# TRACE ELEMENT CONCENTRATIONS IN MELANOTIC SWINE

by

Roseanne Marie Sherman

Thesis submitted to the graduate faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Nuclear Science and Engineering

APPROVED:

Thomas F. Parkinson, Chairman

Hugo Veit

A. K. Furr

April, 1982

Blacksburg, Virginia

## ACKNOWLEDGEMENTS

The author wishes to express unending gratitude to all of the people who were involved in this research: The members of her advisory committee, Dr. A. K. Furr and Dr. Hugo Veit; the American Cancer Society; Mark Goslow; everyone at the Nuclear Reactor Lab--Gene Knight, Al Curtner, Leo Eskin, Judy Deinhardt, Bill Bryan, Eric Ellis, Dennis Prater, Dawn Serrell, Fran Leighton and especially Dean Kirstein who solved innumerable computer problems. She would also like to thank Hal Pendrak of Geological Science for his assistance with the calibration curves and matrix effects. Finally, the author would like to thank Dr. T. F. Parkinson for his patience, support, advice and encouragement.

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# 1. INTRODUCTION

For many years there has been much research involving cancer and carcinogens. It is believed that the presence of certain trace elements and their concentrations may indicate the presence of cancer in tissues. Earlier work on trace elements in human skin biopsies showed significant differences between normal and cancerous tissues (1-11). Therefore, it may be possible to categorize these trace elements and their concentrations and use them as a diagnostic tool to determine the malignancy of tumors.

The purpose of this study was to utilize neutron activation analysis (NAA) and x-ray fluorescence analysis (XRFA) to determine trace element concentrations in swine melanomas. Because studies have indicated similarities between the lesions observed in swine and those observed in humans (12, 13), a study of trace element concentrations in swine melanomas should give insight to human melanomas. A comparison of tumors in the two species is summarized in Table 1.1 (12). Sinclair miniature swine, which are particularly susceptible to developing tumors, were used in this study. Of all the swine born in the Sinclair herd, 21% were observed to have cutaneous melanocytic tumors. Studies of the characteristics of these melanomas have been underway for about 11 years (13). Some preliminary NAA data on Sinclair swine biopsies were reported by Anderson (2).

Table 1.1

Pigmented Lesions in Swine and Their Human Counterparts

| Swine Lesions | Human Counterparts |
|---|---|
| Flat lesions | Junctional nevus |
| Elevated lesions | Compound nevus |
| Raised blue tumors | Blue nevus |
| Peripheral depigmentation | Vitiligo |
| Regressing lesions | Sutton's halo nevus |
| Ulcerative tumors | Melanoma |
| Systematic pigmented tumors | Metastosisol melanoma |
| Congenital tumors | Bathing trunk/congenital |

NAA and XRFA have been applied in numerous studies to determine trace elements in human tissue (1-10, 14-23). A study by Danielson and Steinnes (7) showed that zinc concentrations in cancerous tissues were lower than in normal tissues. Data reported by Gooden (4); Parkinson, Millikan and Anderson (5); Samsuhl, Brune and Wester (6); Parkinson, Millikan and Langebeck (10); and Molokhia and Portnoy (10) agree with Danielson and Steinnes. Gooden (4) also observed somewhat higher manganese concentrations in pathological human tissues than in normal tissues. Roessler, Swanson, Ellis and Williams (9) observed that selenium positively correlated with the presence of mouse tumor tissues and rubidium positively correlated with the presence of metastatic tumors. In addition, they found that both rubidium and selenium appeared to be present in the tissue supporting the metastatic growth. Mulay, Roy, Knox, Suhr and Delaney (11), using emission spectroscopy, determined that there were higher concentrations of zinc, magnesium, manganese and copper in cancerous human breast tissues than in the corresponding non-cancerous breast tissues; there were lower iron concentrations and higher zinc concentrations in the bronchogenic carcinoma than in the corresponding non-cancerous bronchial mucosa; and there were lower tin concentrations in the cancerous tissues of the colon than in the non-cancerous tissues.

A very useful summary of trace element concentrations in human tissues is given by Iyengar, Kollmer and Bowen (24).

Parkinson, Millikan and Langebech (10) also defined a malignancy index, MI

$$MI = \frac{(C_m C_c)_x}{(C_m C_c)_n}$$

based on manganese and copper concentrations. $C_m$ and $C_c$ are the concentrations of Mn and Cu, respectively, and the x and n subscripts refer to unknown and normal tissue samples, respectively. This malignancy index may be used as a diagnostic tool after more pathological tissue analysis.

XRFA and NAA are excellent analytic tools for the biologist. Both have excellent sensitivity for many elements, are non-destructive analytic techniques and require very small quantities of material for analysis: NAA--less than 0.5g and XRFA--0.1g to 10.0g. XRFA has an advantage over NAA in that in some cases the system can be adapted to be used as an "in-vivo" analytic technique. In specimens, NAA can determine elements in the range of atomic numbers 9-92 with the exception of atomic numbers 81-89 and phosphorus, sulfer, technetium, and promethium; XRFA can determine elements in the range of atomic numbers 10-92.

The principle for the NAA procedure is to irradiate the specimen with neutrons which cause the formation of radioactive isotopes. The energy spectrum of the emitted gamma radiation is then analyzed to determine the elements present. The elements are identified by the energies at which photopeaks occur. Knowledge of such factors as the height of the photopeak, irradiation time, post irradiation time, and counter efficiency will allow for the determination of the amount of each element present.

The principle for the XRFA procedure is to irradiate the specimen with primary x-rays or $\gamma$-rays of sufficient energy to excite the characteristic radiation of the particular element or elements to be determined. The excited characteristic or secondary fluorescent radiation is dispersed spectrally and the intensity of the various peaks estimated. As in NAA the elements are identified by the energies at which the peaks occur. From the intensity of the excited x-ray peaks, quantitative analysis of the elements is accomplished. X-ray tubes or gamma- and x-ray emitting radioactive isotopes are used as sources to excite characteristic x-rays in specimens. Table 1.2 lists the common radioactive isotopes used as excitation sources and their characteristics.

Table 1.2

Common Radiactive Isotopes Used as Sources in XRFA

| Isotope | Half-life (years) | Mode of Decay | Energy (keV) | Type of Radiation |
|---|---|---|---|---|
| $^{55}Fe$ | 2.7 | electron capture | 5.9 | Mn K x-rays |
| $^{57}Co$ | 0.7 | electron capture | 136.0 | $\gamma$-rays |
| | | | 122.0 | $\gamma$-rays |
| | | | 14.0 | $\gamma$-rays |
| | | | 6.4 | Fe K x-rays |
| $^{109}Cd$ | 1.3 | electron capture | 88.0 | $\gamma$-rays |
| | | | 22.2 | Ag K x-rays |
| $^{125}I$ | 0.16 | electron capture | 35.0 | $\gamma$-rays |
| | | | 27.0 | Te K x-rays |
| $^{238}Pu$ | 86.4 | alpha | 12-17 | U L x-rays |
| $^{241}Am$ | 458.0 | alpha | 59.6 | $\gamma$-rays |
| | | | 14-21 | Np L x-rays |

# 2. XRF MEASUREMENTS

## 2.1 XRF System Hardware and Software

The XRF system used was that developed and calibrated by Rose (25) and further developed by Holland (26). The system consists of a radioactive isotope excitation source, a lithium drifted silicon (Si(Li)) detector, a high voltage supply, a preamplifier, a linear amplifier, an ND 4420 multichannel analyzer and a magnetic tape unit. Figure 2.1 illustrates the XRF system in the form of a block diagram.

The Si(Li) detector is a semi-conductor crystal maintained at liquid nitrogen temperatures (-320 F) along with its pre-amp. These two components provide a pulsed current to the amplifier and then to the ND 4420 multi-channel analyzer. The ND 4420 unit consists of an analog-to-digital converter, an oscilloscope, a multi-channel pulse height analyzer, and a memory for 2048 channels. The tape unit both writes and reads the data taken from the ND 4420. The data on the tape is the file or tagword number which is automatically incremented after each file is written.

The radioactive isotopes used as excitation sources were an Fe-55 annular source, 10 mCi in July, 1976, and an Am-241 annular source, 100 mCi in February, 1978, used in conjunction with a Mo, Sn or Dy metal target foil. The Fe-55 source provides 6.40 keV photons which in turn excites the Mn used for the source. The Mn produces 5.90 keV x-rays. The Am-241

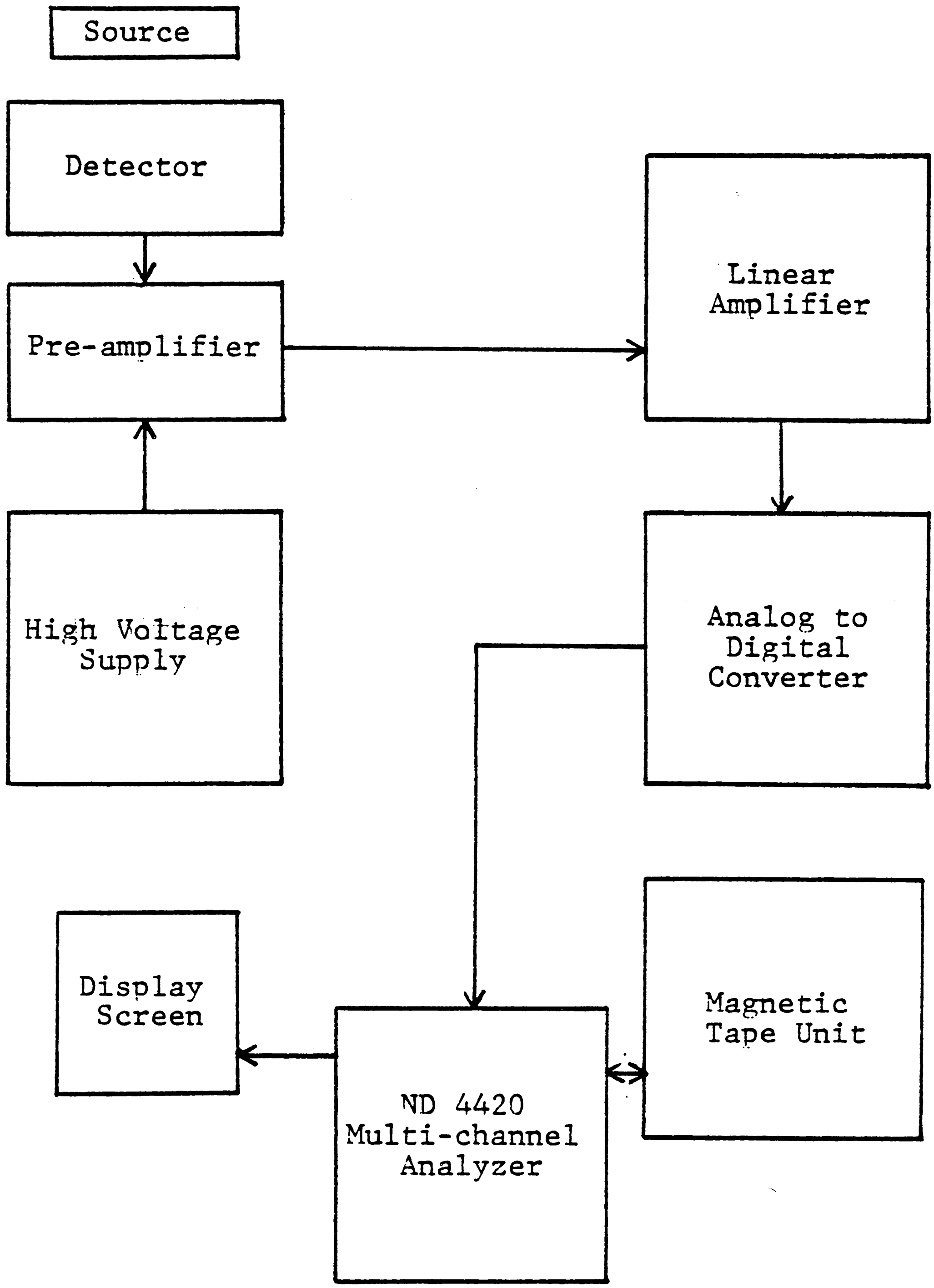



Fig. 2.1 Block Diagram--XRF System

source used in conjunction with the Mo, Sn and Dy target foils produces 17.476, 25.27 and 46.00 keV x-rays, respectively. In this work only data with the Fe-55 and the Am-241 source with a Mo target foil, referred to as Am(Mo), were analyzed. The Am(Sn) and Am(Dy) sources were not used because of difficulties in recalibrating the system with these sources.

Each source was used to analyze specific elements; therefore, there should be as many runs per sample as there are sources. Figures 2.2 and 2.3 illustrate the geometries used between the detector, source, target foil and sample. The source holder was obtained commercially with the Am-241 source. Both sources were purchased from New England Nuclear Labs.

The samples were located in a sample changer which can be rotated manually or automatically after each run. Figure 2.4 shows the sample changer along with the source holder and Si(Li) detector. The sample changer was approximately 8mm above the source. Since the operation time of the ND 4420 data acquisition unit was unpredictable, the sample changer was operated manually. After a sample had been excited and the secondary fluorescence counted for the desired length of time, the acquired data was written on magnetic tape and the sample changer was rotated until the next sample was positioned directly over the source. The sequence was then repeated.

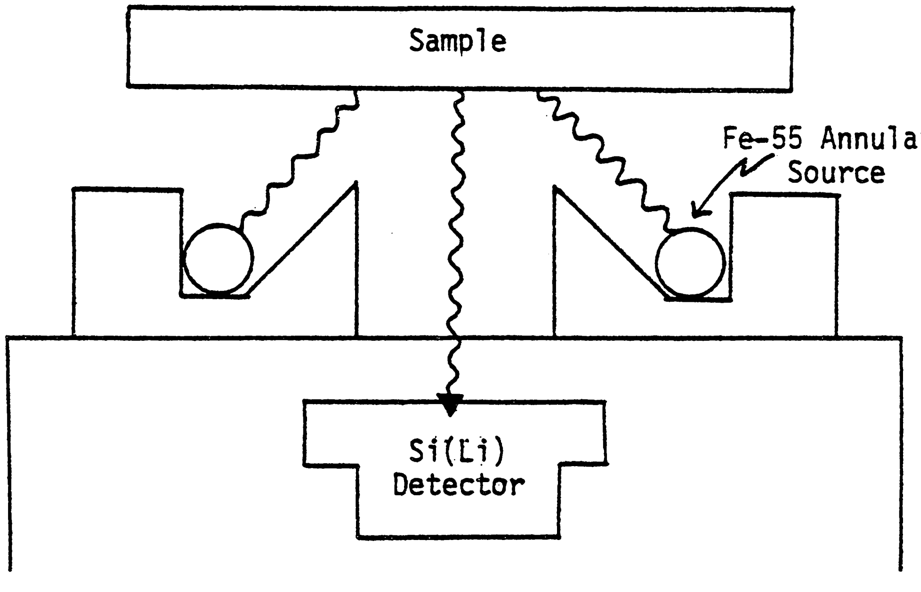



Fig. 2.2 Source Geometry for Fe-55

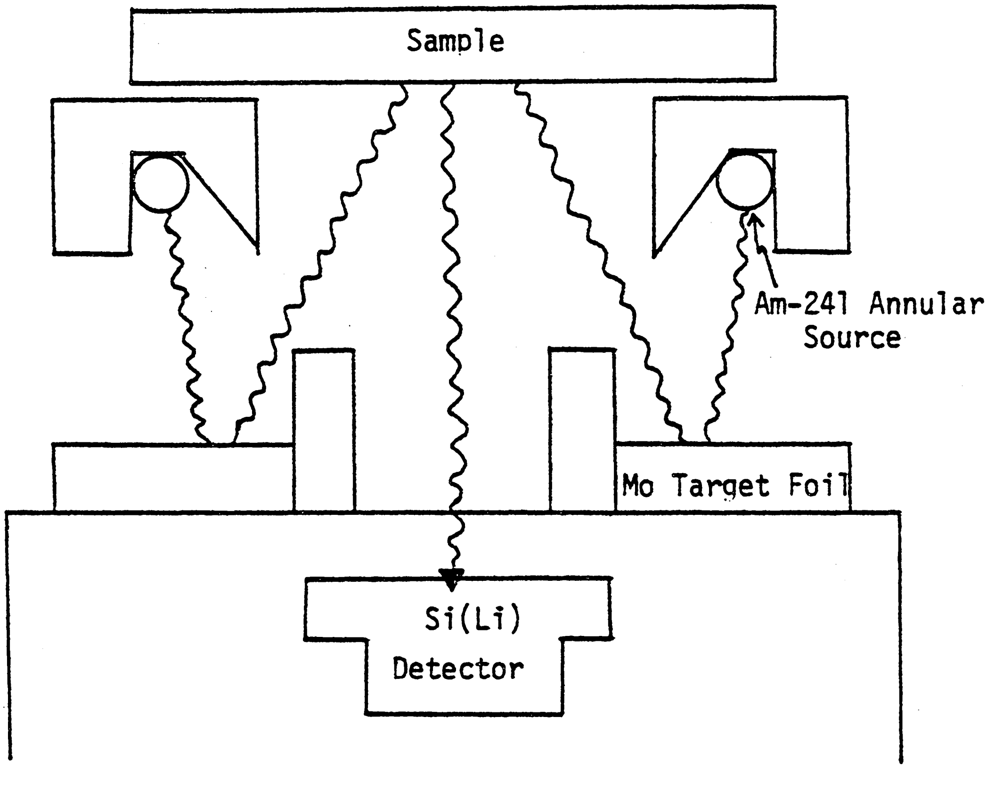



Fig. 2.3 Source Geometry for Am(Mo)

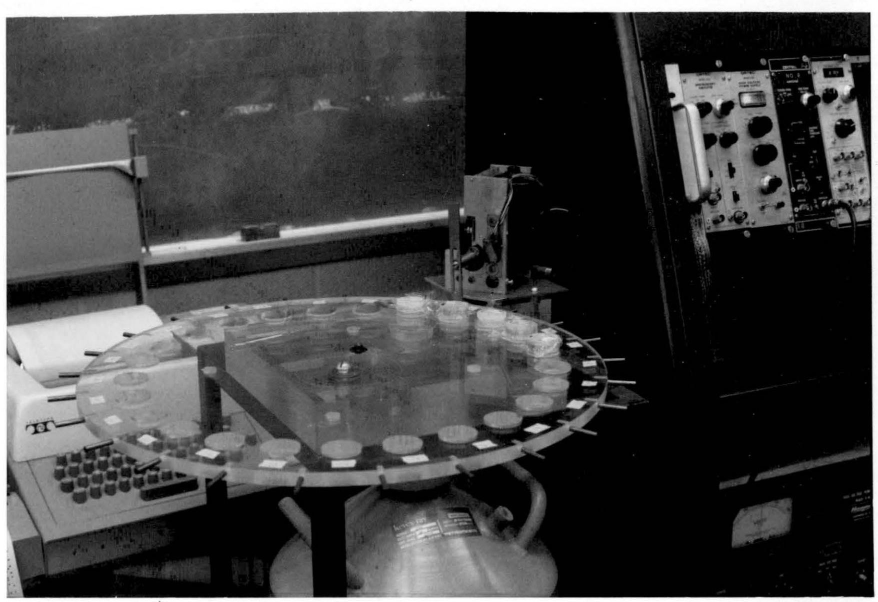


Fig. 2.4 Sample Changer

The linear amplifier is used to control the range of energies to be examined. The gain setting is different for each source used. Table 2.1 lists the gain setting used for each source. These settings were determined by starting a sample run with only the source on the detector. The gain was adjusted until the source peak on the oscilloscope was centered approximately at channel number 1825.

Table 2.1

Linear Amplifier Gain Settings for the Excitation Sources

| Source | Target Foil | Excitation Energy (keV) | Gain Setting | Source Peak Center (channel number) |
|---|---|---|---|---|
| Fe-55 | Mn (Isotope holder) | 5.90 | 200x1.462= 292.4 | 1823 |
| Am-241 | Mo | 17.476 | 0.950x100= 95.0 | 1823 |

## 2.2 XRF System Calibration

In order to perform qualitative XRFA it is necessary to determine the energy of the excitation peak and find the associated elemental x-ray, e.g., $K\alpha$, $K\beta$, $L\gamma$, etc. The relationship between x-ray energy and channel number was determined by using USGS Standard rocks and NBS Standard Reference Materials. The more difficult calibration is to quantify the analyses by relating the peak area to the elemental concentration. As discussed by Rose (25), the observed peak intensity is proportional to the elemental concentration, neglecting matrix effects.

Once the amplifier gain setting was fixed, NBS standards and USGS rocks were analyzed to provide data to generate calibration curves of channel number vs. x-ray energy. The spectrum for NBS 1645 standard with the Fe-55 source is shown in Fig. 2.5. The energy calibration curve for the Fe-55 source obtained from NBS 1645 standard is shown in Fig. 2.6. The spectrum for USGS AGV-1 standard with the Am(Mo) source is shown in Fig. 2.7. The energy calibration curve for the Am(Mo) source obtained from USGS AGV-1 standard is shown in Fig. 2.8. These calibration curves were calculated by a least squares linear regression.

The energy calibration is fairly stable. It should be verified every 3 to 4 months. Each time the XRF system is shut down for more than 24 hours, the source peak should be

