 142-keV x-ray only 0.07% of the time. Both of these signals would be completely masked by the 63- and 93-keV x-rays from thorium-234.

Thus, theoretically, about the only way to determine the thorium-230 lung content would be to look for daughters of radium-226. After having made several measurements at suitably spaced intervals, one would attempt to back-calculate for the amount of thorium-230 which may be resident in the subject. While this sounds like a workable technique in theory, in actual practice, this is quite impractical because even after 12 years the amount of radium-226 grown from the thorium-230 is only 0.01% of the original amount of thorium-230; in 60 years it is only 0.05%. The minimum detectable activity of radium-226 is approximately 6 to 10 nanocuries. Thus, there does not appear to be any practical way of measuring thorium-230 by in vivo techniques.

Since radium-226 is a possible airborne contaminante, several people were measured for this material in effort to determine whether or not they had any deposition of radium-226. None was found.

| | | U-235 MICROGRAMS | NATURAL U MILLIGRAMS |
|---|---|---|---|
| ANDERSON, RAY V | 528-24-3601, 10/06/76 AT 0840 | 0 ± 66 | 5 ± 1 |
| ATWOOD, VON R | 528-40-0342, 10/05/76 AT 1543 | 0 ± 48 | 0 ± 1 |
| BALDWIN, ROBERT D | 529-09-5991, 10/06/76 AT 1218 | 0 ± 45 | 1 ± 1 |
| BEGAY, EUGENE N | 585-50-6473, 10/04/76 AT 1035 | 0 ± 41 | 2 ± 1 |
| BEGAY, WILLIE | 530-24-0717, 10/04/76 AT 1234 | 0 ± 43 | 2 ± 1 |
| BENALLY, RONNIE | 585-84-6430, 10/05/76 AT 2156 | 0 ± 35 | 2 ± 1 |
| BENNETT, GORDON G | NO S.S. NO., 10/05/76 AT 0401 | 0 ± 37 | 7 ± 1 |
| BENNETT, WILSON G | 585-56-6484, 10/04/76 AT 2058 | 0 ± 46 | 3 ± 1 |
| BILLAIE, JOHNNY L | 528-50-1936, 10/04/76 AT 1205 | 0 ± 52 | 0 ± 1 |
| BLISS, DAVID R | 565-06-2098, 10/05/76 AT 0211 | 0 ± 39 | 2 ± 1 |
| BOLDUC, ROLAND D | 029-40-9098, 10/06/76 AT 0513 | 0 ± 40 | 6 ± 1 |
| CANINO, ANTHONY C | 528-88-7382, 10/05/76 AT 1907 | 0 ± 36 | 1 ± 1 |
| CHACON, MANUEL J | 524-24-1702, 10/04/76 AT 1108 | 0 ± 40 | 0 ± 1 |
| CHADWICK, ROGER D | 529-66-4007, 10/05/76 AT 1043 | 0 ± 42 | 1 ± 1 |