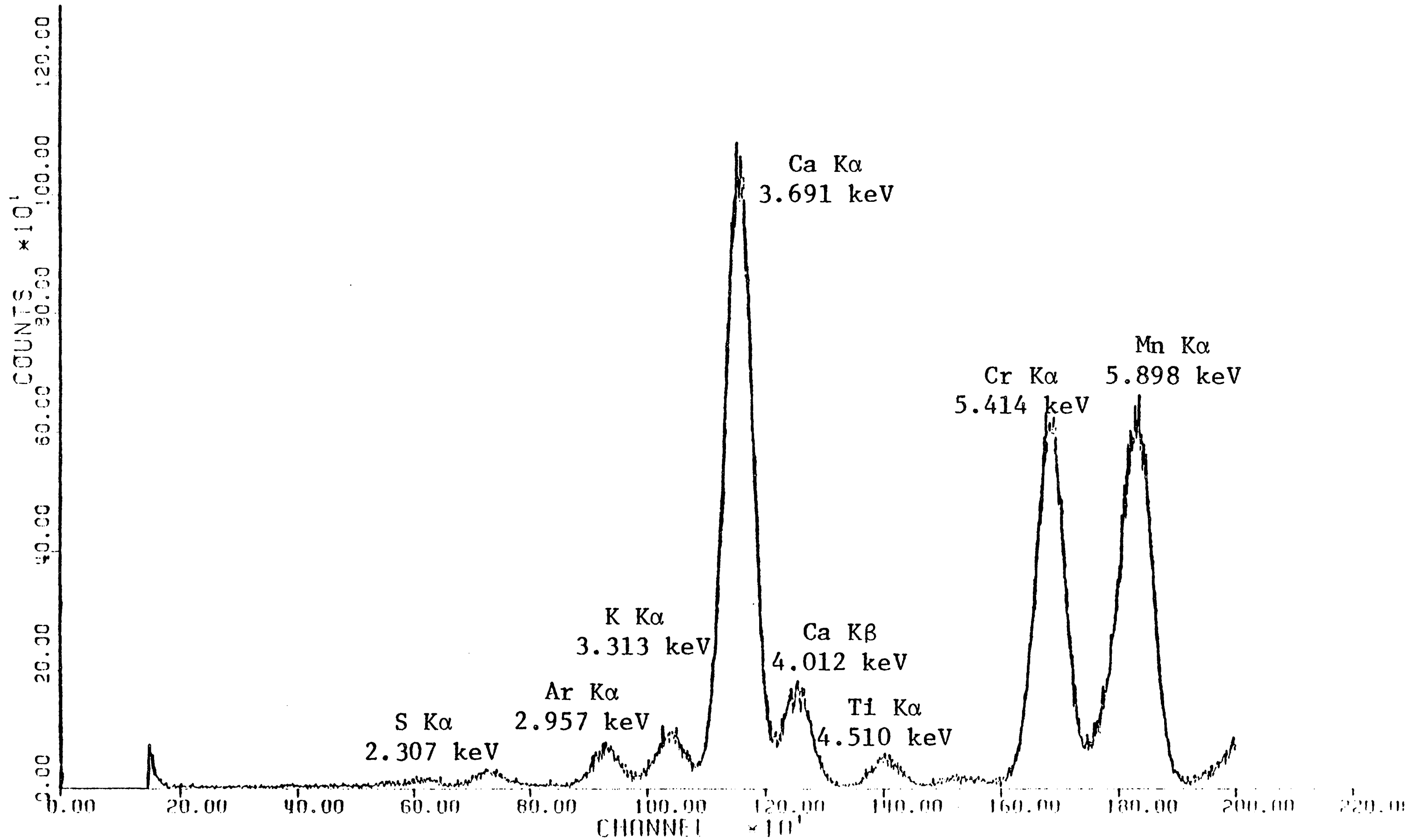



Fig. 2.5 NBS 1645 Spectrum with Fe-55 Source

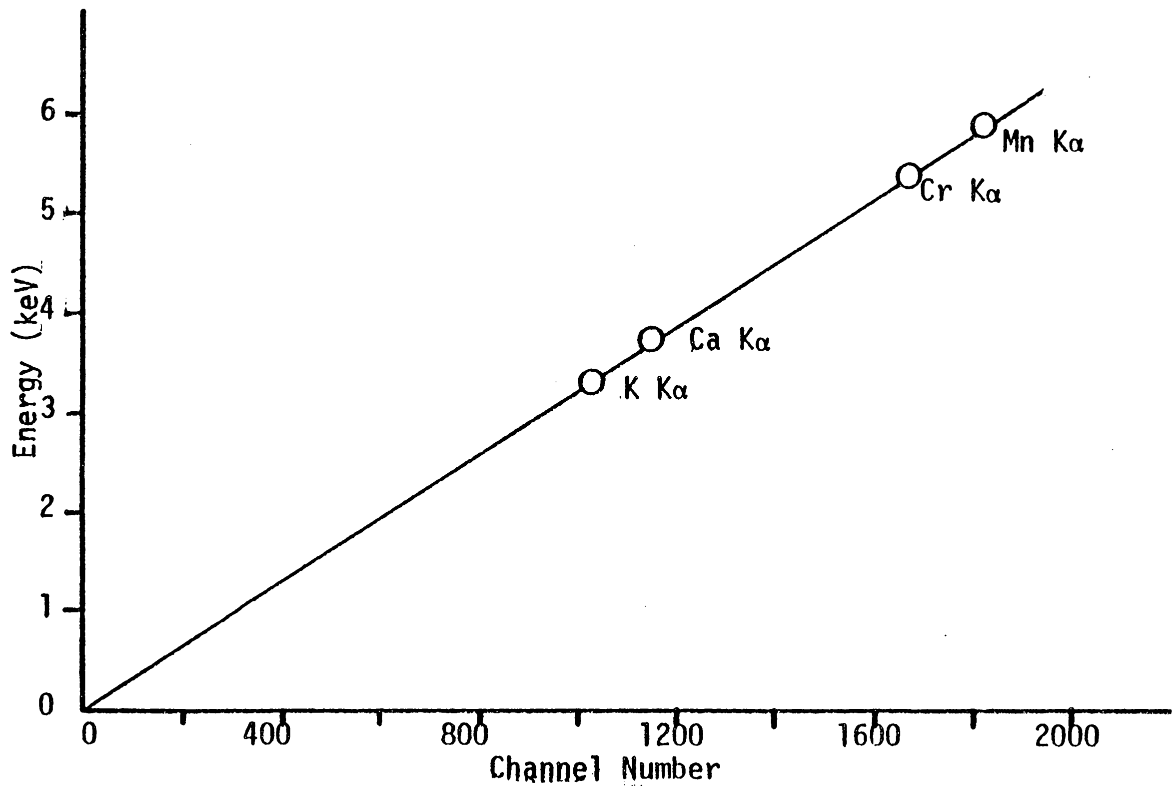



Fig. 2.6 Energy Calibration Curve for Fe-55 Source

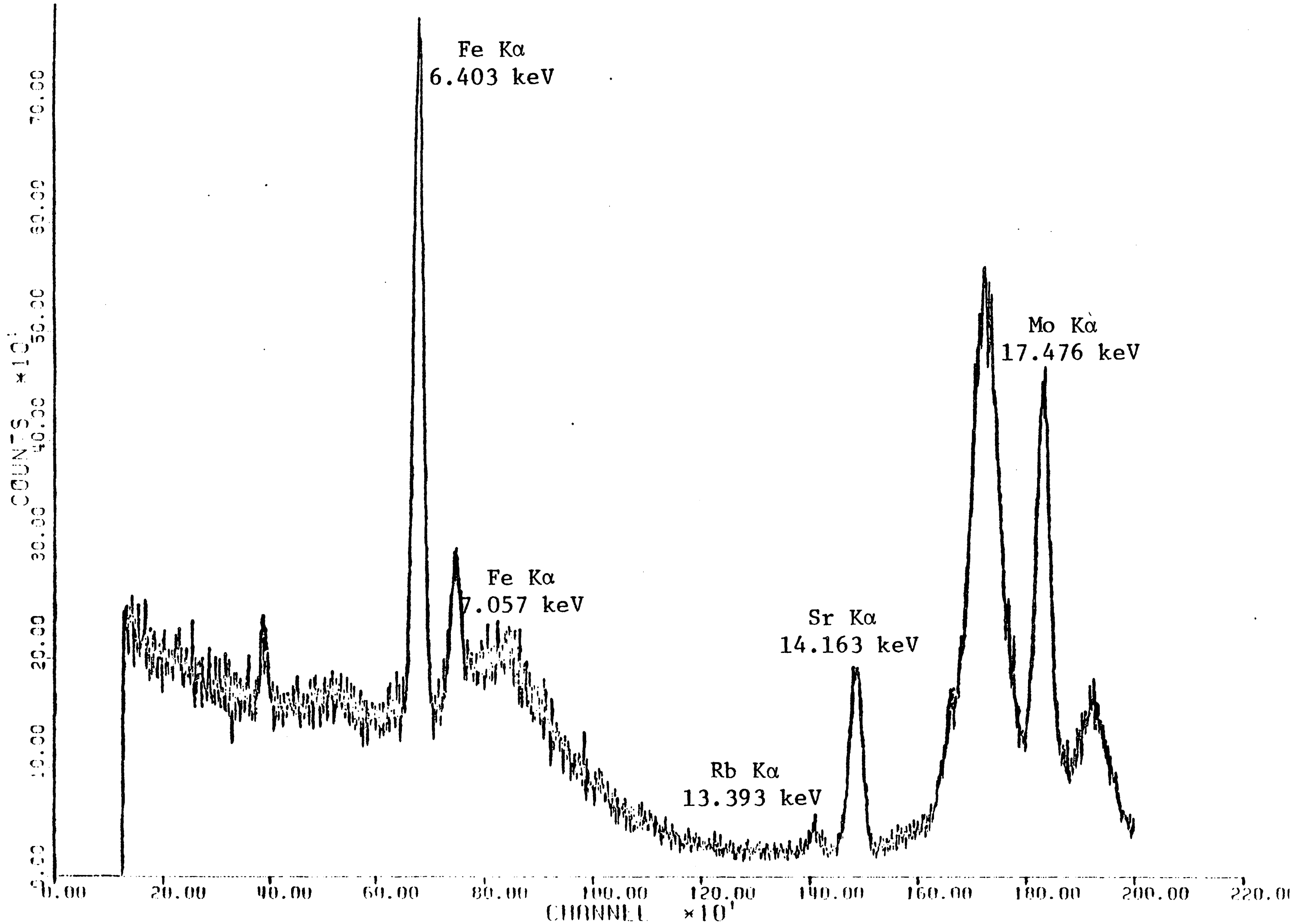



Fig. 2.7 USGS AGV-1 Spectrum with Am(Mo) Source

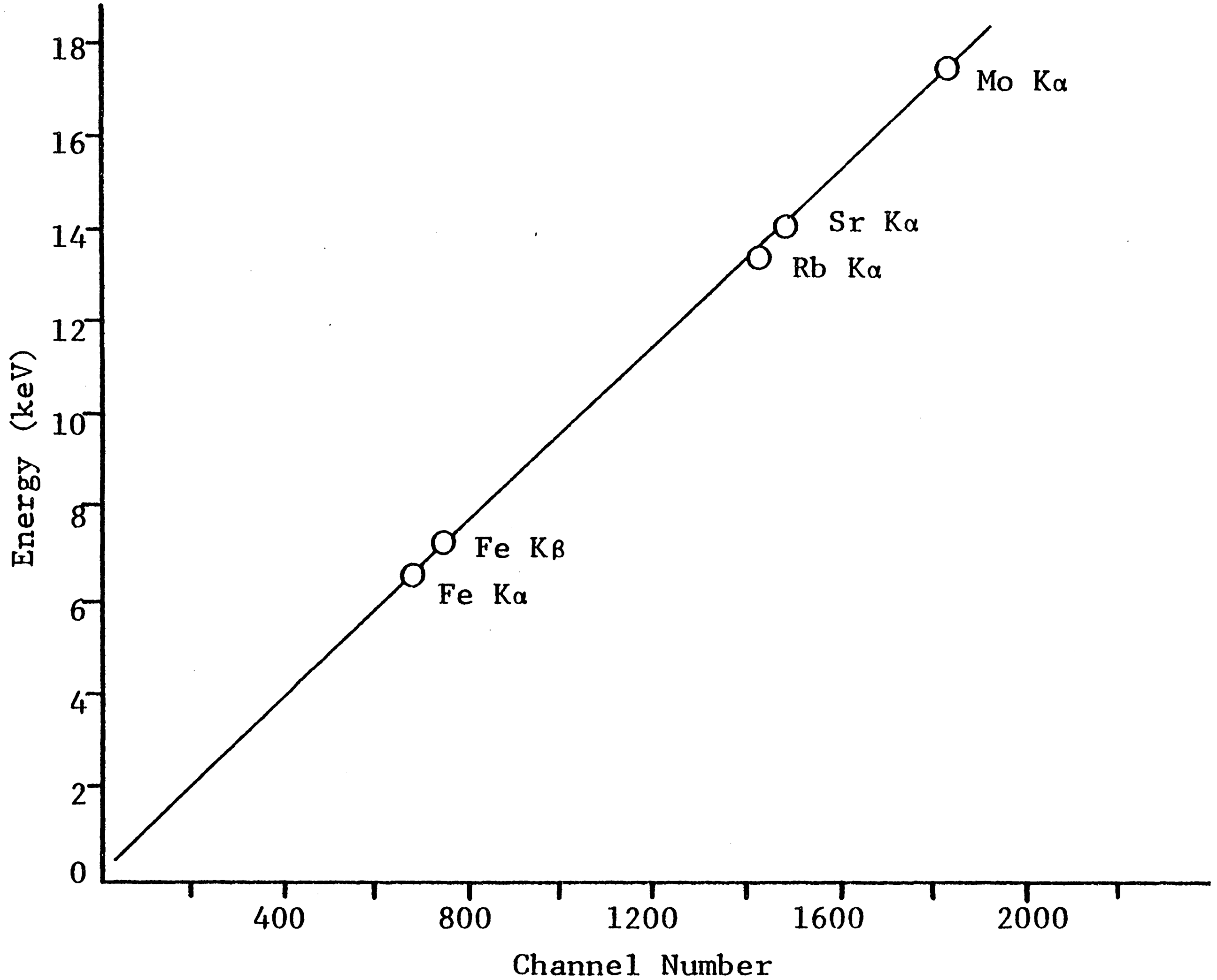



Fig. 2.8 Energy Calibration Curve for Am(Mo) Source

checked to see if it has shifted. A slight adjustment in the fine gain on the linear amplifier will return the source peak to its proper location.

The resolution of the detector is given in terms of the width of its pulseheight distribution at half maximum (FWHM) relative to the average pulse height. The resolution is given by:

$$\%R = \frac{FWHM}{\bar{E}} \times 100$$

where $\bar{E}$ is the energy at the peak center. Figure 2.9 illustrates the %R for the various energies.

The samples were in powdered form. They were placed in small cups* which had a thin (0.0015") Mylar** window between the sample and the detector. The depth of the samples in the cups was greater than 0.1mm since this is the maximum penetrating depth of low energy ($E<50$ keV) x-rays (page 79 in 27).

The XRFA computer code used was that developed by Holland (Appendix D in 26) with the following changes: the energy calibrations were changed from Holland's original values to those determined from Figs. 2.6 and 2.8. These values are in the form of the slope and the y-intercept.

* "Spectro cups" manufactured by Somar Laboratories, Inc.
** Trademark of the E. I. duPont deNemours Company, Inc.

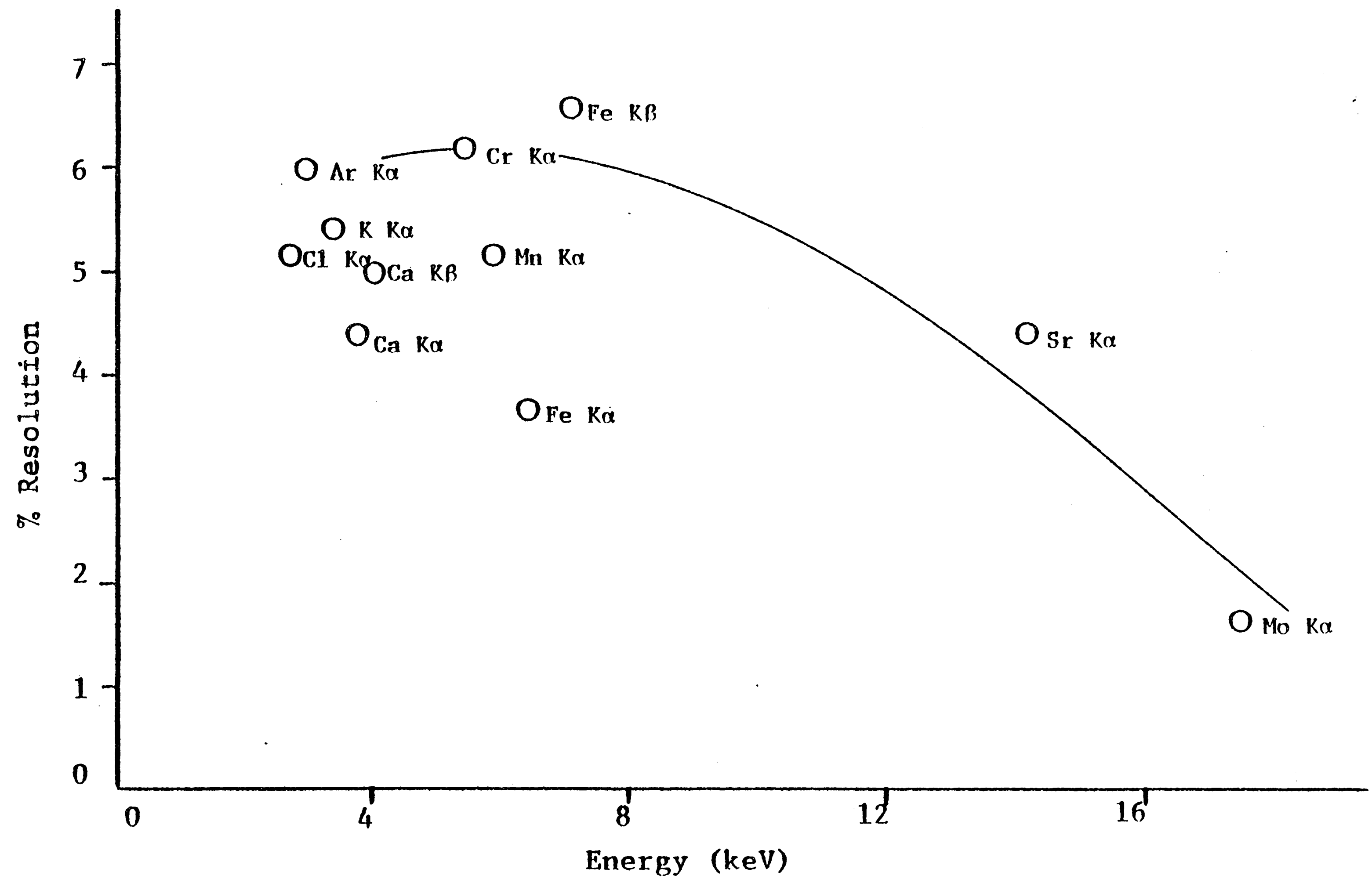



Fig. 2.0 Si(Li) Detector Resolution

Table 2.2 lists the current and previous (26) values for the energy calibrations. The concentration factor for each element to be analyzed was also changed.

The concentration factor, defined as concentration (ppm) per unit peak area, is a measure of this particular XRF system's ability to measure the correct concentration of an element. The concentration factors were determined by analyzing a series of standards and comparing the calculated concentrations to the known concentrations for each element. Neglecting matrix effects, there is a linear relationship between the concentration factor and the concentration. A ratio can be set up to determine the correct concentration factor:

$$\frac{\text{assumed concentration factor}}{\text{calculated concentration}} = \frac{\text{correct concentration factor}}{\text{known concentration}}$$

where the calculated concentration is that generated by the XRF code using some assumed value for the concentration factor. Table 2.3 lists the current and previous (26) values for the concentration factors.

With these two changes having been made, the XRF code can determine Fe, Cu, Zn, Br, and Sr concentrations in samples using the Am(Mo) source and Si, S, Cl, K, Ca, Ti, and Cr concentrations in samples using the Fe-55 source.

Table 2.2

Energy Channel Number Calibration Values

| Source | Previous (26) Slope | Previous (26) Intercept | Current Slope | Current Intercept |
|---|---|---|---|---|
| Am(Mo) | 0.009500 | 0.0 | $0.009612 \pm 5.20\times10^{-5}$ | 0.11125 |
| Fe-55 | 0.003517 | 0.0 | $0.003261 \pm 1.30\times10^{-5}$ | -0.04976 |

Table 2.3

Concentration Factors

| Source | Element | Previous (26) Concentration Factor | Current Concentration Factor |
|---|---|---|---|
| Am(Mo) | Fe | 3.76500 | 4.4940 ± 0.3460 |
| | Cu | 0.03020 | 0.3209 ± 0.0670 |
| | Zn | 1.00000 | 1.2068 ± 0.1030 |
| | Br | 0.00330 | 0.3319 ± 0.0690 |
| | Sr | 0.17700 | 0.1987 ± 0.0310 |
| | Ca | 39.79999 | 36.9370 ± 1.5620 |
| Fe-55 | Si | 1.00000 | 995.0000 ± 4.7930 |
| | S | 5.00000 | 81.1420 ± 1.9820 |
| | Cl | 13.00000 | 21.0000 ± 1.1250 |
| | K | 8.50000 | 5.0845 ± 0.3920 |
| | Ca | 3.90000 | 2.4370 ± 0.2430 |
| | Ti | 1.52800 | 0.8721 ± 0.09870 |
| | Cr | 5.00000 | 4.1346 ± 0.3270 |
| | Mn | 5.00000 | 5.0000 |

The XRF code searches for a peak, determines the element that the peak represents by applying the energy calibration, and calculates the concentration of the element in parts per million (ppm).

In computing the concentration of an element, the peak area must be determined. Figures 2.20 through 2.21 illustrate the concentration of each element as a function of peak area for several standards. These peak areas were determined with 1800 second count times. Where error bars were not included, it was because they are within the range of the symbol. In Figs. 2.10, 2.11, 2.12, 2.16 and 2.20, very low concentration points fall off the curve. This may be due to matrix effects or the method of background subtraction which separates the peak from the background. Figures 2.10 through 2.21 also include concentration factors which were determined by the method outlined previously in this section. These concentration factors should be equal to the slopes of the peak area vs. concentration curves. In most cases, they are not. Both the concentration factors and the peak area vs. concentration curves should pass through the origin. In Figs. 2.10, 2.11 and 2.15, they do not. Again this is probably due to matrix effects or the method of background subtraction.

Figures 2.22 through 2.29 compare the concentrations in NBS Standards and USGS Rock Standards determined by NAA to those determined by XRFA. Where error bars were not included, it was because they are within the range of the symbol. The

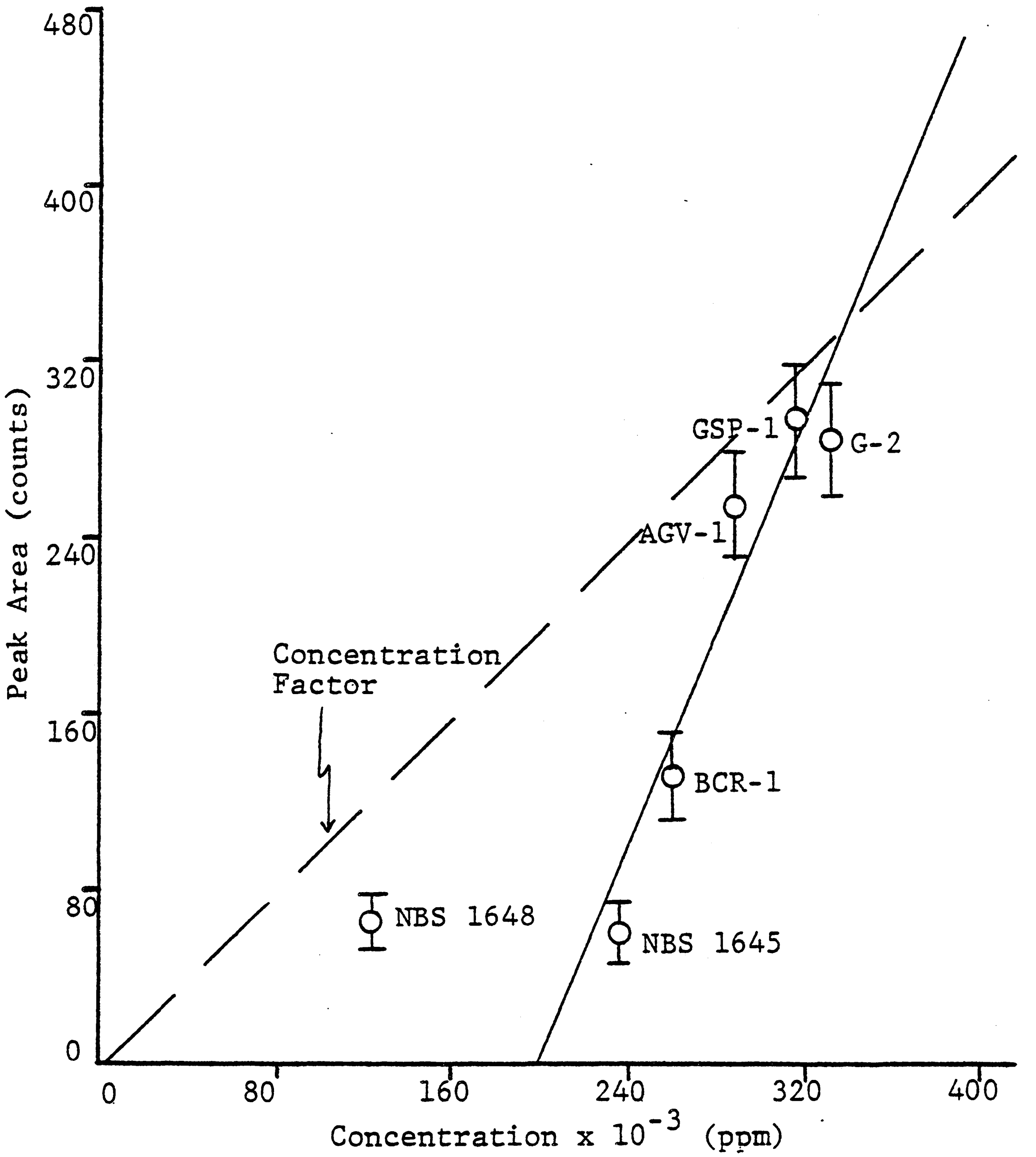



Fig. 2.10 Peak Area vs. Concentration for Si

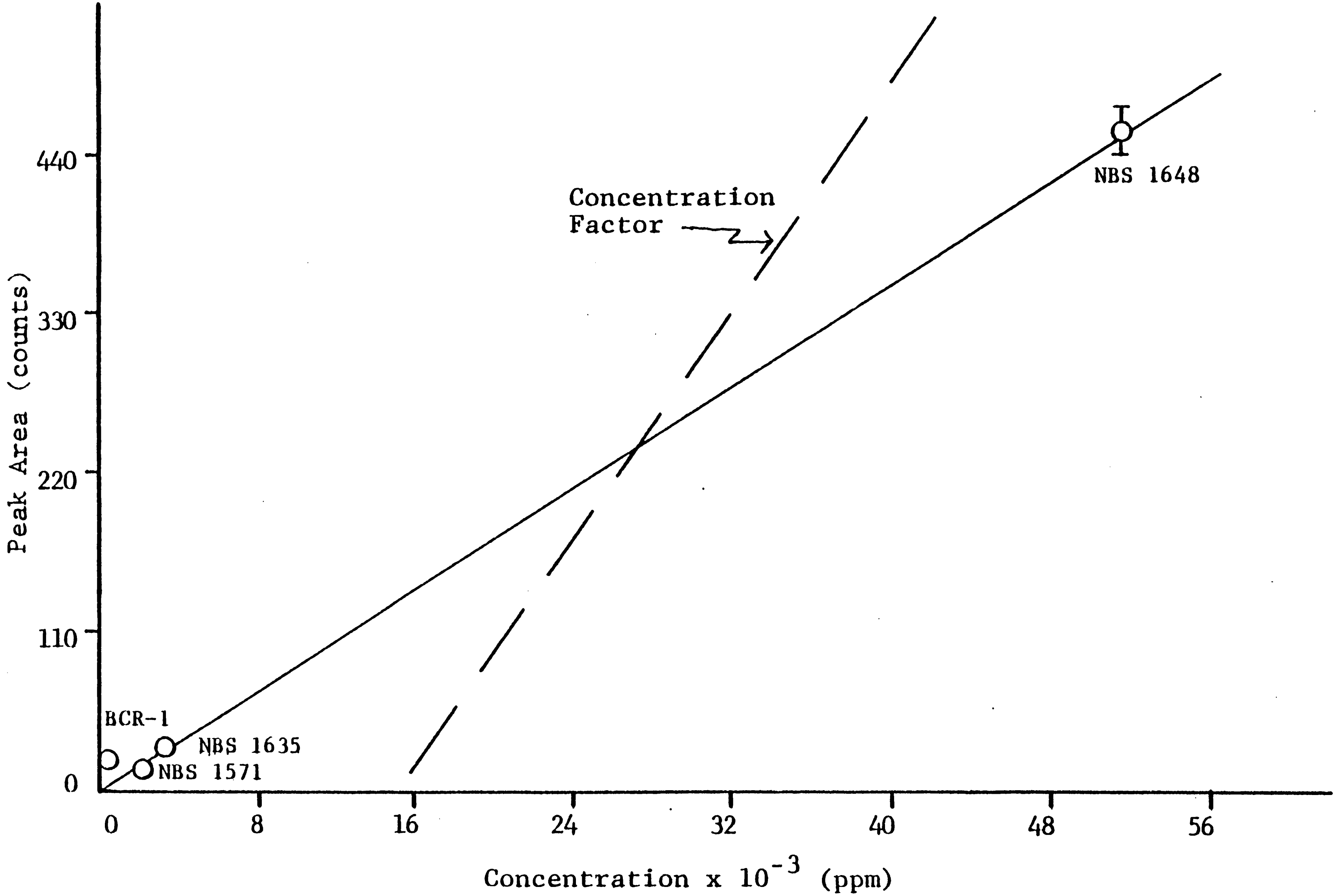
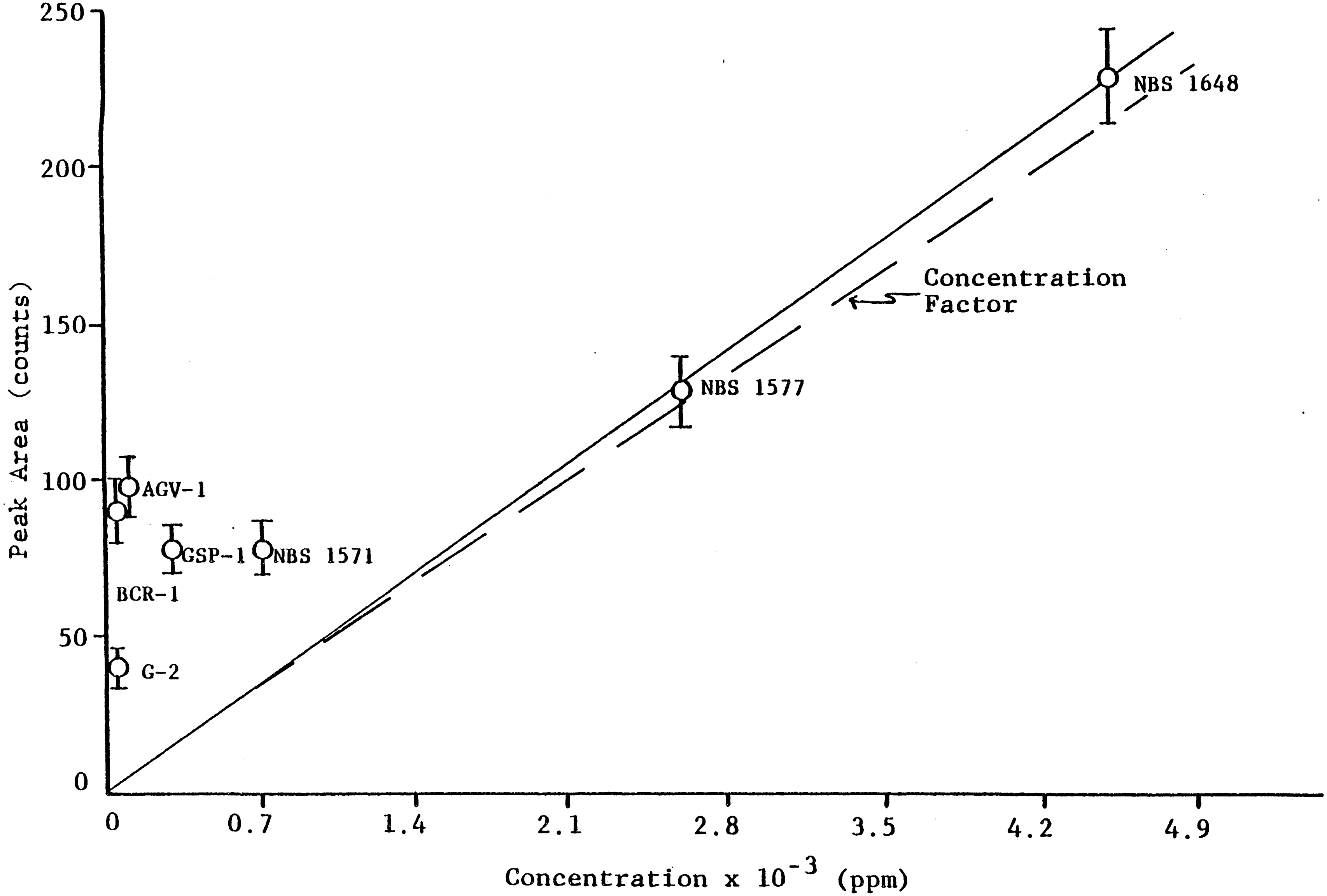



Fig. 2.11 Peak Area vs. Concentration for S




Fig, 2.12 Peak Area vs. Concentration for Cl

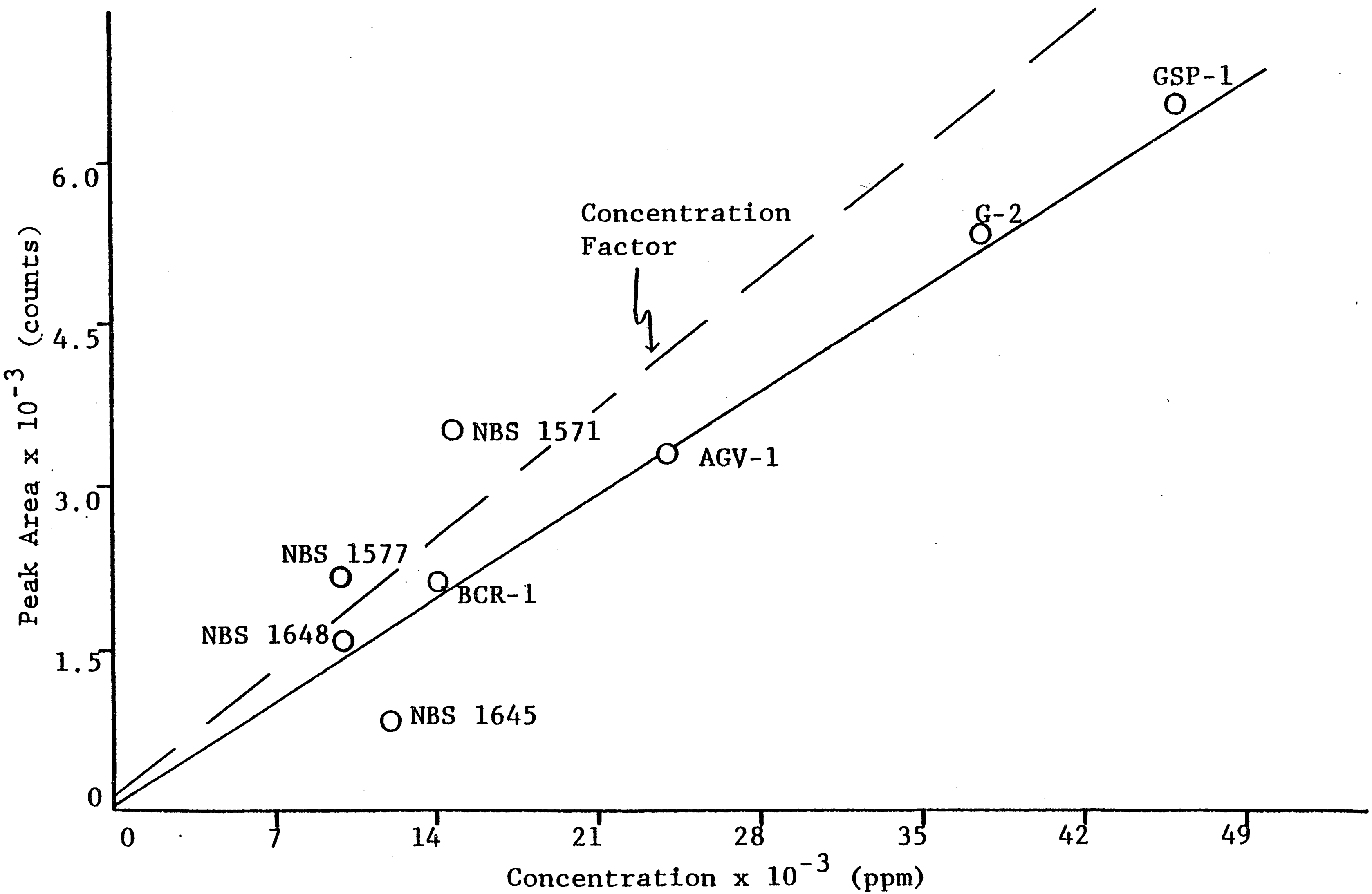



Fig. 2.13 Peak Area vs. Concentration for K

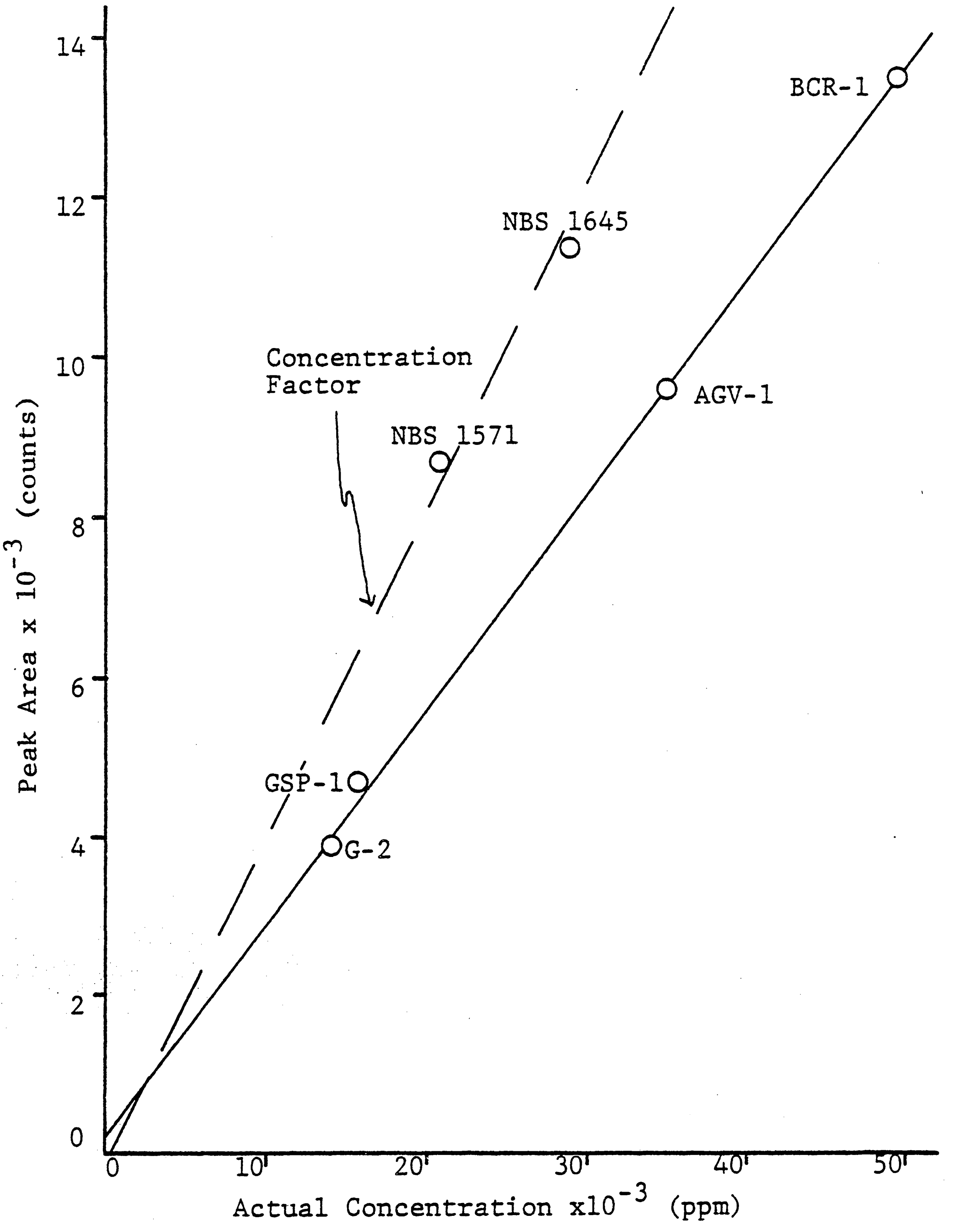



Fig. 2.14 Peak Area vs. Concentration for Ca

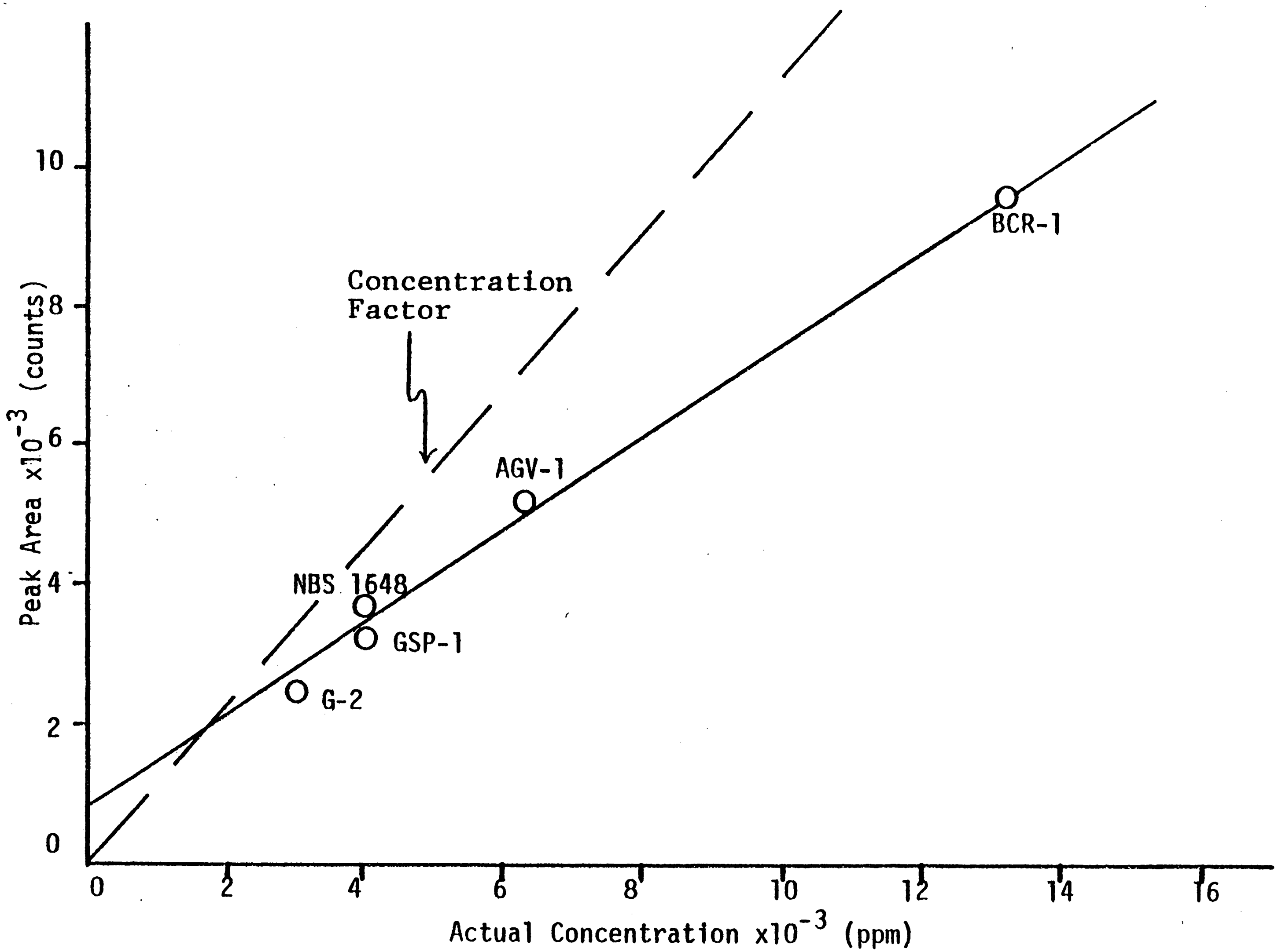



Fig. 2.15 Peak Area vs. Concentration for Ti

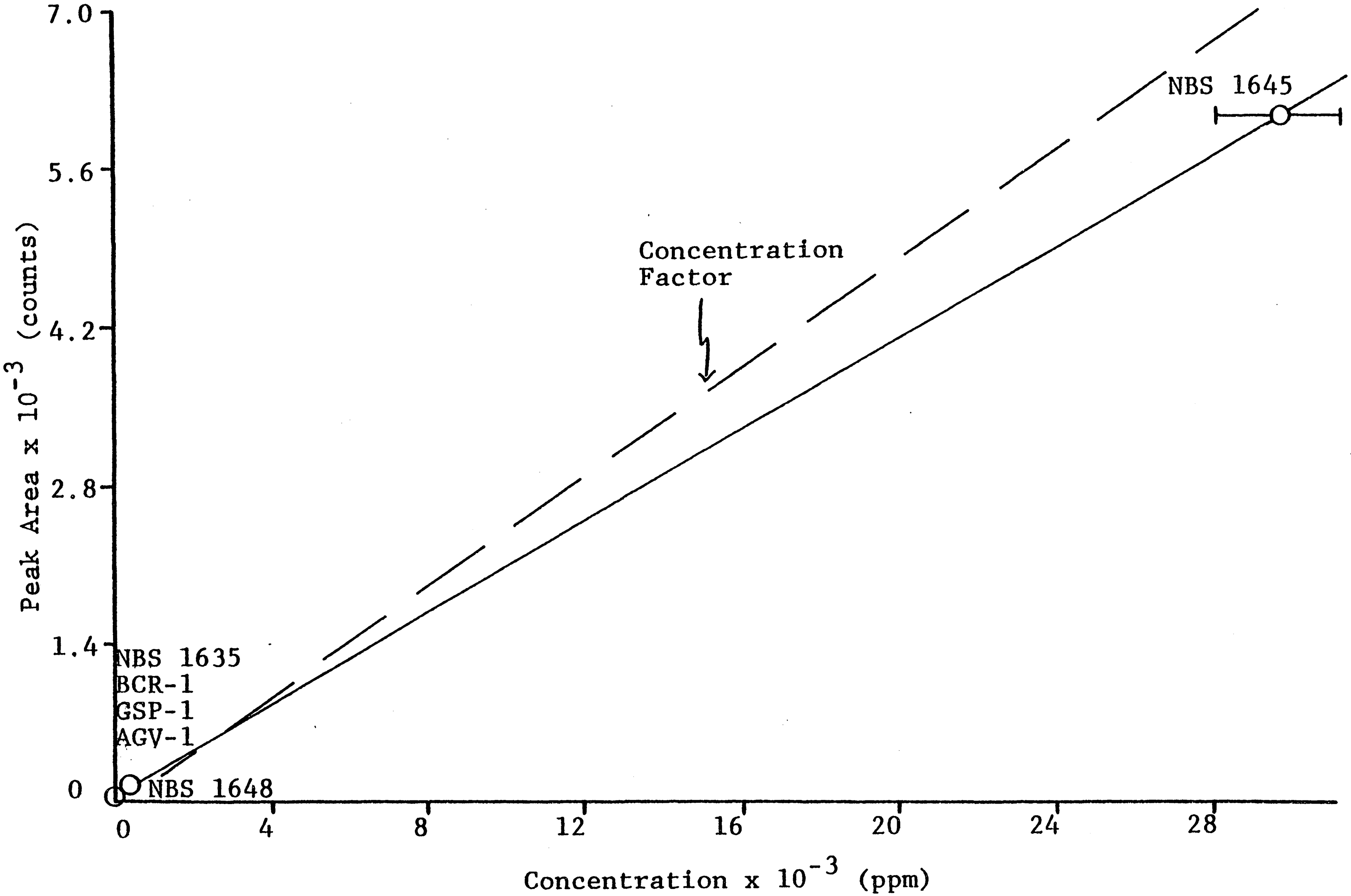



Fig. 2.16 Peak Area vs. Concentration for Cr

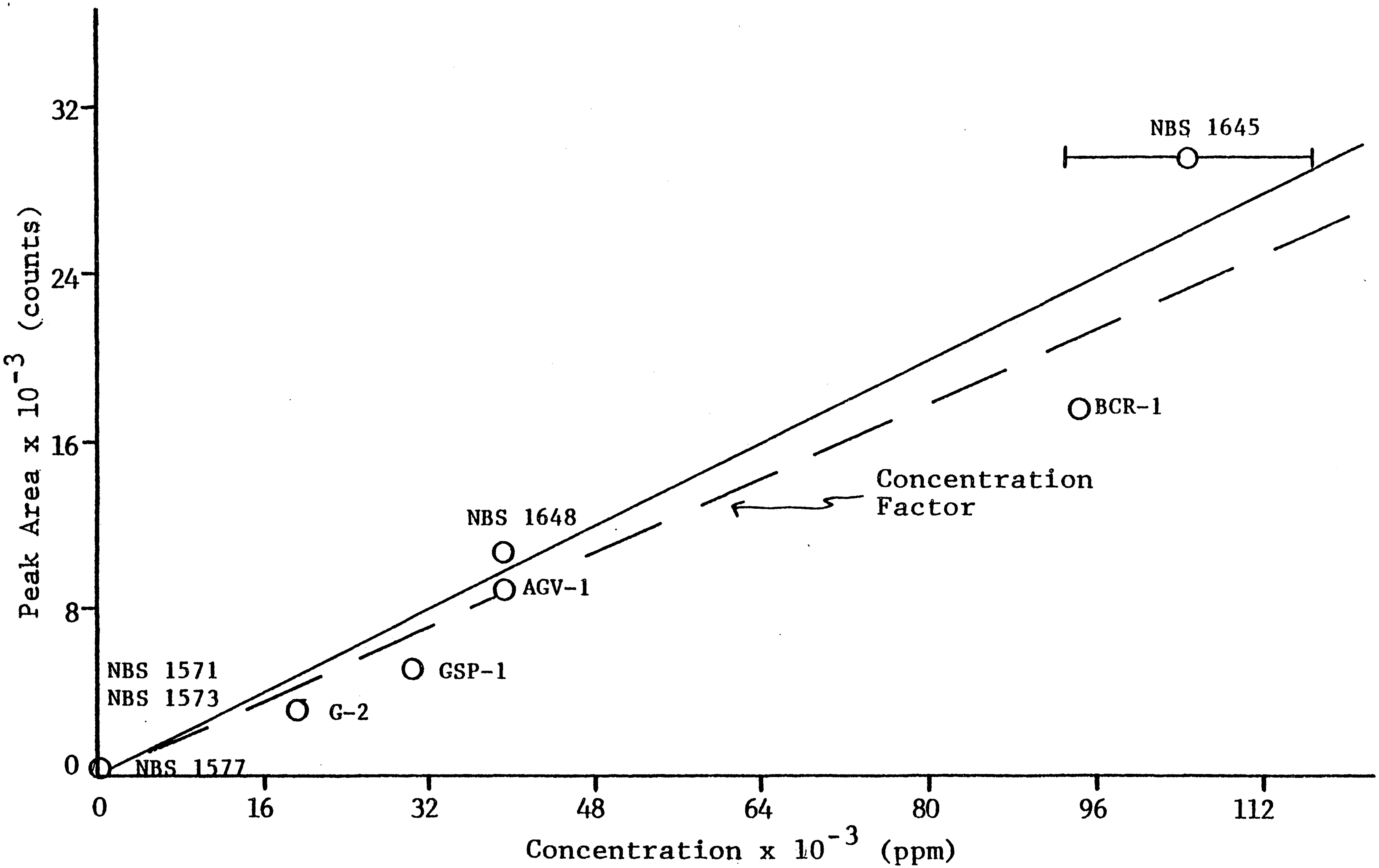



Fig. 2.17 Peak Area vs. Concentration for Fe

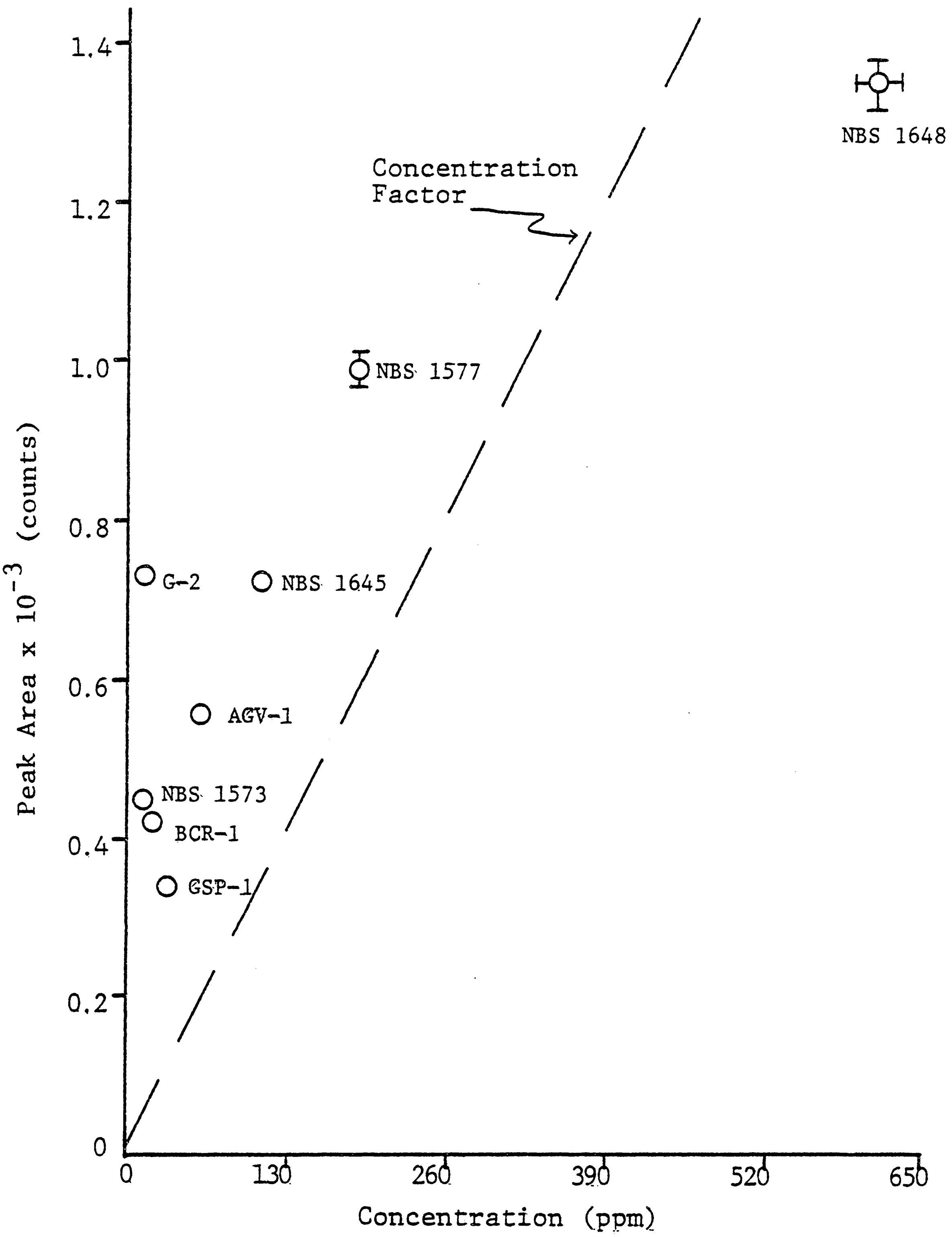



Fig. 2.18 Peak Area vs. Concentration for Cu

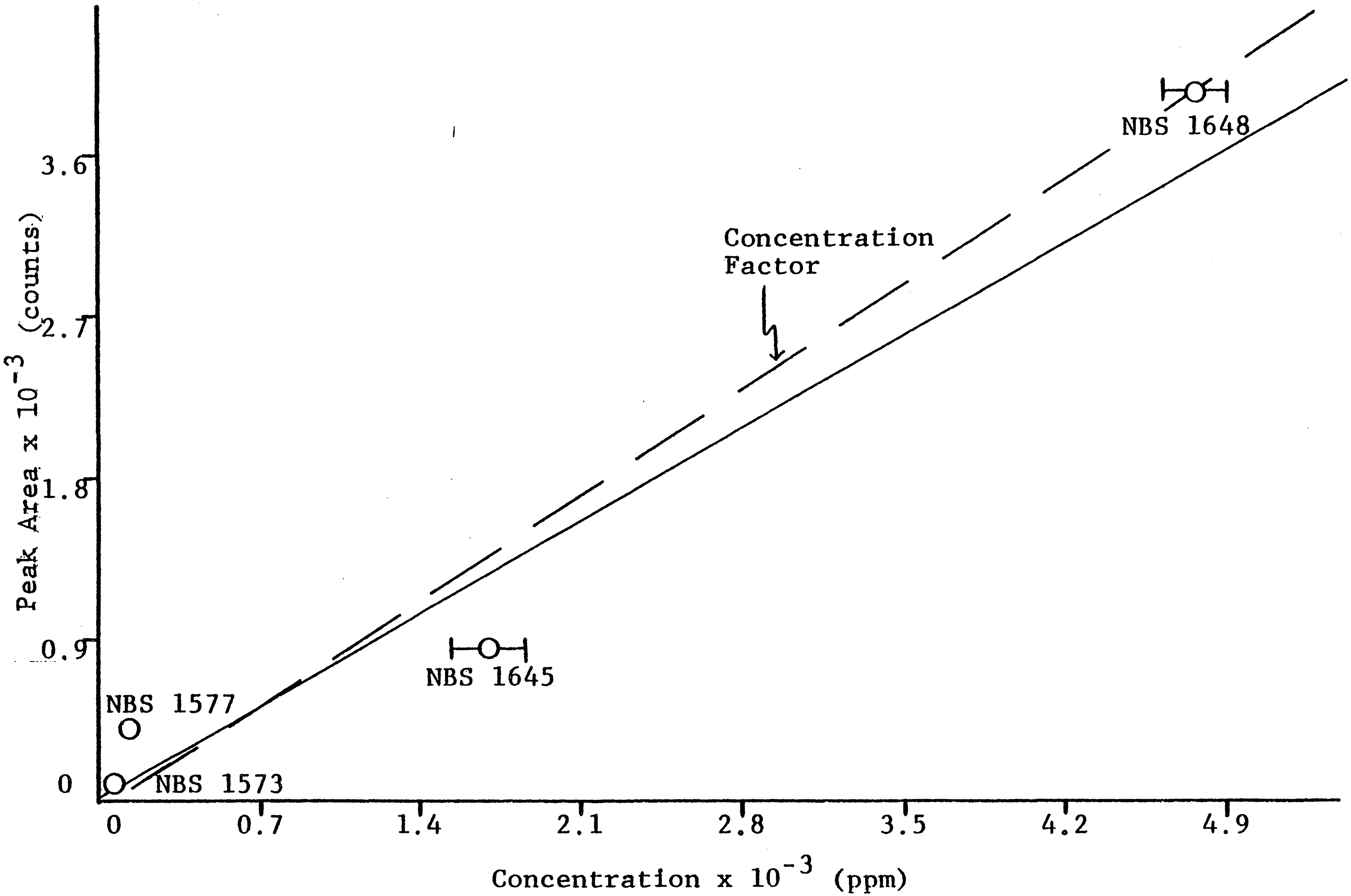



Fig. 2.19 Peak Area vs. Concentration for Zn

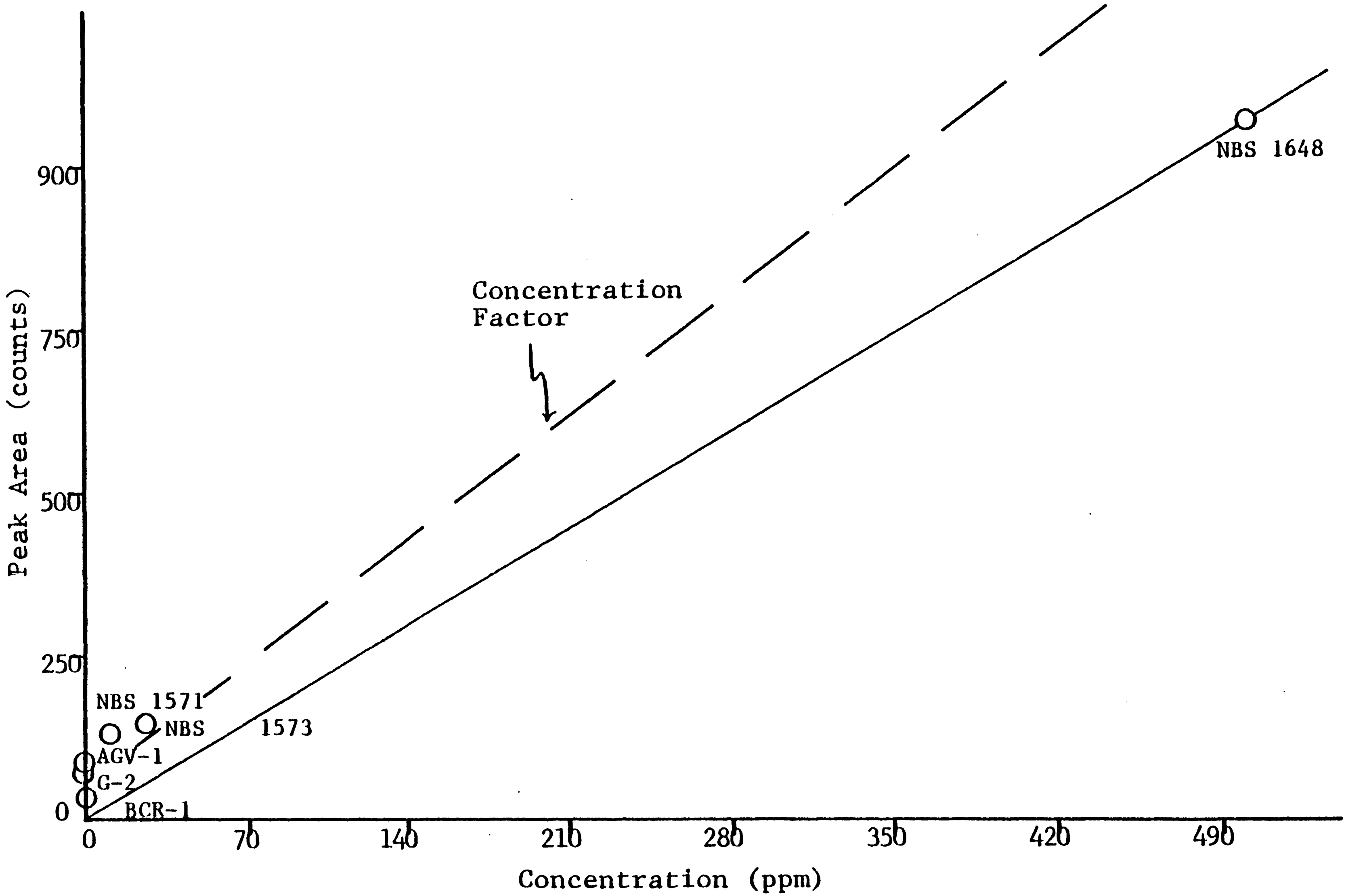



Fig. 2.20 Peak Area vs. Concentration for Br

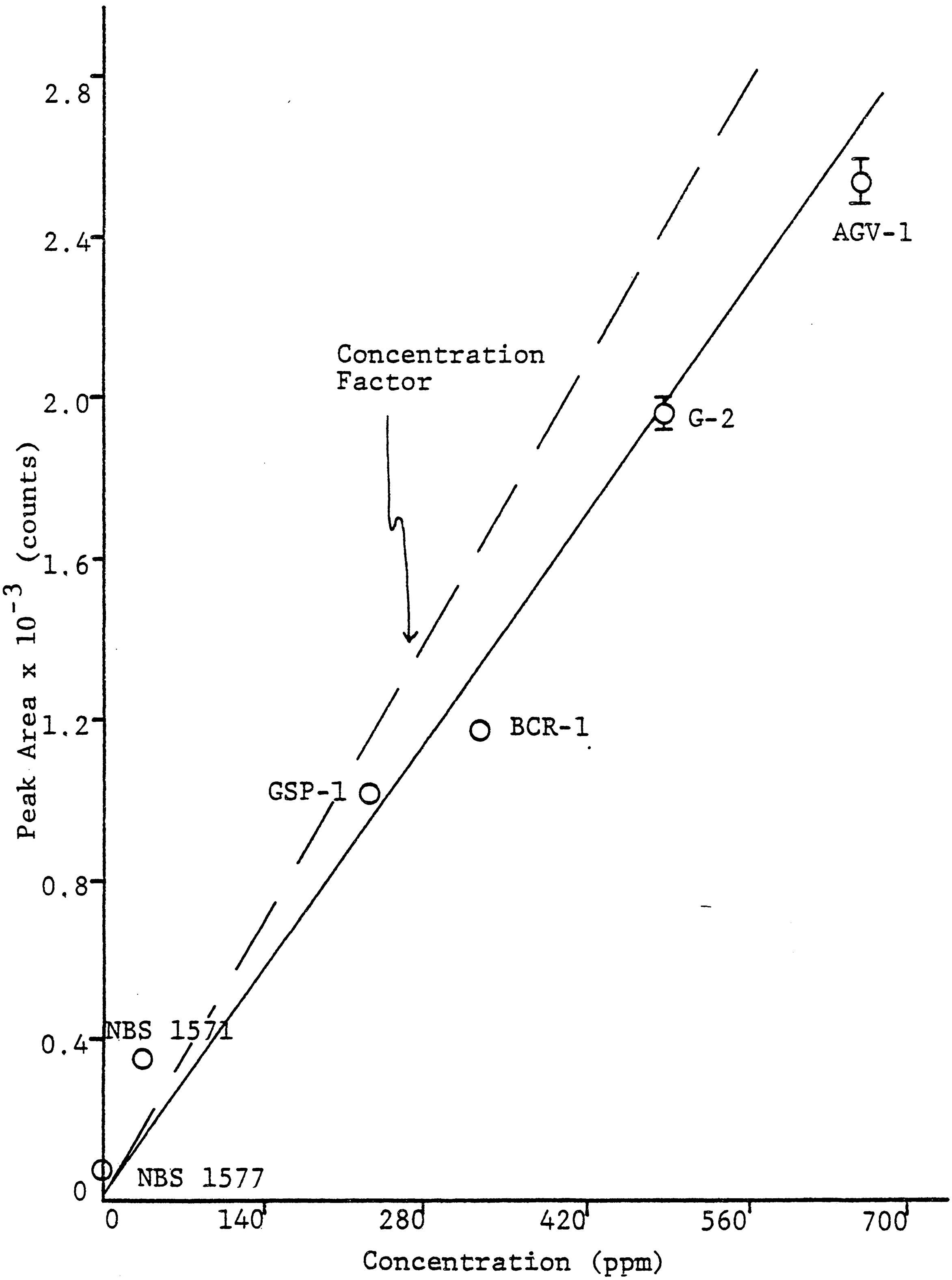



Fig. 2.21 Peak Area vs. Concentration for Sr

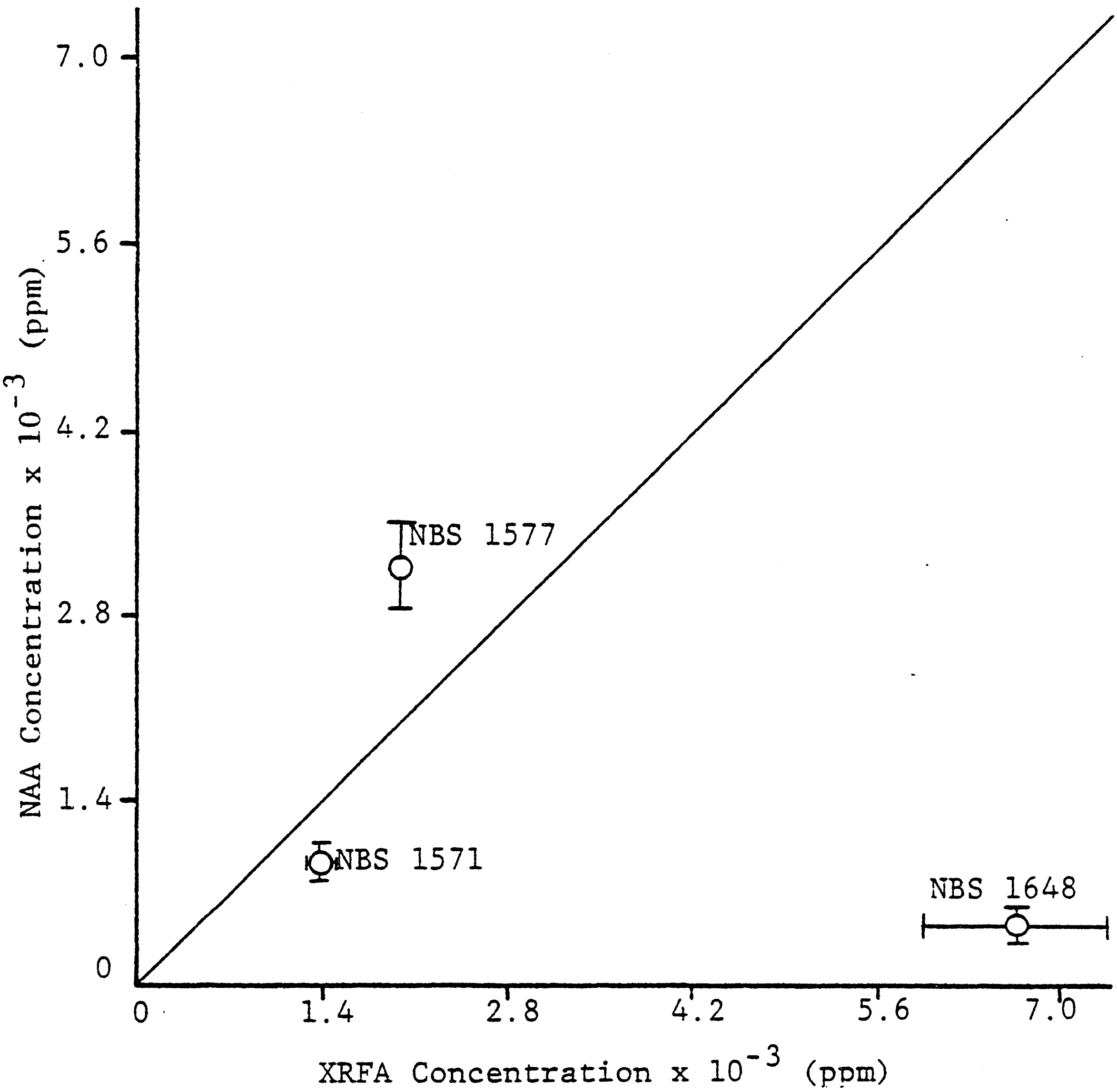



Fig. 2.22 Comparison of Cl Concentrations Determined by NAA and XRFA

Note: Certified Cl concentration in NBS 1648 is 4,500 ppm.