| CLY, ALBERT | NO S.S. NO., 10/04/76 AT 1300 | 0 ± 45 | 4 ± 1 |
| COOK, BILLY R | 558-70-3694. 10/05/76 AT 2225 | 0 ± 40 | 6 ± 1 |
| COOK, BRUCE S | 159-38-5000, 10/06/76 AT 0124 | 0 ± 40 | 3 ± 1 |
| DAUGHETEE, ROY L | 524-54-8478, 10/05/76 AT 0437 | 0 ± 38 | 0 ± 2 |
| DAVIS, JIM W | NO S.S. NO., 10/04/76 AT 1800 | 0 ± 40 | 1 ± 1 |
| DAY, LESTER A | 529-04-1944, 10/04/76 AT 2248 | 0 ± 37 | 2 ± 1 |
| DIETZ, JOE W | 270-22-6375, 10/04/76 AT 1138 | 0 ± 49 | 0 ± 1 |
| DOMENICK, SYLVESTER | 522-20-1971, 10/05/76 AT 2003 | 0 ± 42 | 0 ± 1 |
| DOWNARD, ROBERT H | 536-28-0486, 10/05/76 AT 0630 | 0 ± 51 | 3 ± 1 |
| FULLMER, JAMES G | 522-90-5571, 10/06/76 AT 0058 | 0 ± 40 | 2 ± 1 |
| GAFA, EDWARD L | 529-40-0533, 10/05/76 AT 0240 | 0 ± 43 | 2 ± 1 |
| GARRETT, JOSEPH M | 529-90-2777, 10/04/76 AT 1543 | 0 ± 39 | 0 ± 1 |
| GAY, FRED G | 521-90-0235, 10/06/76 AT 0032 | 0 ± 49 | 7 ± 1 |
| GETTER, HOLYOAK | 549-74-4934, 10/04/76 AT 2031 | 0 ± 40 | 4 ± 1 |
| GIBBY, DUANE R | 549-76-4181, 10/05/76 AT 2338 | 78 ± 35 | 6 ± 1 |
| GORDON, DONALD C | 529-66-7956, 10/05/76 AT 0333 | 0 ± 42 | 4 ± 1 |
| GRAMLICH, WALTER M | 522-94-2694, 10/05/76 AT 0730 | 0 ± 41 | 1 ± 1 |
| GREGORY, GILBERT W | 506-16-2268, 10/04/76 AT 1935 | 0 ± 35 | 0 ± 1 |
| GRIFFITH, RICHARD L | 523-86-9144, 10/06/76 AT 0245 | 0 ± 46 | 12 ± 2 |
| HALE, GERALD W | 235-84-9269, 10/04/76 AT 0845 | 0 ± 35 | 2 ± 1 |
| HAMILTON, JOHN H | 399-46-4286, 10/06/76 AT 0150 | 0 ± 39 | 1 ± 1 |
| HANAGARNE, FRANK L | 585-78-3652, 10/04/76 AT 1327 | 0 ± 46 | 2 ± 1 |
| HARRISON, GERALD D | 557-48-0574, 10/05/76 AT 1612 | 0 ± 47 | 2 ± 1 |
| HASS, DANNY G | 528-66-8723, 10/04/76 AT 2349 | 0 ± 36 | 0 ± 1 |
| HATALIE, TOLIN | 528-74-6910, 10/04/76 AT 2153 | 0 ± 31 | 0 ± 1 |
| HILL, JAMES W | 521-80-4193, 10/05/76 AT 2128 | 0 ± 44 | 2 ± 1 |
| HOLLIE, EVANS JR | 529-70-0204, 10/05/76 AT 1242 | 0 ± 42 | 0 ± 1 |
| HOLYOAK, GARY R | 529-38-0072, 10/06/76 AT 1032 | 0 ± 48 | 5 ± 1 |
| HOPKINS, DENNIS L | 521-90-0796, 10/06/76 AT 1100 | 0 ± 42 | 0 ± 1 |
| HOPKINS, MARVIN | 522-56-8658, 10/06/76 AT 0220 | 0 ± 38 | 9 ± 2 |
| HOPKINS, RONALD | 524-90-7184, 10/05/76 AT 2103 | 0 ± 35 | 1 ± 1 |