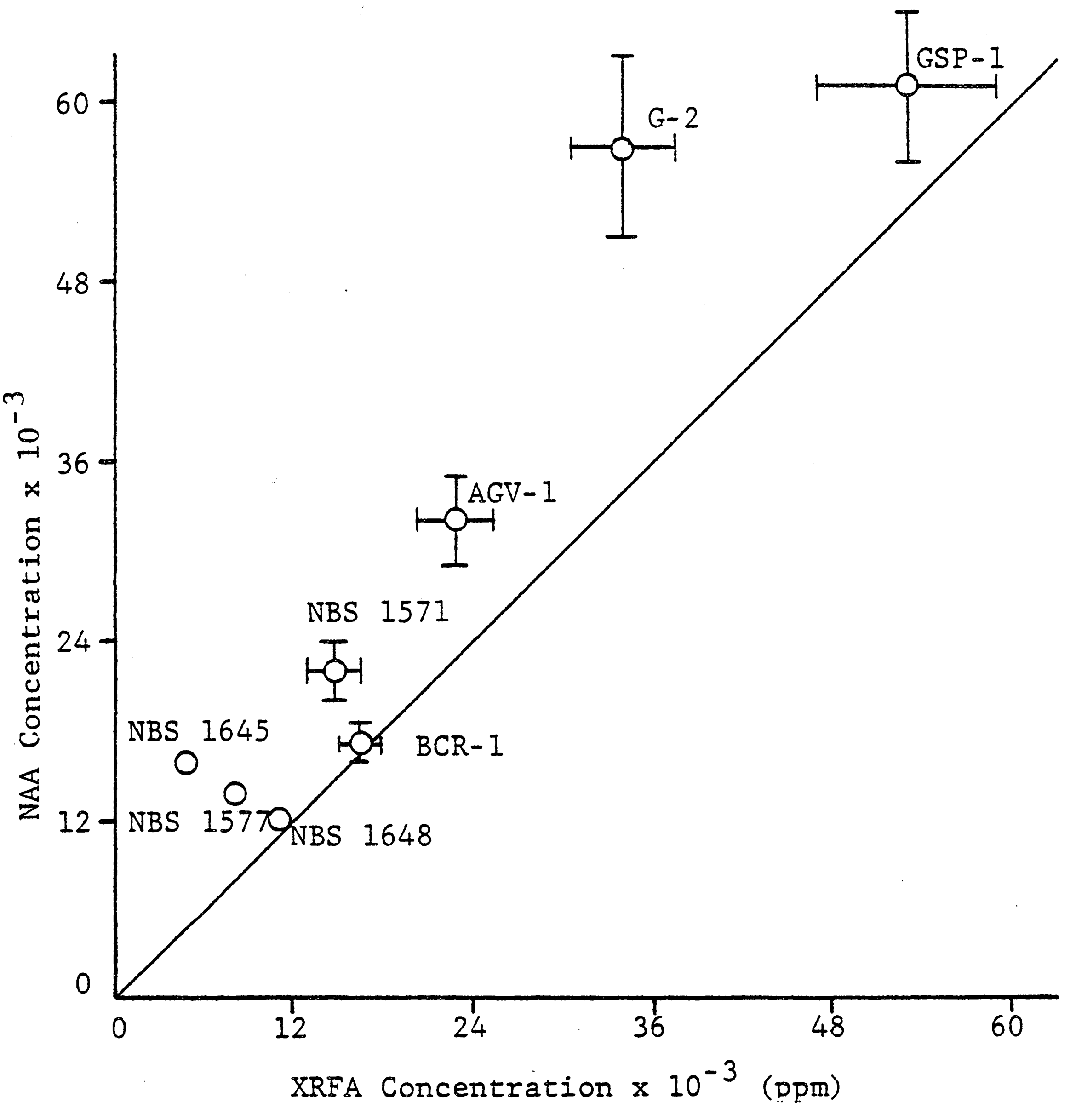



Fig. 2.23 Comparison of K Concentrations Determined by NAA and XRFA

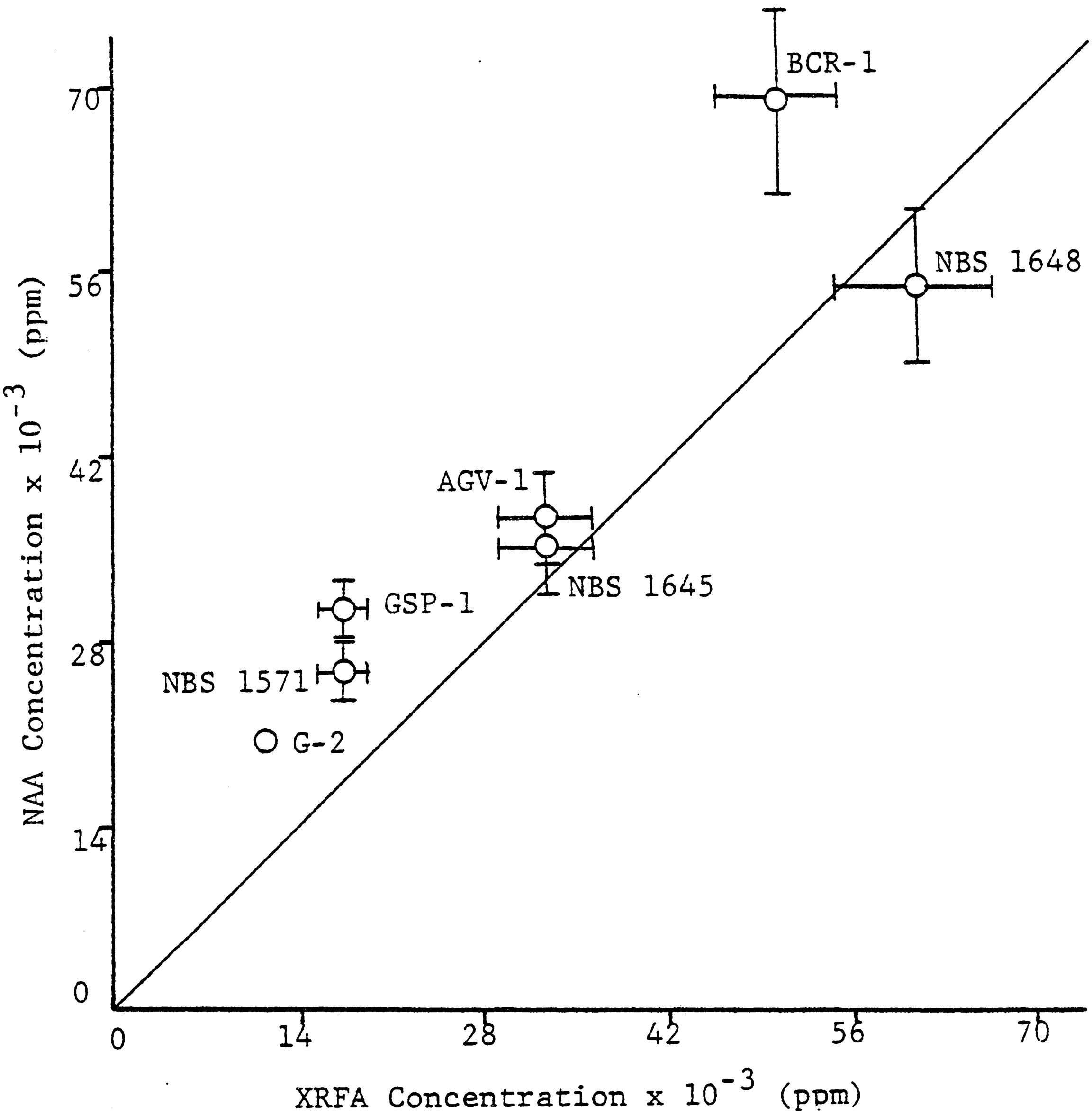



Fig. 2.24 Comparison of Ca Concentrations Determined by NAA and XRFA

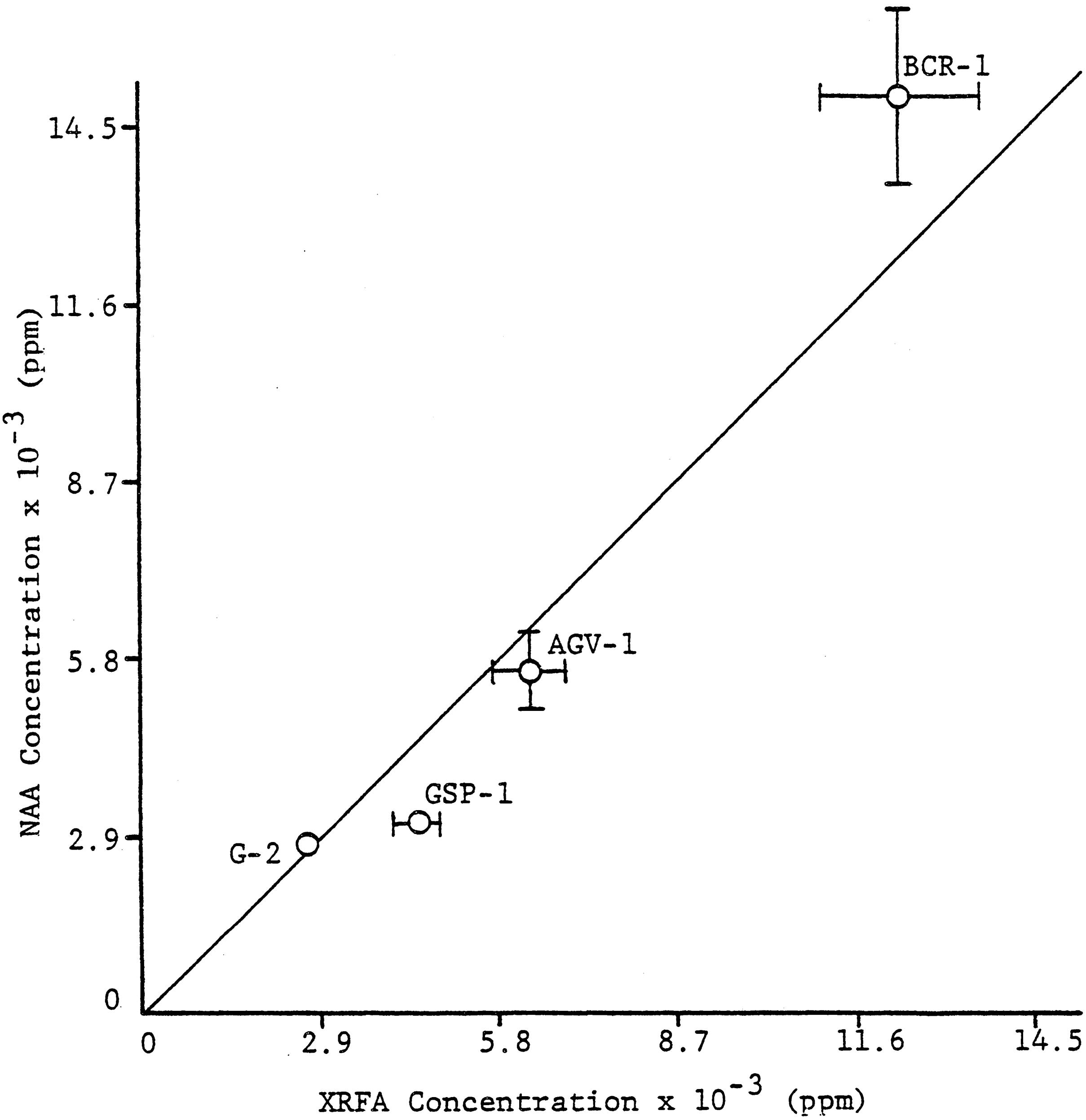



Fig. 2.25 Comparison of Ti Concentrations Determined by NAA and XRFA

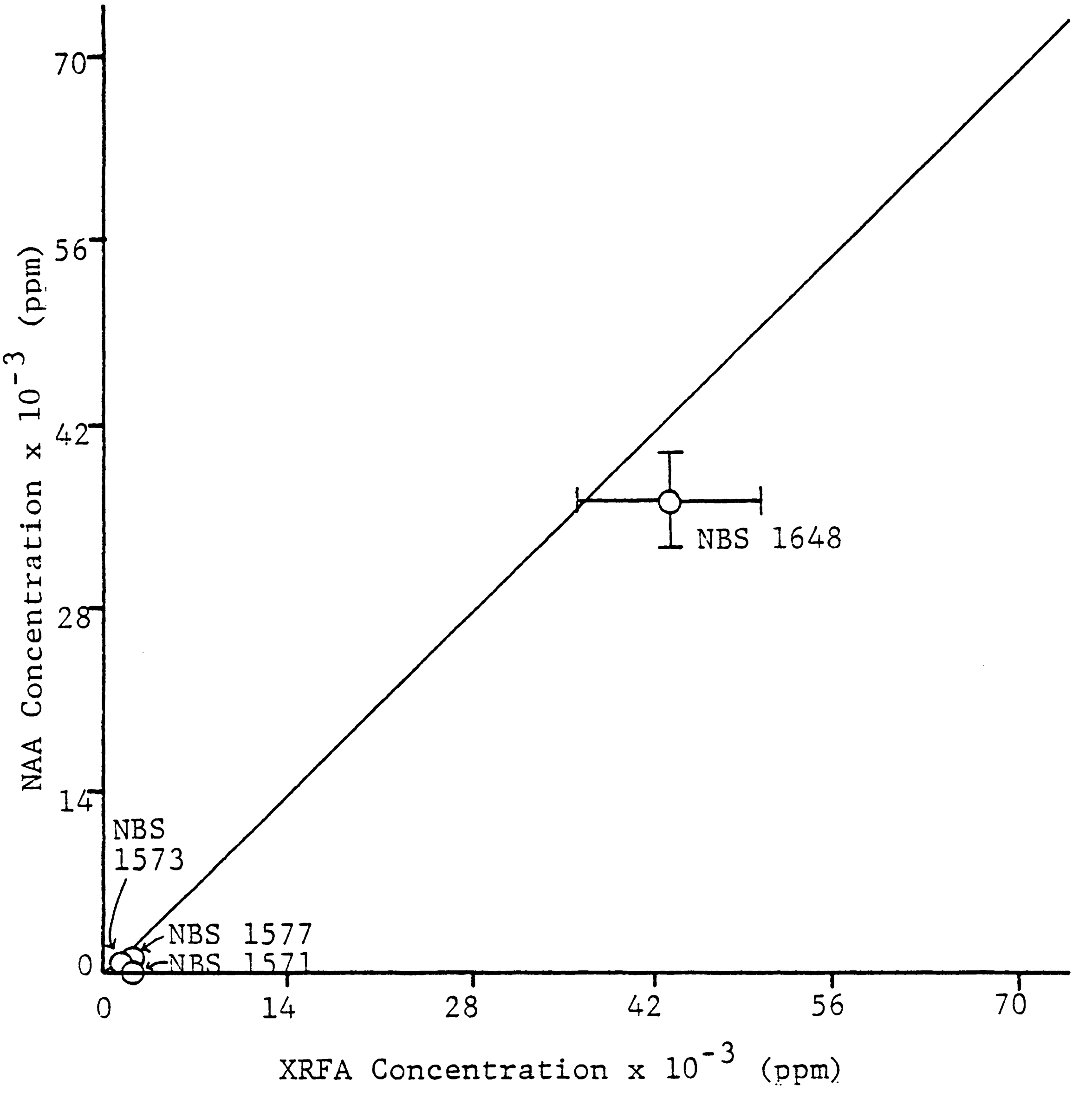



Fig. 2.26 Comparison of Fe Concentrations Determined by NAA and XRFA

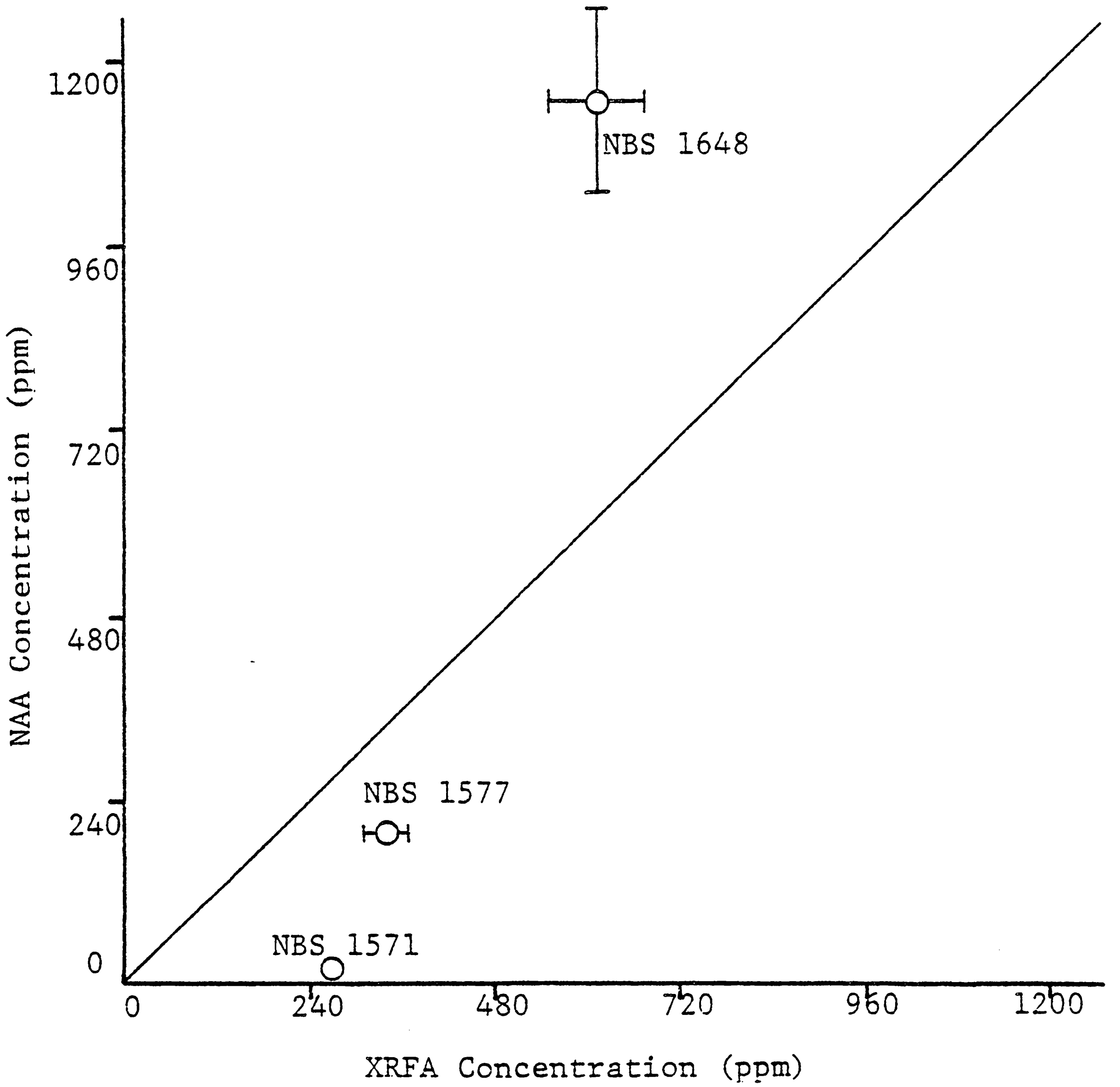



Fig. 2.27 Comparison of Cu Concentrations Determined by NAA and XRFA

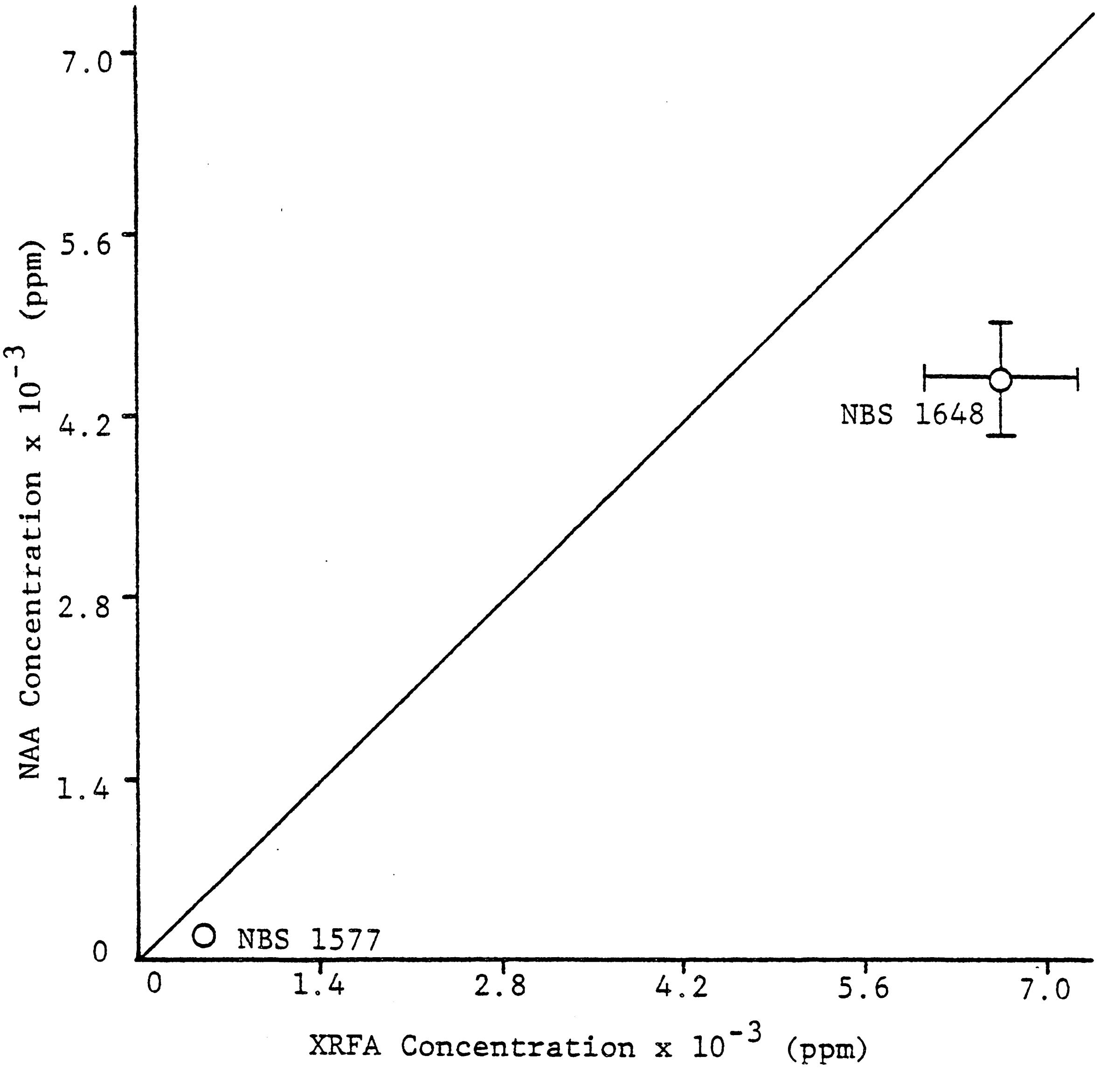



Fig. 2.28 Comparison of Zn Concentrations Determined by NAA and XRFA

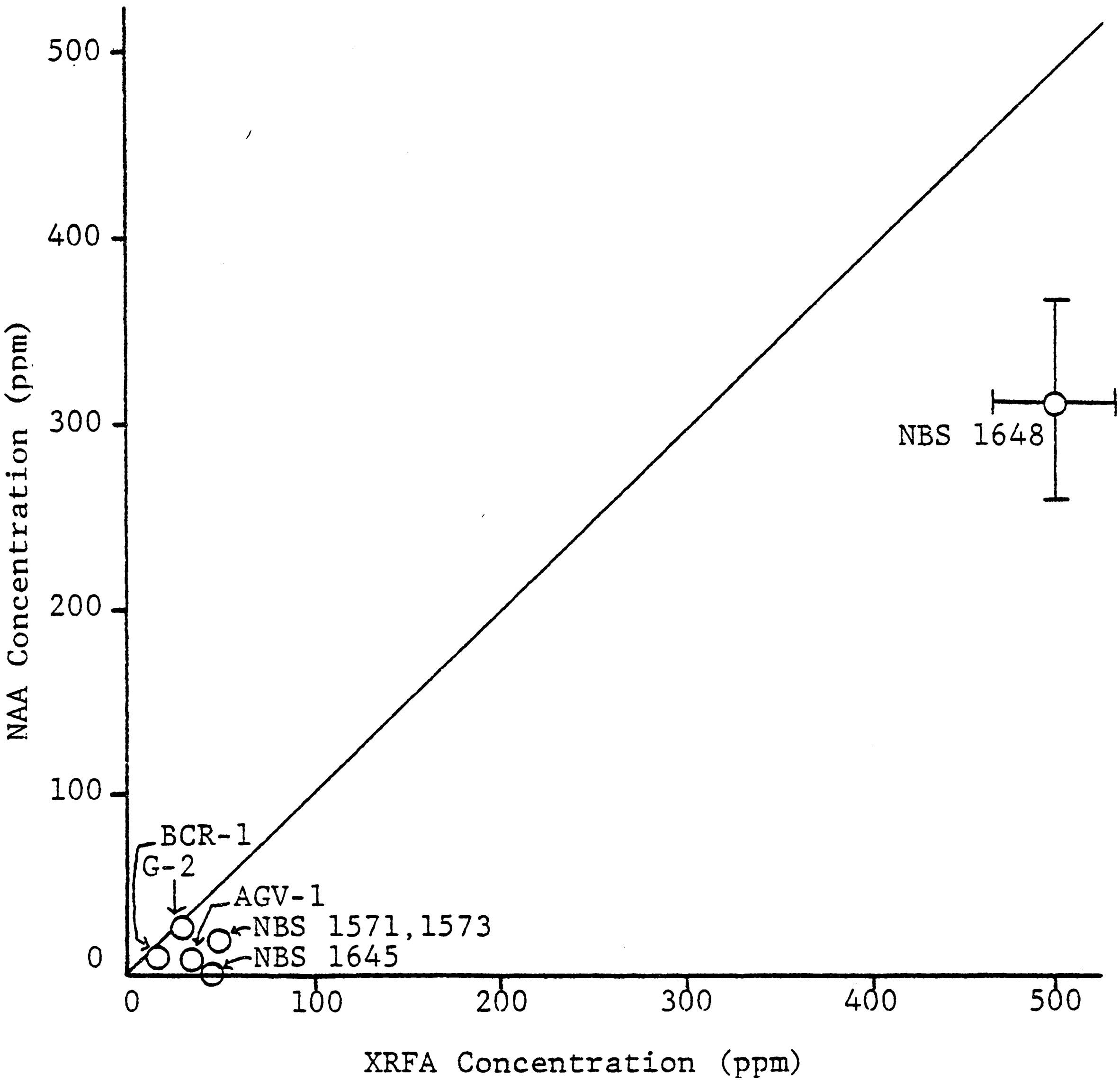



Fig. 2.29 Comparison of Br Concentrations Determined by NAA and XRFA

discrepancies indicate that the XRFA data is in error since the NAA data is quite accurate.

As in any quantitative analytical technique, there is a limit to the amount of an element that can be detected. The minimum detectable concentration (MDC) of an element is a function of detector sensitivity, source strength, source energy, detector geometry, atomic number of the element analyzed, density of the matrix, irradiation time, and the mass attenuation coefficient of the matrix. The calculation of these MDC's is beyond the scope of this work. However, by examining the peak area and background area under the peak, it can be determined whether the concentration is above or below the limit. If the peak area minus the background area is more than three times the square root of the background area, there is 99.9% certainty of detection of the peak (page 348 in 27). Tables 2.4 through 2.15 list the known concentrations, peak areas minus the background areas, three times the square root of the background areas, and whether or not the concentration is below the MDC for each element examined. Again, these peak areas were determined with 1800 second count times. When the peak area minus the background area was very close to three times the square root of the background area, the concentration was indicated to possibly be below the MDC. From this information, Table 2.16 was formed. From the standards available, Table 2.16 indicates the approximate MDC's.

Table 2.4

Comparison of Peak Areas, Background Areas and Concentrations for Si

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 (rock) | $1.30 \times 10^{2} \pm 1.14 \times 10^{1}$ | $3.89 \times 10^{1}$ | 255,000 | no |
| USGS GSP-1 (rock) | $2.92 \times 10^{2} \pm 1.70 \times 10^{1}$ | $5.31 \times 10^{1}$ | 315,000 | no |
| USGS AGV-1 (rock) | $2.48 \times 10^{2} \pm 1.58 \times 10^{1}$ | $4.20 \times 10^{1}$ | 276,000 | no |
| USGS G-2 (rock) | $2.84 \times 10^{2} \pm 1.68 \times 10^{1}$ | $5.61 \times 10^{1}$ | 323,000 | no |
| NBS 1571 (orchard leaves) | $8.79 \pm 2.96$ | $2.18 \times 10^{1}$ | NR* | yes |
| NBS 1577 (bovine liver) | 0.0 | $1.90 \times 10^{1}$ | NR* | yes |
| NBS 1635 (subbituminous coal) | 0.0 | $2.08 \times 10^{1}$ | NR* | yes |
| NBS 1645 (river sediment) | $6.55 \times 10^{1} \pm 8.09$ | $2.80 \times 10^{1}$ | (238,400)** | no |
| NBS 1648 (urban particulate matter) | $6.78 \times 10^{1} \pm 8.23$ | $3.87 \times 10^{1}$ | (125,300)** | no |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.5

Comparison of Peak Areas, Background Areas and Concentrations for S

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $2.14\times10^{1}\pm4.63$ | $1.56 \times 10^{1}$ | 392 | possibly |
| USGS GSP-1 | 0.0 | $1.24 \times 10^{1}$ | 162 | yes |
| USGS AGV-1 | 0.0 | 4.24 | <10 | yes |
| USGS G-2 | 0.0 | $1.62 \times 10^{1}$ | 24 | yes |
| NBS 1571 | $1.43\times10^{1}\pm3.78$ | $2.07 \times 10^{1}$ | (2,300)** | yes |
| NBS 1577 | $8.53\times10^{1}\pm9.23$ | $3.92 \times 10^{1}$ | NR* | no |
| NBS 1635 | $2.90\times10^{1}\pm5.38$ | $3.18 \times 10^{1}$ | (3,300)** | yes |
| NBS 1645 | $2.23\times10^{2}\pm1.49\times10^{1}$ | $5.11 \times 10^{1}$ | NR* | no |
| NBS 1648 | $4.54\times10^{2}\pm2.13\times10^{1}$ | $9.51 \times 10^{1}$ | (51,500)** | no |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.6

Comparison of Peak Areas, Background Areas

and Concentrations for Cl

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $8.93 \times 10^{1} \pm 9.45$ | $3.43 \times 10^{1}$ | 50 | no |
| USGS GSP-1 | $7.81 \times 10^{1} \pm 8.84$ | $3.57 \times 10^{1}$ | 300 | no |
| USGS AGV-1 | $9.76 \times 10^{1} \pm 9.89$ | $3.05 \times 10^{1}$ | 110 | no |
| USGS G-2 | $3.99 \times 10^{1} \pm 6.32$ | $2.16 \times 10^{1}$ | 50 | no |
| NBS 1571 | $7.78 \times 10^{1} \pm 8.82$ | $3.04 \times 10^{1}$ | (700)** | no |
| NBS 1577 | $1.28 \times 10^{2} \pm 1.13 \times 10^{1}$ | $4.75 \times 10^{1}$ | (2,600)** | no |
| NBS 1635 | $8.19 \pm 2.86$ | $1.50 \times 10^{1}$ | NR* | yes |
| NBS 1645 | $1.30 \times 10^{1} \pm 3.60$ | $1.38 \times 10^{1}$ | NR* | yes |
| NBS 1648 | $2.28 \times 10^{2} \pm 1.51 \times 10^{1}$ | $4.92 \times 10^{1}$ | (4,500)** | no |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.7

Comparison of Peak Areas, Background Areas and Concentrations for K

| Standard | Peak Area Minus Background Area (counts) | 3√Background Area (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $2.12x10^{3} \pm 4.60x10^{1}$ | $1.05 \times 10^{2}$ | 14,100 | no |
| USGS GSP-1 | $6.53x10^{3} \pm 8.08x10^{1}$ | $1.71 \times 10^{2}$ | 45,900 | no |
| USGS AGV-1 | $3.27x10^{3} \pm 5.72x10^{1}$ | $1.27 \times 10^{2}$ | 24,000 | no |
| USGS G-2 | $5.33x10^{3} \pm 7.30x10^{1}$ | $1.51 \times 10^{2}$ | 37,400 | no |
| NBS 1571 | $3.54x10^{3} \pm 5.94x10^{1}$ | $1.05 \times 10^{2}$ | 14,700 ± 300 | no |
| NBS 1577 | $2.18x10^{3} \pm 4.67x10^{1}$ | $1.24 \times 10^{2}$ | 9,700 ± 600 | no |
| NBS 1635 | $4.18x10^{1} \pm 6.47$ | $3.47 \times 10^{1}$ | NR* | yes |
| NBS 1645 | $8.10x10^{2} \pm 2.85x10^{1}$ | $9.72 \times 10^{1}$ | (12,000)** | no |
| NBS 1648 | $1.58x10^{3} \pm 3.98x10^{1}$ | $1.20 \times 10^{2}$ | (10,000)** | no |

* NR--No concentration was reported.

** Parenthesis indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.8

Comparison of Peak Areas, Background Areas

and Concentrations for Ca

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{}$Background Area (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $1.35x10^4 \pm 1.16x10^2$ | $1.87 \times 10^2$ | 49,500 | no |
| USGS GSP-1 | $4.65x10^3 \pm 6.82x10^1$ | $1.50 \times 10^2$ | 14,400 | no |
| USGS AGV-1 | $9.62x10^3 \pm 9.81x10^1$ | $1.64 \times 10^2$ | 35,000 | no |
| USGS G-2 | $3.94x10^3 \pm 6.28x10^1$ | $1.49 \times 10^2$ | 13,900 | no |
| NBS 1571 | $8.71x10^3 \pm 9.33x10^1$ | $2.17 \times 10^2$ | 20,900 ± 300 | no |
| NBS 1577 | 0.0 | $5.03 \times 10^1$ | (123)** | yes |
| NBS 1635 | $3.09x10^3 \pm 5.56x10^1$ | $1.20 \times 10^2$ | NR* | no |
| NBS 1645 | $1.14x10^4 \pm 1.07x10^2$ | $1.93 \times 10^2$ | (28,600)** | no |
| NBS 1648 | $1.78x10^4 \pm 1.34x10^2$ | $2.19 \times 10^2$ | NR* | no |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.9

Comparison of Peak Areas, Background Areas and Concentrations for Ti

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $9.67\text{x}10^{3} \pm 9.84\text{x}10^{1}$ | $1.19 \times 10^{2}$ | 13,200 | no |
| USGS GSP-1 | $3.21\text{x}10^{3} \pm 5.67\text{x}10^{1}$ | $7.54 \times 10^{1}$ | 4,000 | no |
| USGS AGV-1 | $5.19\text{x}10^{3} \pm 7.21\text{x}10^{1}$ | $7.24 \times 10^{1}$ | 6,240 | no |
| USGS G-2 | $2.47\text{x}10^{3} \pm 5.00\text{x}10^{1}$ | $7.94 \times 10^{1}$ | 3,000 | no |
| NBS 1571 | $8.97\text{x}10^{1} \pm 9.47$ | $3.03 \times 10^{1}$ | NR* | no |
| NBS 1577 | 0.0 | $2.42 \times 10^{1}$ | NR* | yes |
| NBS 1635 | $3.54\text{x}10^{2} \pm 1.88\text{x}10^{1}$ | $4.81 \times 10^{1}$ | NR* | no |
| NBS 1645 | $8.68\text{x}10^{2} \pm 2.95\text{x}10^{1}$ | $4.51 \times 10^{1}$ | NR* | no |
| NBS 1648 | $3.70\text{x}10^{3} \pm 6.08\text{x}10^{1}$ | $6.92 \times 10^{1}$ | (4,000)** | no |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.10

Comparison of Peak Areas, Background Areas and Concentrations for Cr

| Standard | Peak Area Minus Background Area (counts) | 3√Background Area (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $8.19 \times 10^{1} \pm 9.05$ | $4.11 \times 10^{1}$ | 17.6 | no |
| USGS GSP-1 | $4.82 \times 10^{1} \pm 6.94$ | $4.15 \times 10^{1}$ | 12.5 | possibly |
| USGS AGV-1 | $4.41 \times 10^{1} \pm 6.64$ | $3.88 \times 10^{1}$ | 12.2 | possibly |
| USGS G-2 | 0.0 | $3.58 \times 10^{1}$ | 7 | yes |
| NBS 1571 | 0.0 | $6.17 \times 10^{1}$ | NR* | yes |
| NBS 1577 | $3.41 \times 10^{1} \pm 5.84$ | $5.13 \times 10^{1}$ | NR* | yes |
| NBS 1635 | $2.64 \times 10^{1} \pm 5.14$ | $5.10 \times 10^{1}$ | 2.5 ± 0.3 | yes |
| NBS 1645 | $6.11 \times 10^{3} \pm 7.82 \times 10^{1}$ | $2.12 \times 10^{2}$ | 29,600 ± 2,800 | no |
| NBS 1648 | $1.46 \times 10^{2} \pm 1.21 \times 10^{1}$ | $4.18 \times 10^{1}$ | 403 ± 12 | no |

* NR--No concentration was reported.

Table 2.11

Comparison of Peak Areas, Background Areas

and Concentrations for Fe

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $1.76x10^{4} \pm 1.33x10^{2}$ | $2.87 \times 10^{2}$ | 94,100 | no |
| USGS GSP-1 | $5.03x10^{3} \pm 7.09x10^{1}$ | $2.81 \times 10^{2}$ | 30,300 | no |
| USGS AGV-1 | $8.70x10^{3} \pm 9.33x10^{1}$ | $2.78 \times 10^{2}$ | 47,500 | no |
| USGS G-2 | $3.19x10^{3} \pm 5.65x10^{1}$ | $2.75 \times 10^{2}$ | 18,800 | no |
| NBS 1571 | $4.17x10^{2} \pm 2.04x10^{1}$ | $2.31 \times 10^{2}$ | 300 ± 20 | no |
| NBS 1573 (tomato leaves) | $3.30x10^{2} \pm 1.82x10^{1}$ | $2.52 \times 10^{2}$ | 690 ± 25 | no |
| NBS 1577 | $4.85x10^{2} \pm 2.20x10^{1}$ | $2.29 \times 10^{2}$ | 270 ± 20 | no |
| NBS 1645 | $2.95x10^{4} \pm 1.72x10^{2}$ | $3.05 \times 10^{2}$ | 113,000 ± 12,000 | no |
| NBS 1648 | $1.06x10^{4} \pm 1.03x10^{2}$ | $2.85 \times 10^{2}$ | 39,100 ± 1,000 | no |

Table 2.12

Comparison of Peak Areas, Background Areas and Concentrations for Cu

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $4.17 \times 10^{2} \pm 2.04 \times 10^{1}$ | $2.77 \times 10^{2}$ | 18.4 | no |
| USGS GSP-1 | $3.41 \times 10^{2} \pm 1.85 \times 10^{1}$ | $2.74 \times 10^{2}$ | 33.3 | no |
| USGS AGV-1 | $5.54 \times 10^{2} \pm 2.35 \times 10^{1}$ | $3.03 \times 10^{2}$ | 59.7 | no |
| USGS G-2 | $7.31 \times 10^{2} \pm 2.70 \times 10^{1}$ | $3.06 \times 10^{2}$ | 11.7 | no |
| NBS 1571 | $6.82 \times 10^{2} \pm 2.61 \times 10^{1}$ | $2.70 \times 10^{2}$ | NR* | no |
| NBS 1573 | $4.48 \times 10^{2} \pm 2.12 \times 10^{1}$ | $2.81 \times 10^{2}$ | 11 ± 1 | no |
| NBS 1577 | $9.93 \times 10^{2} \pm 3.15 \times 10^{1}$ | $2.90 \times 10^{2}$ | 193 ± 10 | no |
| NBS 1645 | $7.25 \times 10^{2} \pm 2.69 \times 10^{1}$ | $2.74 \times 10^{2}$ | 109 ± 19 | no |
| NBS 1648 | $1.35 \times 10^{3} \pm 3.67 \times 10^{1}$ | $2.91 \times 10^{2}$ | 609 ± 27 | no |

* NR--No concentration was reported.

Table 2.13

Comparison of Peak Areas, Background Areas and Concentrations for Zn

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | 0.0 | $2.33 \times 10^2$ | 120 | yes |
| USGS GSP-1 | 0.0 | $2.19 \times 10^2$ | 98 | yes |
| USBS AGV-1 | 0.0 | $2.07 \times 10^2$ | 84 | yes |
| USGS G-2 | 0.0 | $2.33 \times 10^2$ | 85 | yes |
| NBS 1571 | 0.0 | $1.46 \times 10^2$ | NR* | yes |
| NBS 1573 | $9.21\times10^1 \pm 9.59$ | $2.43 \times 10^2$ | 62 ± 6 | yes |
| NBS 1577 | $4.13\times10^2 \pm 2.03\times10^1$ | $2.46 \times 10^2$ | 130 ± 10 | no |
| NBS 1645 | $8.60\times10^2 \pm 2.93\times10^1$ | $2.35 \times 10^2$ | 1,720 ± 169 | no |
| NBS 1648 | $3.94\times10^3 \pm 6.29\times10^1$ | $2.71 \times 10^2$ | 4,760 ± 140 | no |

* NR--No concentration was reported.

Table 2.14

Comparison of Peak Areas, Background Areas

and Concentrations for Br

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{}$Background Area (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $3.32x10^{1}\pm5.76$ | $4.30 \times 10^{1}$ | 0.15 | yes |
| USGS GSP-1 | $8.18x10^{1}\pm9.04$ | $8.96 \times 10^{1}$ | NR* | yes |
| USGS AGV-1 | $8.56x10^{1}\pm9.26$ | $7.43 \times 10^{1}$ | 0.50 | yes |
| USGS G-2 | $7.34x10^{1}\pm8.56$ | $7.00 \times 10^{1}$ | 0.30 | yes |
| NBS 1571 | $1.34x10^{2}\pm1.16x10^{1}$ | $1.07 \times 10^{2}$ | (10)** | no |
| NBS 1573 | $1.52x10^{2}\pm1.23x10^{1}$ | $1.04 \times 10^{2}$ | (26)** | no |
| NBS 1577 | $7.36x10^{1}\pm8.58$ | $9.60 \times 10^{1}$ | NR* | yes |
| NBS 1645 | $1.07x10^{2}\pm1.04x10^{1}$ | $7.16 \times 10^{1}$ | NR* | no |
| NBS 1648 | $1.07x10^{3}\pm3.27x10^{1}$ | $1.31 \times 10^{2}$ | (500)** | no |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.15

Comparison of Peak Areas, Background Areas and Concentrations for Sr

| Standard | Peak Area Minus Background Area (counts) | $3\sqrt{\text{Background Area}}$ (counts) | Reported Concentration (ppm) | Below Minimum Detectable Concentration? |
|---|---|---|---|---|
| USGS BCR-1 | $1.17 \times 10^{3} \pm 3.42 \times 10^{1}$ | $1.15 \times 10^{2}$ | 330 | no |
| USGS GSP-1 | $1.02 \times 10^{3} \pm 3.20 \times 10^{1}$ | $1.20 \times 10^{2}$ | 233 | no |
| USGS AGV-1 | $2.54 \times 10^{3} \pm 5.04 \times 10^{1}$ | $1.26 \times 10^{2}$ | 657 | no |
| USGS G-2 | $1.96 \times 10^{3} \pm 4.43 \times 10^{1}$ | $1.27 \times 10^{2}$ | 479 | no |
| NBS 1571 | $3.50 \times 10^{2} \pm 1.87 \times 10^{1}$ | $1.07 \times 10^{2}$ | (37)** | no |
| NBS 1573 | $3.43 \times 10^{2} \pm 1.85 \times 10^{1}$ | $1.16 \times 10^{2}$ | NR* | no |
| NBS 1577 | $6.79 \times 10^{1} \pm 8.24$ | $7.60 \times 10^{1}$ | (0.14)** | yes |
| NBS 1645 | $2.72 \times 10^{3} \pm 5.21 \times 10^{1}$ | $1.25 \times 10^{2}$ | NR* | no |
| NBS 1648 | $9.21 \times 10^{2} \pm 3.04 \times 10^{1}$ | $1.28 \times 10^{2}$ | NR* | yes |

* NR--No concentration was reported.