| | | U-235 MICROGRAMS | NATURAL U MILLIGRAMS |
|---|---|---|---|
| HOUT, GARY D | 555-04-0261, 10/06/76 AT 0541 | 0 ± 50 | 5 ± 2 |
| HUBBELL, ALFRED G | 367-62-8298, 10/05/76 AT 1108 | 0 ± 42 | 3 ± 1 |
| KING, JOHN A | 525-24-0738, 10/05/76 AT 0117 | 0 ± 39 | 10 ± 2 |
| KUHEL, ROBERT H | NO S.S. NO., 10/05/76 AT 1215 | 0 ± 32 | 1 ± 1 |
| LEECH, DWIGHT | 528-22-0968, 10/05/76 AT 2033 | 0 ± 51 | 9 ± 2 |
| LEFF, TOMMY E | 522-38-6947, 10/05/76 AT 1515 | 0 ± 50 | 3 ± 1 |
| LITTLE, ROBERT E | 530-36-3793, 10/05/76 AT 1730 | 0 ± 57 | 4 ± 1 |
| MACHADO, JERRY | 945-10-9328, 10/05/76 AT 1015 | 0 ± 42 | 0 ± 1 |
| MARKHAM, LARRY J | 528-48-6388, 10/04/76 AT 0908 | 0 ± 33 | 0 ± 1 |
| MARTIN, JOSEPH J | 549-50-4201, 10/06/76 AT 0908 | 0 ± 54 | 0 ± 1 |
| MC GANN, KEVIN B | 303-54-4830, 10/06/76 AT 0445 | 0 ± 40 | 4 ± 1 |
| MC NEELY, WAULSTINE | NO S.S. NO., 10/04/76 AT 2002 | 0 ± 42 | 0 ± 1 |
| MONNIERE, MICHAEL A | 521-82-7227, 10/04/76 AT 0816 | 0 ± 34 | 5 ± 1 |
| MORGAN, JOSEPH F | 524-01-9701, 10/04/76 AT 1010 | 0 ± 43 | 16 ± 2 |
| NACKI, LESTER | 585-76-1411, 10/05/76 AT 1830 | 0 ± 52 | 6 ± 1 |
| NELSON, JAMES L | 468-34-5076, 10/05/76 AT 1447 | 72 ± 57 | 6 ± 2 |
| NOWAK, JEFFREY H | 173-46-6647, 10/05/76 AT 0050 | 32 ± 34 | 3 ± 1 |
| OLIVER, DELBERT O | 259-70-7065, 10/05/76 AT 0922 | 0 ± 41 | 0 ± 1 |
| OLIVER, JOHN A | 528-40-0052, 10/05/76 AT 0658 | 0 ± 61 | 8 ± 2 |
| OLIVER, JOHN C | NO S.S. NO., 10/06/76 AT 0347 | 0 ± 40 | 1 ± 1 |
| POOL, SIDNEY M | 461-24-2883, 10/06/76 AT 1154 | 0 ± 42 | 2 ± 1 |
| PRICE, WILLIAM F | 539-54-3554, 10/05/76 AT 1135 | 67 ± 38 | 2 ± 1 |
| PRZYBYLSKI, DANIEL | 565-96-5932, 10/05/76 AT 2250 | 0 ± 33 | 4 ± 1 |
| ROBERT, KENNETH G | 521-40-3283, 10/04/76 AT 1515 | 0 ± 57 | 7 ± 2 |
| ROBERTSON, KIM R | 528-80-9965, 10/06/76 AT 0006 | 0 ± 46 | 3 ± 1 |
| RODMAN, DAVID L | 316-54-3412, 10/06/76 AT 1125 | 0 ± 42 | 1 ± 1 |