** Parentheses indicate non-certified values since they are based on the results of a non-reference method or were not determined by two or more independent methods.

Table 2.16

Approximate Minimum Detectable Concentrations

| Element | Atomic Number | Approximate MDC (ppm) |
|---|---|---|
| Si | 14 | <125,300* |
| S | 16 | >3,300** |
| Cl | 17 | <50 |
| K | 19 | <1,200 |
| Ca | 20 | 123 |
| Ti | 22 | <2,998 |
| Cr | 24 | 12.5 |
| Fe | 26 | <270 |
| Cu | 29 | <11 |
| Zn | 30 | >62 |
| Br | 35 | >0.50 |
| Sr | 38 | >0.14 |

* Less than indicates that this is the lowest concentration available which is still above the MDC.

** Greater than indicates that this is the highest concentration available which is still below the MDC.

## 2.3 In-vivo Experiments on Swine

The in-vivo experiments were conducted on two swine--one with two melanotic lesions and one with no lesions. The swine were anesthetized with four milligrams per pound body weight of sodium pentabarbitol given intramuscularly before they were brought to the VPI & SU Nuclear Reactor Laboratory. Additional amounts of the anesthetic were administered intramuscularly during the course of the experiment to maintain a surgical plane of anesthesia. The bristles were clipped from the areas to be analyzed, but no cleaning procedures were performed. A table with a hole cut out of it was placed approximately 40mm over the excitation source and Si(Li) detector. A pig was placed on the table with the lesion or area of skin to be irradiated located over the hole in the table so that only that area of skin was exposed to the radiation. This is illustrated in Fig. 2.30. The irradiation and count time for each area was 1800 seconds with each source. Each irradiation session lasted one hour so that the pig would not be anesthetized for too long. The irradiation sessions were spaced approximately one week apart to allow the pig to recover from the previous session.

Three types of skin were analyzed by XRFA: normal skin, classified as Type A; non-cancerous skin surrounding the melanotic skin, classified as Type B; and melanotic skin, classified as Type C. The following are descriptions of the

Fig. 2.30 In-vivo XRFA Experiment

melanotic lesions examined and their locations on the pig's body: (1) the lesion was located on the left flank anterior to the left limb approximately 15 cm directly anterior to the left hip joint. The lesion consisted of a dark nodule (1.6 x 2.0 cm) raised approximately 8 mm above the surface of the skin. The deep epidermis was a black matrix covered by a pale off-white cornified apithelium. (2) The lesion was located on the right paramedial portion of the abdomen approximately 8 mm anterior to the prepuce and approximately 6 cm lateral to the mid-line. The lesion itself was oval, measuring 2 x 2.5 cm. Peripheral to this lesion was a pale zone of epidermis about 1 to 1.5 cm wide that was clear of any pigmentation, which created a bullseye appearance to the entire lesion. The overall width of the clear area was 4 to 5 cm.

Following the completion of all the in-vivo XRFA, the swine were sacrificed and biopsies were taken which were analyzed by XRFA and NAA.

## 2.4 Results of XRFA

Tissues of the swine with Type A skin included the thyroid, liver, brain, heart, spleen, lungs, kidneys, lymph nodes, bristles and blood. Five samples of each tissue were analyzed by XRFA. Averages of the five values for each trace element concentration in ppm for the different tissues are listed in Appendix A. Appendix B lists the trace element concentrations in ppm from the in-vivo XRFA of Types A, B, and C skin. These are not average values. Due to problems in transferring the data from one magnetic tape to another, the XRFA data for the melanotic lesion (Type C) from the left flank and the normal skin (Type A) from the abdomen were unattainable. Therefore, this information was not included in Appendix B. Figures 2.31 through 2.34 illustrate the in-vivo XRF spectra with the Fe-55 source for the abdomen lesion (Type C), the skin adjacent to the left flank lesion (Type B), the skin adjacent to the abdomen lesion (Type B), the normal skin from the left flank (Type A), respectively. Figures 2.35 through 2.38 illustrates the in-vivo XRF spectra with the Am(Mo) source for the same skin samples as above.

Ratios of Type B to Type A, Type C to Type A, and Type C to Type B trace element concentrations were set up to compare the concentrations in the skin. Table 2.17 lists these ratios. No ratio was listed if a concentration was

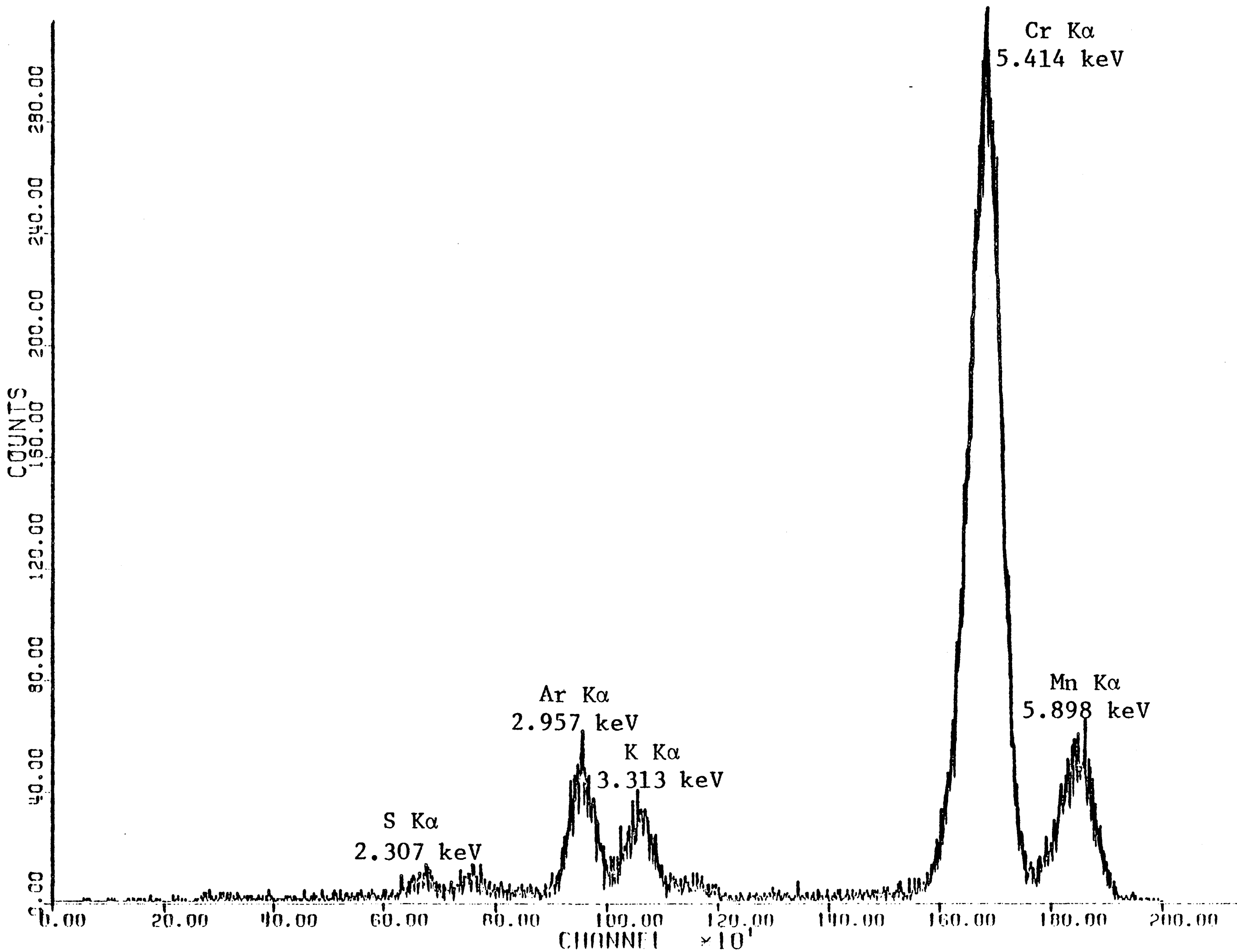



Fig. 2.31 In-vivo XRF Spectrum with Fe-55 Source for Abdomen Lesion

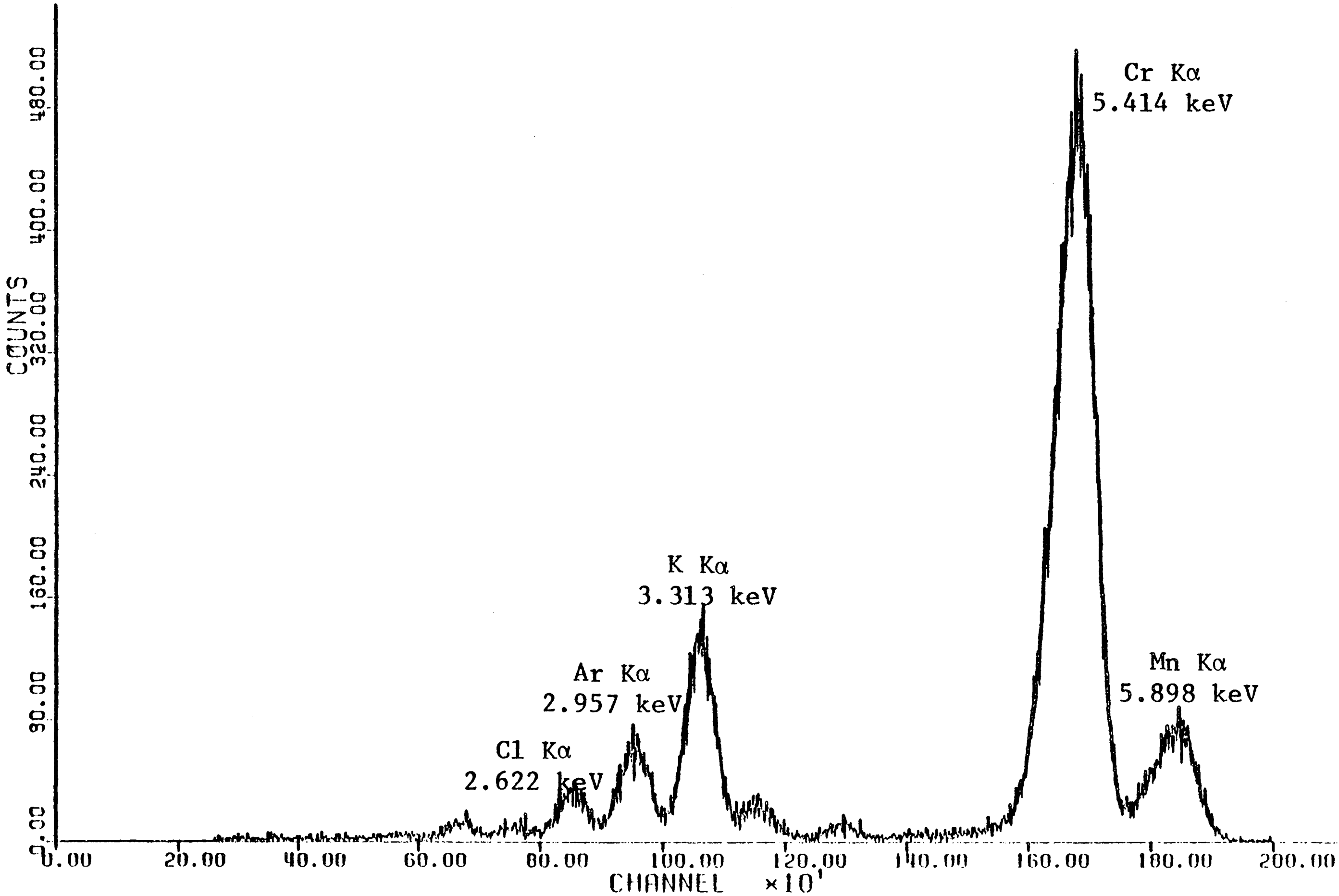



Fig. 2.32 In-vivo XRF Spectrum with Fe-55 Source for Skin Adjacent to Left Flank

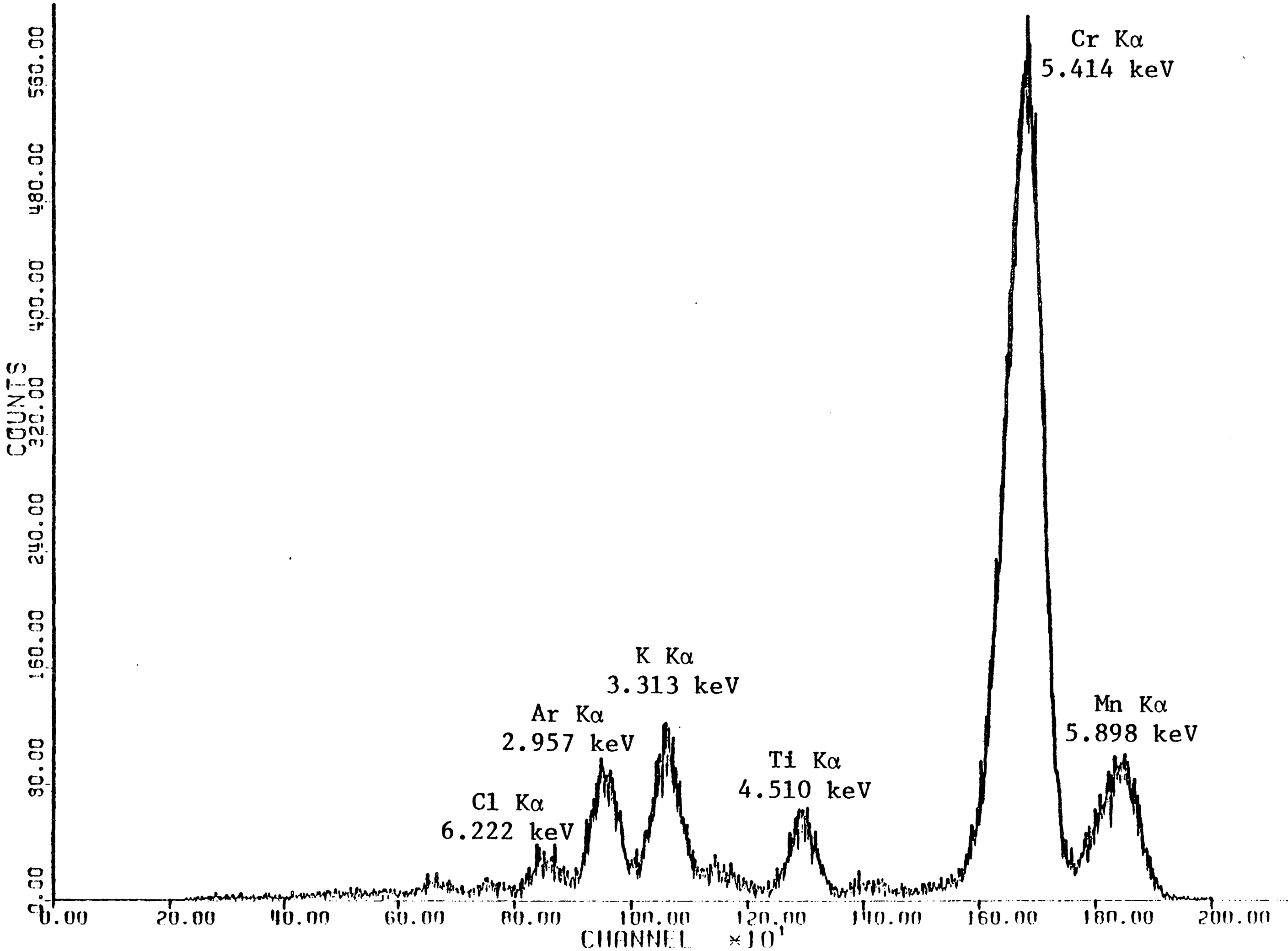



Fig. 2.33 In-vivo XRF Spectrum with Fe-55 Source for Skin Adjacent to Abdomen Lesion

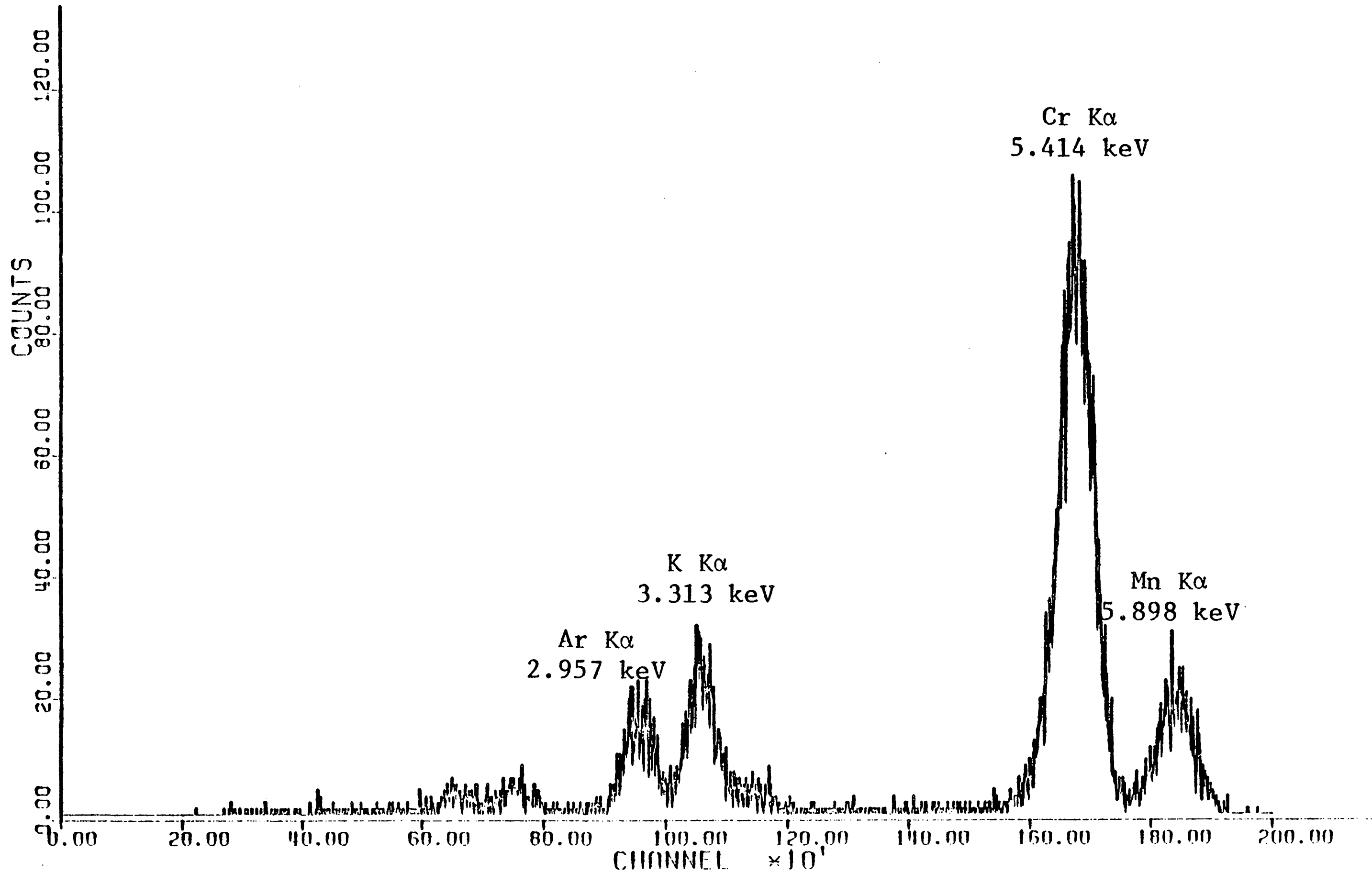



Fig. 2.34 In-vivo XRF Spectrum with Fe-55 Source for Normal Left Flank Skin

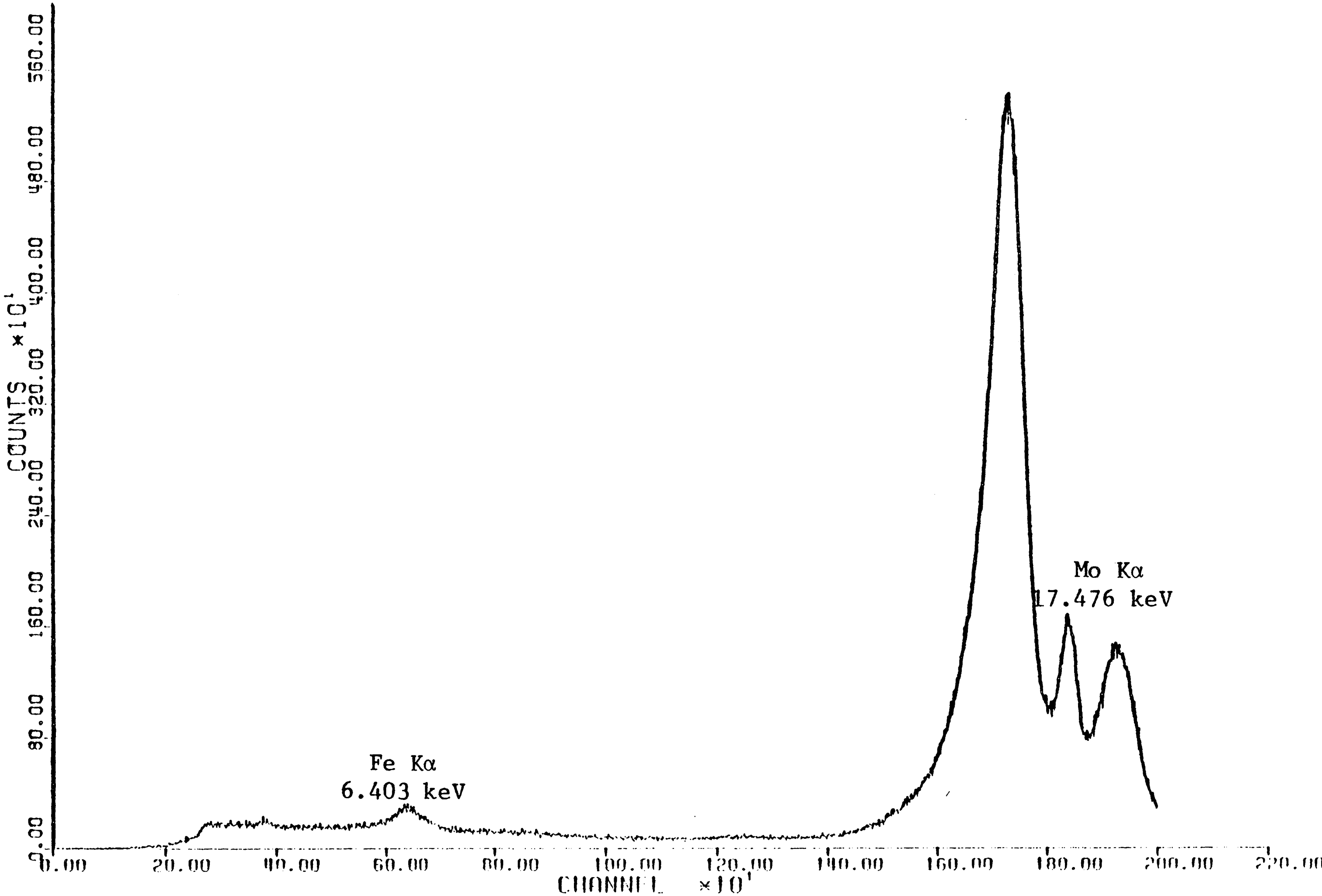



Fig. 2.35 In-vivo XRF Spectrum with Am(Mo) Source for Abdomen Lesion

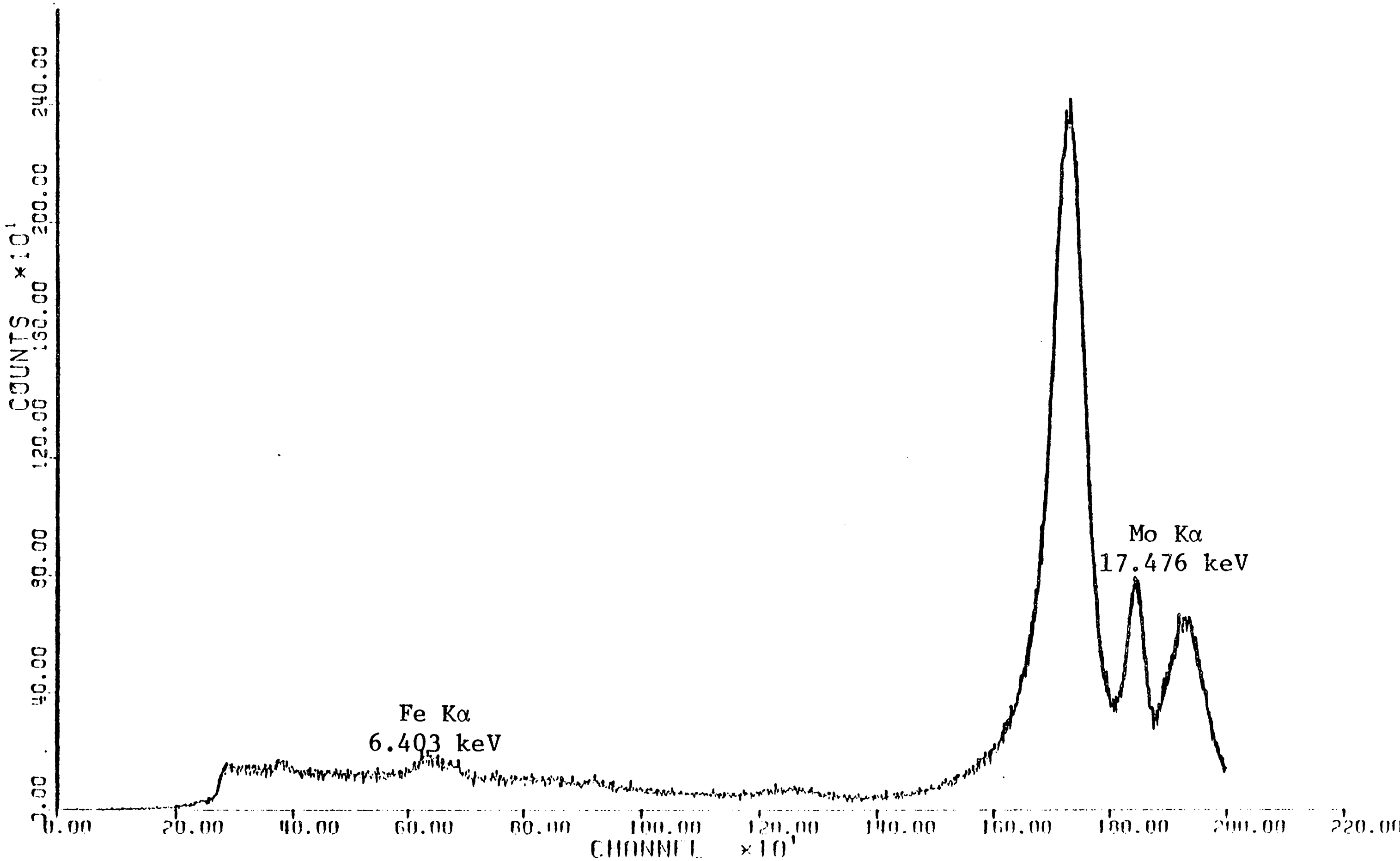



Fig. 2.36 In-vivo XRF Spectrum with Am(Mo) Source for Skin Adjacent to Left Flank Lesion