| RODMAN, JOSEPH M | 566-74-4390, 10/04/76 AT 0935 | 0 ± 32 | 4 ± 1 |
| ROPER, DON P | 522-72-6043, 10/04/76 AT 1705 | 0 ± 42 | 3 ± 1 |
| ROSS, DAVID A | 563-80-2076, 10/04/76 AT 1906 | 0 ± 30 | 0 ± 1 |
| ROSS, GEORGE E | 521-26-5835, 10/04/76 AT 1635 | 0 ± 61 | 5 ± 1 |
| ROSS, MIKE C | 530-52-3352, 10/05/76 AT 0758 | 0 ± 38 | 1 ± 1 |
| ROSS, TOMMY D | 523-48-2149, 10/04/76 AT 1733 | 0 ± 49 | 5 ± 1 |
| SAGGB, JOE | 444-36-2532, 10/05/76 AT 0850 | 0 ± 39 | 0 ± 1 |
| SAMUELSON, DANIAL W | 520-60-1902, 10/04/76 AT 2220 | 0 ± 35 | 2 ± 1 |
| SEBASTIAN, SIDNEY E | 525-24-9085, 10/06/76 AT 0810 | 0 ± 49 | 5 ± 1 |
| SHIELDS, DARVIN H | 539-42-7536, 10/06/76 AT 0938 | 82 ± 67 | 5 ± 1 |
| SIDWELL, LUNDY M | 490-70-3884, 10/05/76 AT 0950 | 0 ± 43 | 3 ± 1 |
| SIMPSON, JOHN J | 522-66-8151, 10/05/76 AT 1417 | 0 ± 57 | 4 ± 1 |
| SMITH, GREGORY M | 232-92-5335, 10/04/76 AT 1422 | 0 ± 30 | 3 ± 1 |
| SMITH, RICK D | 234-88-4490, 10/05/76 AT 1800 | 0 ± 38 | 1 ± 1 |
| STASH, JOHN E | NO S.S. NO., 10/04/76 AT 2323 | 0 ± 48 | 6 ± 1 |
| STEWART, JACK C | 528-66-2494, 10/04/76 AT 1837 | 57 ± 34 | 1 ± 1 |
| STEWART, STEVEN W | 528-66-2457, 10/04/76 AT 0023 | 0 ± 48 | 8 ± 1 |
| STOYE, BILL G | 528-64-2917, 10/05/76 AT 0145 | 0 ± 38 | 2 ± 1 |
| SUNDERLAND, HERBERT E | 512-03-3551, 10/05/76 AT 1642 | 0 ± 43 | 0 ± 1 |
| THAYNE, GLEN W | 528-26-2373, 10/06/76 AT 1004 | 0 ± 25 | 3 ± 1 |
| TSO, AMOS | 511-66-0578, 10/04/76 AT 2125 | 73 ± 46 | 5 ± 1 |
| WELLS, DENNIS E | 528-50-1554, 10/05/76 AT 1335 | 0 ± 51 | 9 ± 1 |
| WHITE, DOUGLAS H | NO S.S. NO., 10/05/76 AT 1937 | 70 ± 45 | 5 ± 1 |
| WHITTAKER, CLARE H | 364-26-1072, 10/04/76 AT 1448 | 0 ± 35 | 0 ± 1 |
| WHITTAKER, CLARE H JR | 527-88-3678, 10/05/76 AT 0306 | 0 ± 44 | 4 ± 1 |
| WILSON, KENNETH D | 528-66-7827, 10/06/76 AT 0322 | 0 ± 50 | 5 ± 1 |
| WIMER, DAVIS E | 543-05-2887, 10/05/76 AT 1307 | 0 ± 56 | 1 ± 1 |
| YAZZIE, CLIFFORD | 527-84-0884, 10/05/76 AT 0824 | 0 ± 37 | 2 ± 1 |