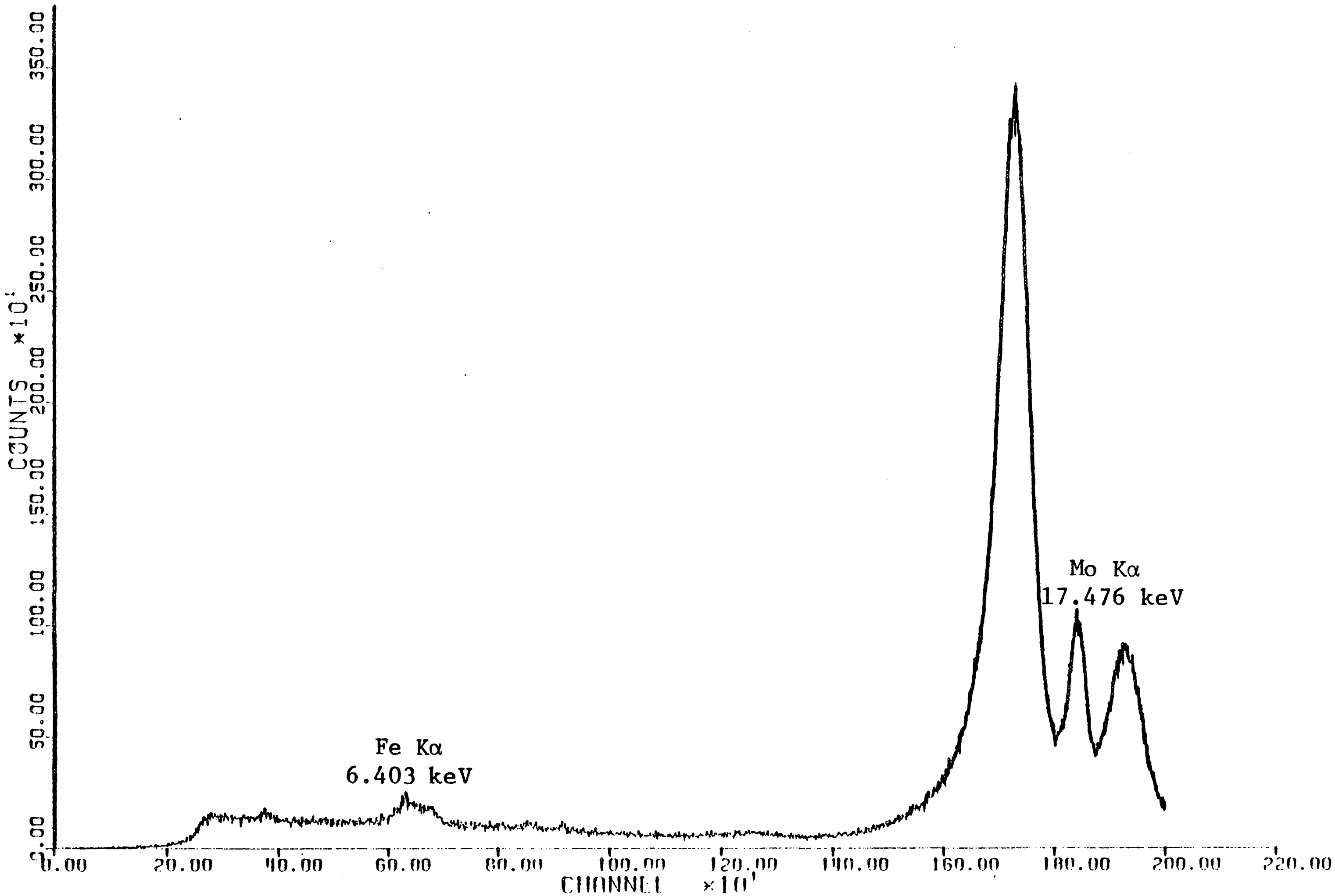



Fig. 2.37 In-vivo XRF Spectrum with Am(Mo) Source for Skin Adjacent to Abdomen Lesion

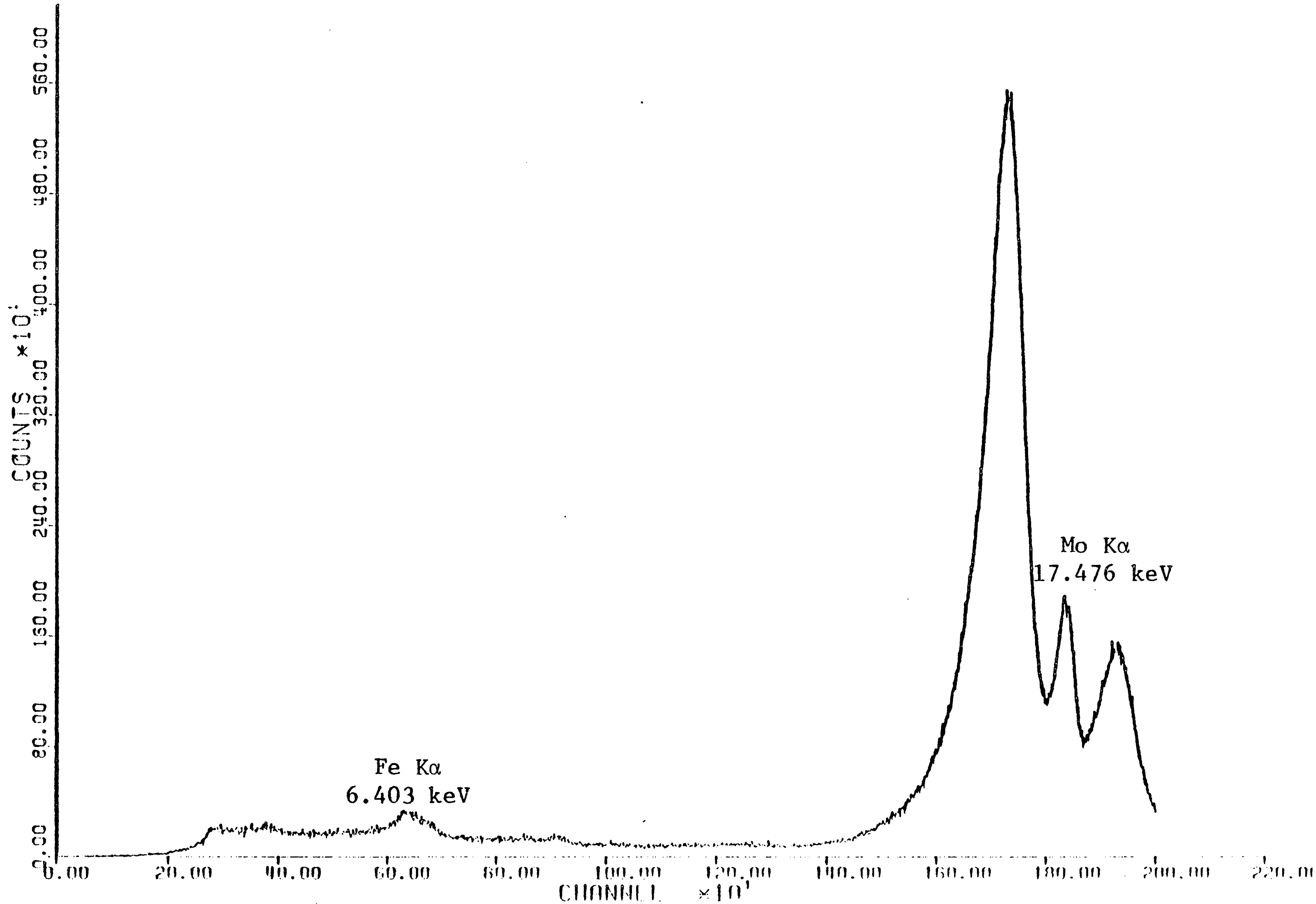



Fig. 2.38 In-vivo XRF Spectrum with Am(Mo) Source for Normal Left Flank Skin

Table 2.17

Trace Element Concentration Ratios from In-vivo XRFA

| Element | Abdomen $\frac{\text{Type C}}{\text{Type B}}$ | Left Flank $\frac{\text{Type B}}{\text{Type A}}$ |
|---|---|---|
| Si | $1.39\times10^{-1}\pm1.93\times10^{-5}$ | |
| Cl | $5.57\pm4.93\times10^{-4}$ | |
| K | $1.14\pm5.05\times10^{-3}$ | $3.28\times10^{-1}\pm8.83\times10^{-4}$ |
| Ca | $3.34\pm3.74\times10^{-3}$ | $2.44\pm9.73\times10^{-4}$ |
| Ti | $3.27\times10^{-1}\pm5.69\times10^{-4}$ | |
| Cr | $1.88\pm3.54\times10^{-3}$ | |

below the minimum detectable concentration (<MDC). Again, this table is incomplete due to missing data.

# 3. NAA MEASUREMENTS

## 3.1 Description of Method

The samples obtained from the Sinclair swine were prepared by thoroughly cleaning the area to be removed with a methanol or ethanol solution and then by removing the tumor with a sterile scalpel. The samples were then transferred to high purity polyethylene vials used for NAA which contained analytical grade ethanol as a preservative. Prior analysis showed very low concentrations of impurities in the ethanol (2). The samples were brought to the reactor lab where they were removed from the vials, dried thoroughly and weighed on a ME22 Mettler balance with a BE22 Mettler balance control and a BA 25 Mettler digital balance display to one hundred thousandth of a gram (±0.01 mg). After the samples had been sealed and weighed, they were placed in the reactor for activation according to the following irratiation sequence: the sample was first irradiated in the reactor thermal column (flux approximately $3.6 \times 10^9$ neutrons per square centimeter per second) for a period up to ten minutes and after a short wait time its gamma spectrum was determined with a lithium drifted germanium detector at a count time of approximately eight minutes. Following the thermal column activation, the sample was placed in the reactor central stringer (flux approximately $1.0 \times 10^{12}$ neutrons per square centimeter per second) and activated for one to ten minutes, depending on the sample's initial activity. The sample's gamma spectrum was determined with the Ge(Li) detector with a count time of eight minutes following a wait time of one minute. The sample was then placed in the central stringer for approximately six hours. Following a wait time of approximately five thousand minutes necessary to allow the activity from the short-lived isotopes to decay, the sample was counted for approximately one hour on the Ge(Li) detector. Finally, after an additional wait time of approximately ten days, the sample was counted on the Ge(Li) detector for approximately one hour.

The swine biopsies were classified as before: Type A--from normal swine; Type B--normal tissues from swine with melanomas; and Type C--melanotic tissue.

## 3.2 Results of NAA on Swine Biopsies

Biopsies of Type A were the same as those analyzed by XRFA. The averages of the trace element concentrations in ppm for five samples of each Type A tissue are listed in Appendix C. Tissues from the pig with Type B skin included the lymph nodes, brain, heart, lungs, kidneys, liver, and spleen. The averages of the trace element concentrations in ppm for five samples of each tissue are listed in Appendix D. Type A, B, and C skin biopsies were taken from the abdomen and left flank of the swine. These biopsies were taken from the same skin regions that were analyzed by in-vivo XRFA (see section 2.3). These trace element concentrations in ppm are listed in Appendix E.

In order to compare Type A, B, and C trace element concentrations, ratios were set up for each tissue. Table 3.1 lists the Type B to Type A trace element concentration ratios for all the tissues except skin. Table 3.2 lists the Type B to Type A, Type C to Type A and Type C to Type B trace element concentration ratios for the skin biopsies.

The NAA software determines the trace element concentrations by converting peak areas to concentrations. Small peaks are frequently indistinguishable from the background. Therefore, the concentrations are reported as being less than the concentration which is equivalent to three times the square root of the background or MDC. When the concentrations are

Table 3.1

Trace Element Concentration Ratios from NAA

| Element | Liver $\frac{\text{Type B}}{\text{Type A}}$ | Brain $\frac{\text{Type B}}{\text{Type A}}$ | Heart $\frac{\text{Type B}}{\text{Type A}}$ |
|---|---|---|---|
| Al | $1.27 \pm 1.58\times10^{-1}$ | $1.87 \pm 3.17\times10^{-2}$ | $8.96\times10^{-1} \pm 5.44\times10^{-2}$ |
| Br | $1.24 \pm 1.40\times10^{-2}$ | $1.07 \pm 2.52\times10^{-2}$ | $8.51\times10^{-1} \pm 1.13\times10^{-1}$ |
| Cl | $1.48 \pm 6.62\times10^{-2}$ | $9.50\times10^{-1} \pm 1.94\times10^{-2}$ | $1.29 \pm 6.27\times10^{-2}$ |
| Co | $9.87\times10^{-1} \pm 7.25\times10^{-2}$ | $1.14 \pm 5.15\times10^{-2}$ | $8.47\times10^{-1} \pm 3.86\times10^{-3}$ |
| Cu | $1.53\times10^{-1} \pm 2.58\times10^{-2}$ | $2.82 \pm 1.63\times10^{-1}$ | - - - - - - - - - - - |
| Fe | $5.77\times10^{-1} \pm 2.18\times10^{-2}$ | $9.71\times10^{-1} \pm 8.02\times10^{-2}$ | $9.67\times10^{-1} \pm 1.69\times10^{-2}$ |
| K | $9.87\times10^{-1} \pm 6.85\times10^{-3}$ | $1.02 \pm 1.20\times10^{-2}$ | $8.50\times10^{-1} \pm 5.58\times10^{-3}$ |
| Mg | - - - - - - - - - - - | - - - - - - - - - - - | $9.83\times10^{-1} \pm 2.51\times10^{-1}$ |
| Mn | $6.56\times10^{-1} \pm 5.46\times10^{-2}$ | - - - - - - - - - - - | $9.18\times10^{-1} \pm 1.74\times10^{-1}$ |
| Mo | $4.01\times10^{-1} \pm 2.28\times10^{-3}$ | - - - - - - - - - - - | - - - - - - - - - - - |
| Na | $1.07 \pm 1.06\times10^{-2}$ | $1.09 \pm 3.19\times10^{-2}$ | $1.33 \pm 1.26\times10^{-3}$ |
| Rb | $6.91\times10^{-1} \pm 5.54\times10^{-2}$ | $1.13 \pm 2.20\times10^{-2}$ | $8.60\times10^{-1} \pm 1.55\times10^{-1}$ |
| Sb | $5.07\times10^{-1} \pm 3.48\times10^{-2}$ | - - - - - - - - - - - | - - - - - - - - - - - |
| Zn | $5.05\times10^{-1} \pm 1.83\times10^{-2}$ | - - - - - - - - - - - | - - - - - - - - - - - |

Table 3.1 (continued)

| Element | Spleen $\frac{\text{Type B}}{\text{Type A}}$ | Lungs $\frac{\text{Type B}}{\text{Type A}}$ | Kidneys $\frac{\text{Type B}}{\text{Type A}}$ |
|---|---|---|---|
| Al | $2.09 \pm 6.77 \times 10^{-1}$ | $1.27 \times 10^{-1} \pm 1.03 \times 10^{-2}$ | $1.60 \pm 3.85 \times 10^{-1}$ |
| Au | - - - - - - - - - - - | - - - - - - - - - - - | $1.48 \pm 1.72 \times 10^{-1}$ |
| Br | $8.68 \times 10^{-1} \pm 3.34 \times 10^{-2}$ | $6.87 \times 10^{-1} \pm 7.48 \times 10^{-3}$ | $9.13 \times 10^{-1} \pm 8.69 \times 10^{-3}$ |
| Cl | $1.24 \pm 2.73 \times 10^{-2}$ | $1.14 \pm 2.26 \times 10^{-3}$ | $1.65 \pm 2.47 \times 10^{-2}$ |
| Co | $1.15 \pm 2.00 \times 10^{-1}$ | $4.65 \times 10^{-1} \pm 9.24 \times 10^{-2}$ | $9.15 \times 10^{-1} \pm 5.65 \times 10^{-2}$ |
| Fe | $7.90 \pm 5.23 \times 10^{-1}$ | $2.10 \pm 8.23 \times 10^{-2}$ | $2.59 \times 10^{-1} \pm 5.19 \times 10^{-2}$ |
| K | $6.73 \times 10^{-1} \pm 4.98 \times 10^{-2}$ | $9.16 \times 10^{-1} \pm 6.28 \times 10^{-3}$ | $7.81 \times 10^{-1} \pm 6.30 \times 10^{-4}$ |
| Mg | $1.43 \pm 1.55 \times 10^{-1}$ | $8.17 \times 10^{-1} \pm 3.18 \times 10^{-2}$ | - - - - - - - - - - - |
| Mn | - - - - - - - - - - - | - - - - - - - - - - - | $1.48 \pm 8.31 \times 10^{-2}$ |
| Na | $1.11 \pm 2.30 \times 10^{-2}$ | $8.12 \times 10^{-1} \pm 2.86 \times 10^{-4}$ | $1.20 \pm 2.53 \times 10^{-3}$ |
| Rb | $6.12 \times 10^{-1} \pm 1.54 \times 10^{-1}$ | $8.58 \times 10^{-1} \pm 3.38 \times 10^{-2}$ | $9.33 \times 10^{-1} \pm 6.05 \times 10^{-2}$ |
| Sb | $1.78 \pm 9.76 \times 10^{-2}$ | - - - - - - - - - - - | - - - - - - - - - - - |
| Se | - - - - - - - - - - - | - - - - - - - - - - - | $5.39 \times 10^{-1} \pm 8.96 \times 10^{-2}$ |
| Sm | $1.26 \pm 1.15 \times 10^{-1}$ | - - - - - - - - - - - | - - - - - - - - - - - |
| Zn | $5.88 \times 10^{-1} \pm 7.32 \times 10^{-2}$ | - - - - - - - - - - - | - - - - - - - - - - - |

Table 3.1 (continued)

| Element | Lymph Nodes $\frac{\text{Type B}}{\text{Type A}}$ |
|---|---|
| Al | $2.13 \pm 4.01\times10^{-1}$ |
| Br | $9.95\times10^{-1} \pm 1.59\times10^{-1}$ |
| Cl | $1.13 \pm 2.31\times10^{-2}$ |
| Co | $1.46 \pm 4.91\times10^{-3}$ |
| Fe | $2.01 \pm 3.37\times10^{-1}$ |
| I | $2.34\times10^{1} \pm 8.45\times10^{-1}$ |
| K | $5.97\times10^{-1} \pm 7.79\times10^{-2}$ |
| Mg | $2.45 \pm 2.02\times10^{-1}$ |
| Mn | $4.08 \pm 2.70\times10^{-1}$ |
| Na | $1.08 \pm 2.12\times10^{-1}$ |
| Rb | $1.23 \pm 1.40\times10^{-1}$ |
| Sb | $2.53 \pm 5.89\times10^{-2}$ |
| V | $1.17 \pm 1.86\times10^{-1}$ |
| Zn | $1.06 \pm 1.90\times10^{-1}$ |

Table 3.2

Trace Element Concentration Ratios from NAA on Skin Biopsies

| Element | Abdomen $\frac{\text{Type B}}{\text{Type A}}$ | Abdomen $\frac{\text{Type C}}{\text{Type A}}$ | Abdomen $\frac{\text{Type C}}{\text{Type B}}$ |
|---|---|---|---|
| Al | $1.57\times10^{-1} \pm 6.92\times10^{-4}$ | $2.74\times10^{-1} \pm 2.27\times10^{-3}$ | 1.74 ± 6.77x10-3 |
| Au | - - - - - - - - - - - - - | - - - - - - - - - - - - - | $1.29 \pm 3.59\times10^{-2}$ |
| Br | $1.36 \pm 2.79\times10^{-3}$ | $1.34 \pm 5.08\times10^{-4}$ | $9.83\times10^{-1} \pm 1.65\times10^{-3}$ |
| Cr | $3.90 \pm 5.42\times10^{-2}$ | $4.53\times10^{-2} \pm 4.44\times10^{-4}$ | $1.16 \pm 2.79\times10^{-2}$ |
| Co | - - - - - - - - - - - - - | - - - - - - - - - - - - - | $1.47 \pm 3.09\times10^{-2}$ |
| Hg | - - - - - - - - - - - - - | $6.63\times10^{-1} \pm 9.30\times10^{-2}$ | - - - - - - - - - - - - - |
| I | - - - - - - - - - - - - - | - - - - - - - - - - - - - | $1.50 \pm 4.30\times10^{-4}$ |
| Mg | $3.79\times10^{-2} \pm 4.20\times10^{-3}$ | - - - - - - - - - - - - - | - - - - - - - - - - - - - |
| Mn | - - - - - - - - - - - - - | - - - - - - - - - - - - - | $1.58 \pm 2.22\times10^{-3}$ |
| Na | $8.91\times10^{-1} \pm 1.08\times10^{-2}$ | $8.42\times10^{-1} \pm 1.56\times10^{-2}$ | $9.45\times10^{-1} \pm 6.03\times10^{-3}$ |
| Sb | $2.07\times10^{-1} \pm 3.32\times10^{-3}$ | $4.10\times10^{-1} \pm 6.97\times10^{-3}$ | $1.98 \pm 1.87\times10^{-3}$ |
| Sm | $5.36\times10^{-1} \pm 6.23\times10^{-3}$ | $8.08\times10^{-1} \pm 1.36\times10^{-2}$ | $1.51 \pm 4.23\times10^{-2}$ |
| Ti | - - - - - - - - - - - - - | - - - - - - - - - - - - - | $1.53 \pm 3.70\times10^{-2}$ |
| Zn | $1.68\times10^{-1} \pm 1.17\times10^{-2}$ | $7.26\times10^{-1} \pm 1.77\times10^{-2}$ | $4.33 \pm 1.83\times10^{-1}$ |

Table 3.2 (continued)

| Element | Left Flank $\frac{\text{Type B}}{\text{Type A}}$ | Left Flank $\frac{\text{Type C}}{\text{Type A}}$ | Left Flank $\frac{\text{Type C}}{\text{Type B}}$ |
|---|---|---|---|
| Al | $3.67\times10^{-1} \pm 1.74\times10^{-3}$ | $2.07 \pm 7.54\times10^{-3}$ | $5.65 \pm 6.27\times10^{-3}$ |
| Br | $1.35 \pm 5.07\times10^{-3}$ | $1.72 \pm 1.13\times10^{-2}$ | $1.27 \pm 1.31\times10^{-2}$ |
| Cl | $1.03 \pm 2.66\times10^{-3}$ | $1.21 \pm 2.42\times10^{-3}$ | $1.17 \pm 6.88\times10^{-4}$ |
| Co | - - - - - - - - - - - | $9.30\times10^{-1} \pm 1.78\times10^{-2}$ | - - - - - - - - - - - |
| Fe | - - - - - - - - - - - | - - - - - - - - - - - | $2.07 \pm 8.23\times10^{-1}$ |
| I | - - - - - - - - - - - | - - - - - - - - - - - | $2.44 \pm 5.60\times10^{-3}$ |
| Mn | $3.02\times10^{-1} \pm 3.26\times10^{-3}$ | $1.84 \pm 1.11\times10^{-2}$ | $6.10 \pm 5.70\times10^{-2}$ |
| Na | $9.05\times10^{-1} \pm 2.57\times10^{-3}$ | $1.35 \pm 1.66\times10^{-3}$ | $1.49 \pm 6.05\times10^{-3}$ |
| Rb | $7.57\times10^{-1} \pm 1.86\times10^{-2}$ | - - - - - - - - - - - | - - - - - - - - - - - |
| Sb | - - - - - - - - - - - | - - - - - - - - - - - | $1.14 \pm 7.61\times10^{-3}$ |
| Sm | $7.54\times10^{-1} \pm 2.87\times10^{-2}$ | $1.04 \pm 2.14\times10^{-2}$ | $1.38 \pm 2.31\times10^{-2}$ |
| Zn | $5.73\times10^{-1} \pm 5.09\times10^{-3}$ | $2.73 \pm 3.89\times10^{-4}$ | $4.77 \pm 4.26\times10^{-2}$ |

reported in this manner, the ratios are indeterminate. For this reason, only the ratios of definite concentrations are listed in Tables 3.1 and 3.2. For the ratios of clear statistical significance, results from Table 3.2 are plotted in Figs. 3.1, 3.2, and 3.3.