# APPENDIX II,
# URANIUM CALIBRATION

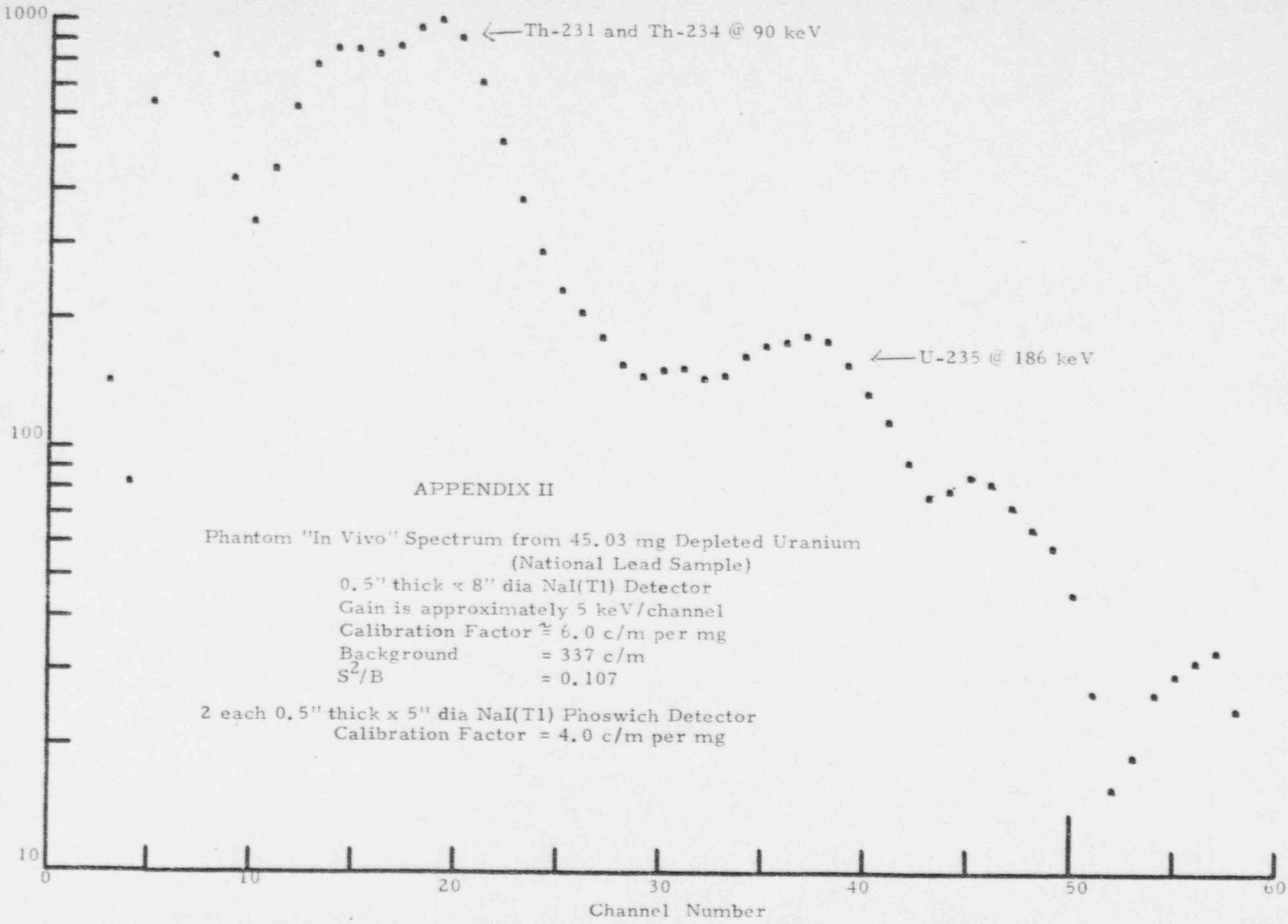
```
*WRITE ALL
C-FOCAL , 8/68

01.10 S C0=201.667*FEXP(6*0.132578);T !,"C0 =",26.03,C0,!!
01.20 F I=6,13;T !!,I3.03;D 2
01.30 T !!!!!!!!!;Q

02.30 D 2.9;F J=0,0.25,0.75;D 2.99;D 2.9;T T(I)
02.35 D 2.97;F J=0,0.25,0.75;D 2.99;T C(I)
02.40 RETURN
02.90 S T(I)=IJ;S C(I)=C0*FEXP(-IJ*0.132578)
02.97 T !,"CALIB. FACTO., C/I PER MC"
02.98 T !,"CHEST THICKNESS, INCHES  "
02.99 S IJ=I+J;S I=4*IJ
*
*
*CO

C0 =  532.440
```

| | | | | |
|---|---|---|---|---|
| CHEST THICKNESS, INCHES | 6.000 | 6.250 | 6.500 | 6.750 |
| CALIB. FACTOR, C/I PER MC | 262.900 | 254.309 | 246.038 | 238.017 |
| | | | | |
| CHEST THICKNESS, INCHES | 7.000 | 7.250 | 7.500 | 7.750 |
| CALIB. FACTOR, C/I PER MC | 230.257 | 222.750 | 215.488 | 208.463 |
| | | | | |
| CHEST THICKNESS, INCHES | 8.000 | 8.250 | 8.500 | 8.750 |
| CALIB. FACTOR, C/I PER MC | 201.667 | 195.092 | 188.732 | 182.579 |
| | | | | |
| CHEST THICKNESS, INCHES | 9.000 | 9.250 | 9.500 | 9.750 |
| CALIB. FACTOR, C/I PER MC | 176.627 | 170.862 | 165.298 | 159.927 |
| | | | | |
| CHEST THICKNESS, INCHES | 10.000 | 10.250 | 10.500 | 10.750 |
| CALIB. FACTOR, C/I PER MC | 154.696 | 149.653 | 144.774 | 140.054 |
| | | | | |
| CHEST THICKNESS, INCHES | 11.000 | 11.250 | 11.500 | 11.750 |
| CALIB. FACTOR, C/I PER MC | 135.483 | 131.071 | 126.798 | 122.664 |
| | | | | |
| CHEST THICKNESS, INCHES | 12.000 | 12.250 | 12.500 | 12.750 |
| CALIB. FACTOR, C/I PER MC | 118.665 | 114.797 | 111.054 | 107.434 |
| | | | | |
| CHEST THICKNESS, INCHES | 13.000 | 13.250 | 13.500 | 13.750 |
| CALIB. FACTOR, C/I PER MC | 103.931 | 100.543 | 97.265 | 94.094 |




## APPENDIX II

Phantom "In Vivo" Spectrum from 45.03 mg Depleted Uranium
(National Lead Sample)

0.5" thick x 8" dia NaI(Tl) Detector
Gain is approximately 5 keV/channel
Calibration Factor $\cong$ 6.0 c/m per mg
Background = 337 c/m
$S^2/B$ = 0.107

2 each 0.5" thick x 5" dia NaI(Tl) Phoswich Detector
Calibration Factor = 4.0 c/m per mg

| | |
|---|---|
| Gibby, Duane | 549-76-4181 |
| Hired 11-25-74 | |
| 11-25-74 to 2-2-75 | Laborer |
| 2-2-75 to 9-11-75 | RIP Operator |
| 9-11-75 to present | Plant Tech. |
| Nelson, James L. | 468-34-5076 |
| Hired 7-12-76 | |
| 7-12-76 to present | Maintenance Department |
| Nowak, Jeffrey H. | 173-46-6647 |
| Hired 6-21-76 | |
| 6-21-76 to 7-4-76 | Laborer |
| 7-4-76 to 9-12-76 | V205 Furnace Operator |
| 9-12-76 to present | SX Operator |
| Price, William F. | 539-50-3554 |
| Hired 12-1-75 | |
| 12-1-75 to 12-21-75 | Operator Trainee |
| 12-21-75 to 10-10-76 | V205 Precip. Operator |
| 10-10-76 to present | Relief Operator |
| Shields, Darvin H. | 529-42-7536 |
| Hired 4-17-57 | |
| 4-17-57 to 7-31-57 | Laborer |
| 7-31-57 to 3-19-58 | RIP Operator |
| 3-19-58 to 4-23-63 | Fluorimetric Chemist |
| 4-23-63 to 3-1-68 | Control Chemist |
| 3-1-68 to present | Metallurgical Technician |
| Tso, Amos | 571-66-0578 |
| Hired 7-13-76 | |
| 7-13-76 to 10-24-76 | Laborer |
| 10-24-76 to present | Copper Operator |
| White, Douglas H. | 528-52-4656 |
| Hired 4-12-57 | |
| 4-12-57 to 5-16-57 | Laborer |
| 5-16-57 to 7-20-60 | Painter |
| 7-20-60 to 2-15-62 | Mechanic Helper |
| 2-15-62 to 5-1-65 | Mechanic |
| 5-1-65 to 12-16-67 | Mechanic "A" |
| 12-16-67 to 6-1-69 | Lead Mechanic |
| 6-1-69 to present | Maintenance Foreman |
| Stewart, Jack C. | 528-66-2494 |
| Hired 8-21-74 | |
| 8-21-74 to 8-11-75 | Operator Crushing Dept. |
| 8-11-75 | Terminated |
| 1-27-76 | Rehired |
| 1-27-76 to 3-16-76 | Laborer |
| 3-16-76 to present | Loader Operator |