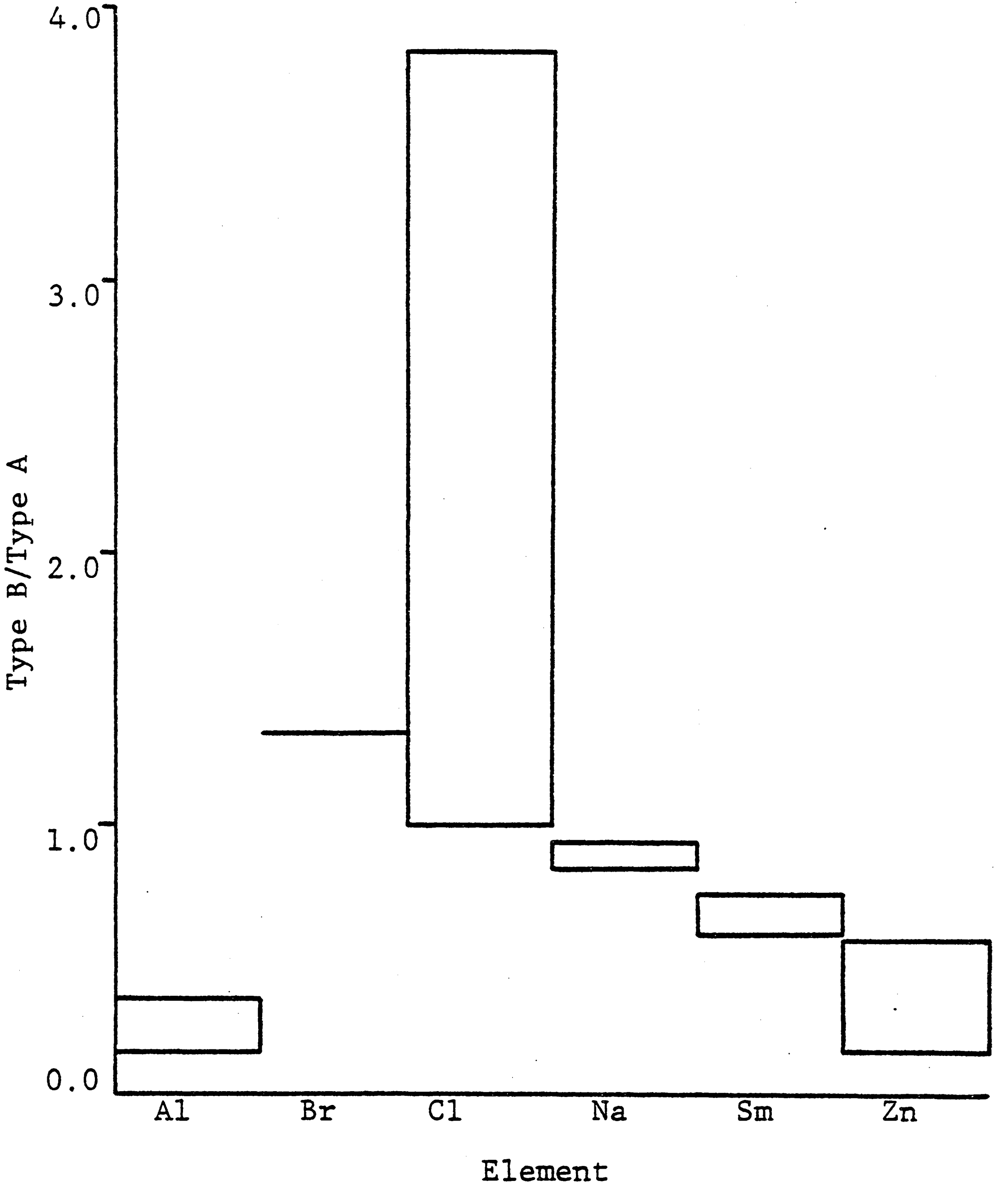



Fig. 3.1 Range of Trace Element Concentration Ratios: Type B to Type A

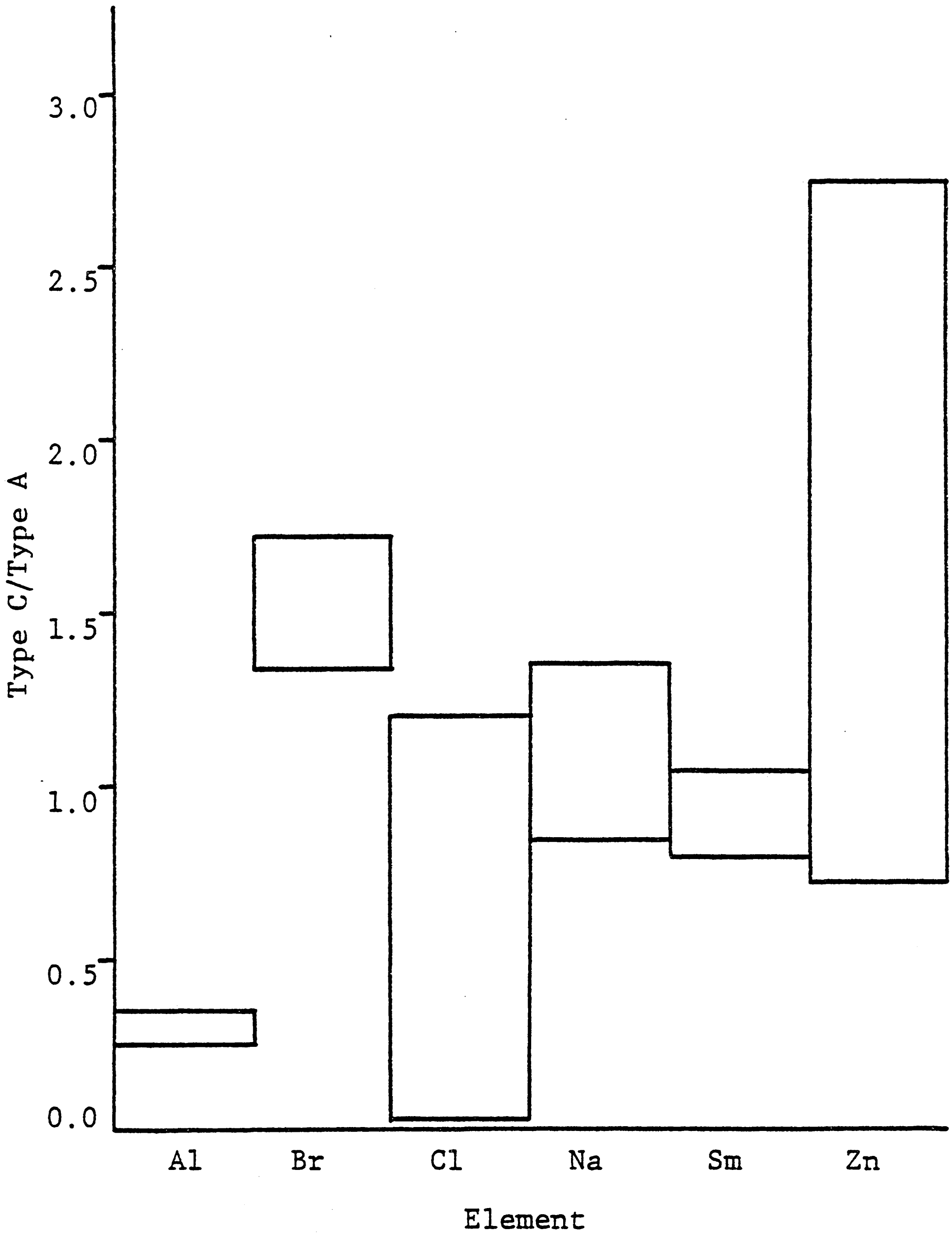



Fig. 3.2 Range of Trace Element Concentration Ratios: Type C to Type A

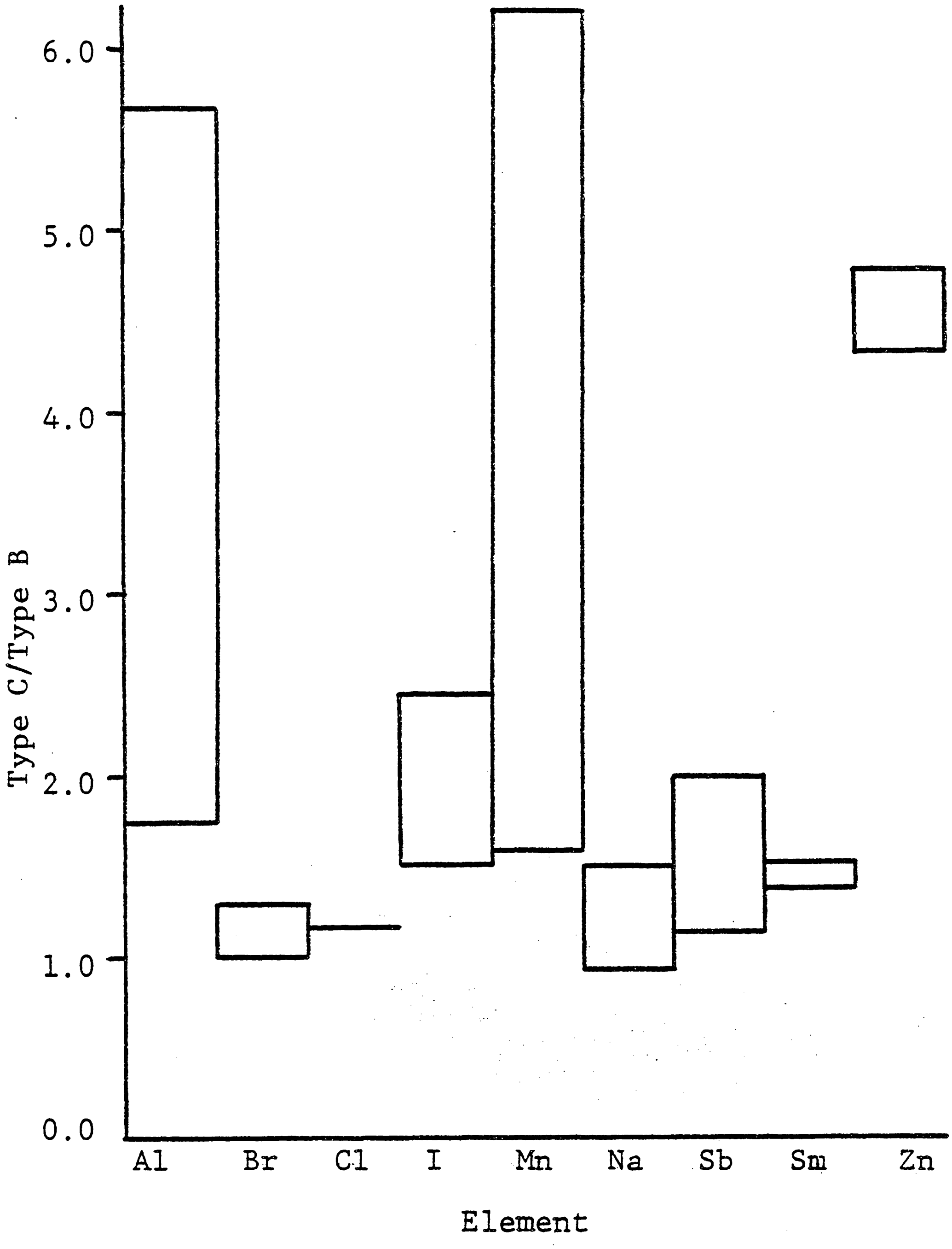



Fig. 3.3 Range of Trace Element Concentration Ratios: Type C to Type B

# 4. DISCUSSION OF RESULTS

Each elemental concentration in Type B and C tissue was compared to that in Type A. Thus, the concentration ratios in Tables 2.17, 3.1 and 3.2 are an indication of whether there were increases or decreases in the concentrations. Tables 4.1 and 4.2 summarize these elevations and depressions.

There were no concentration ratios calculated for the data reported in Appendix A because no XRFA data on the corresponding Type B tissues were available.

As seen in Fig. 4.1, there is good agreement in comparing the trace element concentrations determined by XRFA to those determined by NAA for all elements except chromium and titanium. Iron, which is present in fair amounts in all of the tissue samples, strongly fluoresces both chromium and titanium. This would explain the high concentrations of titanium and chromium in the samples as indicated by XRFA.

The XRFA data is not as accurate as the NAA data. More work is needed to perfect the XRF code. As indicated in section 2.2, the concentration factors and peak area vs. concentration curves do not agree. For this reason, the XRFA data should not be considered as accurate.

Much of the data obtained by XRFA is inclusive, i.e., the trace element concentrations were below the MDC's. This was due to the poor sensitivity of the XRF system at 1800 second count times. However, the information is valuable because it is proof that in-vivo XRFA is a viable analytical technique.

Table 4.1

Trace Element Concentration Trends in Type B Swine Biopsies

| Element | Liver | Brain | Heart | Spleen | Lungs | Kidneys | Lymph Nodes |
|---|---|---|---|---|---|---|---|
| Al | + | + | - | + | - | + | + |
| Au | o | o | + | o | o | o | o |
| Br | + | + | - | - | - | - | - |
| Cl | + | - | + | + | + | + | o |
| Co | o | + | - | + | - | - | + |
| Cu | - | - | o | o | o | o | o |
| Fe | o | - | - | + | + | - | + |
| I | o | o | o | o | o | o | + |
| K | - | + | - | - | - | - | - |
| Mg | o | o | - | + | - | o | + |
| Mn | - | o | - | o | o | + | + |
| Mo | - | o | o | o | o | o | o |
| Na | + | + | + | + | - | + | + |
| Rb | + | - | + | + | + | + | - |
| Sb | - | o | o | + | o | o | + |
| Se | o | o | o | o | o | - | o |
| Sn | o | o | o | + | o | o | o |
| V | o | o | o | o | o | o | + |
| Zn | - | - | - | - | - | - | + |

+ indicates a concentration elevation compared to Type A (normal-control)
- indicates a concentration depression compared to Type A (normal-control)
o indicates indeterminate concentration ratio

Table 4.2

Trace Element Concentration Trends in Swine Skin Biopsies

| | Type B | | Type C | |
|---|---|---|---|---|
| Element | Left Flank | Abdomen | Left Flank | Abdomen |
| Al | - | - | + | - |
| Br | + | o | o | o |
| Ca | + | + | + | - |
| Cl | + | + | + | - |
| Co | o | o | - | o |
| Hg | o | o | o | - |
| K | - | o | o | o |
| Mg | o | - | o | o |
| Mn | - | o | + | o |
| Na | - | - | + | - |
| Rb | - | o | o | o |
| Sb | o | - | o | - |
| Sm | - | - | + | - |
| Zn | - | - | + | - |

\+ indicates a concentration elevation compared to Type A (normal-control)
\- indicates a concentration depression compared to Type A (normal-control)
o indicates indeterminate concentration ratio

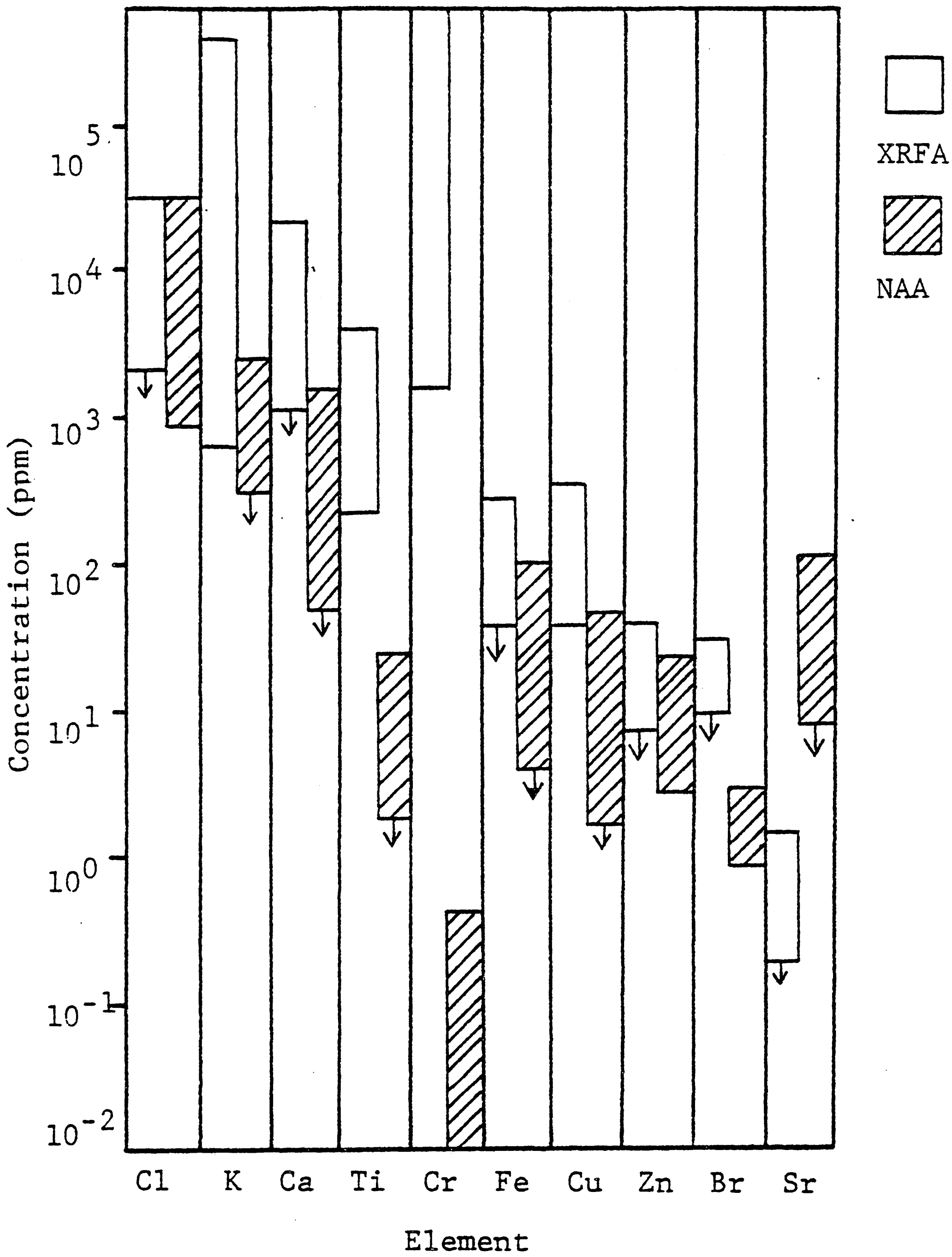



Fig. 4.1 Range of XRFA and NAA Trace Element Concentrations in Swine Skin

# 5. CONCLUSIONS AND RECOMMENDATIONS

Because only two lesions from a single swine were examined in this study, the data is not statistically valid enough to make any conclusions. However, the depressed zinc concentration in the left flank lesion is in agreement with data reported by Gooden (4); Parkinson et al. (5); Samsuhl et al. (6); Danielson et al. (7); Parkinson et al. (10); and Molokhia et al. (19). The increase in the manganese concentration in the left flank lesion is in agreement with data reported by Gooden (4) and Parkinson et al. (5). Only in the case of bromine is the trend consistent for the two lesions. For all of the other elements where there is a change, an increase in the left flank lesion corresponds to a decrease in the abdomen lesion. Therefore, it would be reasonable to assume that the different types of lesions will have different trends in trace element concentrations and it will be necessary to classify these lesions and their corresponding trace element concentration trends.

Basically the NAA work is devleoped quite extensively. It would be desirable to decrease the MDC's by increasing the sensitivity of the system.

The XRF system's sensitivity can be increased by increasing the count times or by using a stronger source. A study would need to be conducted to determine the maximum count times and source strengths allowable which would not be detrimental to the subject when conducting in-vivo XRFA experiments.

The data from the XRFA on the swine biopsies and the in-vivo XRFA with the Am(Dy) and Am(Sn) sources is on magnetic tape. To evaluate this data it is necessary to calibrate the XRF system with these two sources. Once a new multi-channel analyzer is available, this could be accomplished quite easily. Additional work on the XRF code is also necessary before the data with these two sources can be analyzed.

More research on the matrix effects is needed. Standards that are similar in composition to the unknown being analyzed, in this case tissue samples, should be used to calibrate the software. The matrix coefficients used in the present XRF code were determined with USGS rock standards since they were all that were available.

The calculation of minimum detectable concentrations (MDC's) will provide useful information in future XRFA. The MDC decreases with increasing count time and varies with each source. For a given source and specific count time, the MDC for any element may be determined by analyzing samples with a known amount of the element in a base matrix and decreasing the concentration of the element until its peak area is equal to three times the square root of the background area. This should be repeated for every element that is included in the XRF code.

Much more research is necessary concerning the XRF code. The peak stripping routine needs to be modified. The code does not always distinguish between $K\alpha$ and $K\beta$ peaks and in some cases the XRF code considers these two peaks as one. This in turn results in a higher concentration than is actually present. The matrix subroutine also needs to be modified. In its present state, a change in a matrix coefficient by three orders of magnitude results in a fractional change in the concentration. This indicates that the matrix subroutine does not do what it was intended to. Additional standards with intermediate concentrations are necessary to calibrate the XRF code. This will result in more accurate concentration factors. Additional elements can be added to the XRF code. With these additions, concentration factors, matrix coefficients and MDC's will need to be calculated.

Finally, more lesions need to be examined by NAA and in-vivo XRFA to get a reasonable population for proper statistical analysis. Factor analysis should be considered in relating the change in one elemental concentration to another.

Much work is needed to improve this XRF system to the point where it is as valuable as NAA. However, this research has proven that there is great potential for XRFA, especially as an in-vivo analytical technique.

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## Equipment List for XRF System

KeVex Model 3000 Si(Li) Detector, Window area: 30 $mm^2$, Window thickness: 0.025 mm, Resolution: 170 eV at 5.9 keV, Detector bias -1000V

KeVex Model 2003 Preamplifier

Tennelec TC941 High Voltage Bias Supply

Tennelec TC205A Linear Amplifier

ND4420 Multichannel Analyzer

ND Analog to Digital Converter

Tektronix Type 602 Display Unit

Pertec Magnetic Tape Unit

New England Nuclear Fe-55 and Am-241 Sources

## Equipment List for NAA

Ortec Photon Spectrometer System Ge(Li) Detector, 7-10% Efficiency, 1.99-2.0 keV Resolution, 31:1 to 35:1 Peak to Compton, Detector bias +3000 V

Ortec Model 120-4 Preamplifier

Ortec Model 119 High Voltage Filter

Ortec Model 472 Spectroscopy Amplifier

ND4420 Multichannel Analyzer

ND Analog to Digital Converter

Tektronix Type 602 Display Unit

Pertec Magnetic Tape Unit

Appendix A

Trace Element Concentrations in Type A Swine Biopsies

as Determined by XRFA

| Element | Blood | Skin (right) | Skin (left) |
|---|---|---|---|
| Si | $2.62\times10^{5} \pm 2.70\times10^{4}$ | <MDC | <MDC |
| S | <MDC | <MDC | <MDC |
| Cl | <MDC | <MDC | <MDC |
| K | $1.05\times10^{4} \pm 1.10\times10^{3}$ | $1.64\times10^{4} \pm 1.70\times10^{3}$ | $1.71\times10^{4} \pm 3.01\times10^{3}$ |
| Ca | $4.85\times10^{3} \pm 1.19\times10^{3}$ | $6.31\times10^{3} \pm 1.31\times10^{3}$ | $5.11\times10^{3} \pm 5.20\times10^{2}$ |
| Ti | $3.06\times10^{2} \pm 6.78\times10^{1}$ | $4.24\times10^{2} \pm 9.12\times10^{1}$ | $4.61\times10^{2} \pm 9.84\times10^{1}$ |
| Cr | $4.71\times10^{5} \pm 4.80\times10^{4}$ | $5.90\times10^{5} \pm 8.48\times10^{4}$ | $5.51\times10^{5} \pm 6.91\times10^{4}$ |
| Fe | <MDC | <MDC | $1.78\times10^{3} \pm 1.80\times10^{2}$ |
| Cu | $6.94\times10^{1} \pm 1.69\times10^{1}$ | $8.13\times10^{1} \pm 8.20$ | $8.37\times10^{1} \pm 1.04\times10^{1}$ |
| Zn | <MDC | <MDC | $3.62\times10^{2} \pm 3.70\times10^{1}$ |
| Br | <MDC | <MDC | <MDC |
| Sr | <MDC | <MDC | <MDC |

All concentrations in Appendix A are reported in ppm.

| Element | Bristles (right) | Bristles (left) | Thyroid |
|---|---|---|---|
| Si | <MDC | <MDC | <MDC |
| S | $2.56\times10^{5} \pm 3.49\times10^{4}$ | $2.96\times10^{4} \pm 4.23\times10^{3}$ | <MDC |
| Cl | <MDC | <MDC | $3.29\times10^{4} \pm 4.35\times10^{3}$ |
| K | $3.95\times10^{5} \pm 4.21\times10^{4}$ | $5.33\times10^{4} \pm 5.40\times10^{3}$ | $1.28\times10^{4} \pm 3.16\times10^{3}$ |
| Ca | $7.16\times10^{3} \pm 7.20\times10^{2}$ | $6.07\times10^{3} \pm 6.10\times10^{2}$ | <MDC |
| Ti | $5.71\times10^{5} \pm 2.65\times10^{4}$ | $3.32\times10^{2} \pm 1.61\times10^{1}$ | <MDC |
| Cr | $1.54\times10^{3} \pm 3.02\times10^{2}$ | $4.49\times10^{5} \pm 5.20\times10^{4}$ | $5.50\times10^{5} \pm 6.10\times10^{4}$ |
| Fe | $1.54\times10^{3} \pm 3.72\times10^{2}$ | $2.56\times10^{3} \pm 7.87\times10^{2}$ | $2.84\times10^{3} \pm 3.46\times10^{2}$ |
| Cu | $1.09\times10^{2} \pm 2.25\times10^{1}$ | $9.47\times10^{1} \pm 1.58\times10^{1}$ | $3.61\times10^{3} \pm 4.82\times10^{2}$ |
| Zn | $5.23\times10^{2} \pm 5.30\times10^{1}$ | $5.12\times10^{2} \pm 8.07\times10^{1}$ | <MDC |
| Br | $6.77\times10^{1} \pm 6.92$ | $6.68\times10^{1} \pm 1.60\times10^{1}$ | <MDC |
| Sr | <MDC | <MDC | $1.47\times10^{2}$ $1.85\times10^{1}$ |

| Element | Liver | Brain | Heart |
|---|---|---|---|
| Si | <MDC | $4.55 \times 10^{5} \pm 8.21 \times 10^{4}$ | <MDC |
| S | $1.63 \times 10^{4} \pm 3.89 \times 10^{3}$ | <MDC | <MDC |
| Cl | <MDC | <MDC | <MDC |
| K | $6.25 \times 10^{3} \pm 7.95 \times 10^{2}$ | $1.39 \times 10^{4} \pm 1.46 \times 10^{3}$ | $1.56 \times 10^{4} \pm 1.60 \times 10^{3}$ |
| Ca | $4.03 \times 10^{3} \pm 6.59 \times 10^{2}$ | $4.96 \times 10^{3} \pm 5.00 \times 10^{2}$ | $3.38 \times 10^{3} \pm 3.63 \times 10^{2}$ |
| Ti | $3.36 \times 10^{2} \pm 8.31 \times 10^{1}$ | $4.40 \times 10^{2} \pm 5.60 \times 10^{1}$ | $4.55 \times 10^{2} \pm 4.60 \times 10^{1}$ |
| Cr | $4.95 \times 10^{5} \pm 5.63 \times 10^{4}$ | $5.14 \times 10^{5} \pm 5.31 \times 10^{4}$ | $5.01 \times 10^{5} \pm 5.21 \times 10^{4}$ |
| Fe | $1.63 \times 10^{3} \pm 1.81 \times 10^{2}$ | <MDC | <MDC |
| Cu | $1.56 \times 10^{2} \pm 1.57 \times 10^{1}$ | $6.93 \times 10^{1} \pm 1.30 \times 10^{1}$ | <MDC |
| Zn | <MDC | <MDC | <MDC |
| Br | $9.24 \times 10^{1} \pm 1.34 \times 10^{1}$ | <MDC | <MDC |
| Sr | <MDC | <MDC | <MDC |

| Element | Spleen | Lungs | Kidneys |
|---|---|---|---|
| Si | <MDC | <MDC | $1.07 \times 10^{5} \pm 1.87 \times 10^{4}$ |
| S | $1.86 \times 10^{4} \pm 1.90 \times 10^{3}$ | <MDC | <MDC |
| Cl | <MDC | <MDC | <MDC |
| K | $1.06 \times 10^{4} \pm 1.10 \times 10^{3}$ | $1.81 \times 10^{4} \pm 1.85 \times 10^{3}$ | $1.31 \times 10^{4} \pm 1.61 \times 10^{3}$ |
| Ca | $3.73 \times 10^{3} \pm 3.80 \times 10^{2}$ | $1.10 \times 10^{3} \pm 1.58 \times 10^{2}$ | $1.41 \times 10^{3} \pm 3.99 \times 10^{2}$ |
| Ti | $4.20 \times 10^{2} \pm 8.31 \times 10^{1}$ | $2.77 \times 10^{2} \pm 8.83 \times 10^{1}$ | $3.99 \times 10^{2} \pm 4.69 \times 10^{1}$ |
| Cr | $5.33 \times 10^{5} \pm 5.40 \times 10^{4}$ | $4.21 \times 10^{5} \pm 4.30 \times 10^{4}$ | $3.84 \times 10^{5} \pm 4.01 \times 10^{4}$ |
| Fe | <MDC | $3.31 \times 10^{3} \pm 4.35 \times 10^{2}$ | <MDC |
| Cu | $6.60 \times 10^{1} \pm 6.80$ | $8.74 \times 10^{2} \pm 1.22 \times 10^{2}$ | <MDC |
| Zn | <MDC | <MDC | <MDC |
| Br | <MDC | <MDC | <MDC |
| Sr | <MDC | <MDC | <MDC |

| Element | Lymph Nodes |
|---|---|
| Si | $3.74\times10^{5} \pm 4.32\times10^{4}$ |
| S | <MDC |
| Cl | <MDC |
| K | $1.17\times10^{4} \pm 1.21\times10^{3}$ |
| Ca | $1.95\times10^{4} \pm 5.03\times10^{3}$ |
| Ti | $4.30\times10^{2} \pm 9.21\times10^{1}$ |
| Cr | $4.11\times10^{5} \pm 4.62\times10^{4}$ |
| Fe | $8.79\times10^{2} \pm 9.36\times10^{1}$ |
| Cu | <MDC |
| Zn | <MDC |
| Br | <MDC |
| Sr | <MDC |

Appendix B

Trace Element Concentrations in Swine Skin as Determined by In-vivo XRFA

Abdomen

| Element | Type B | Type C |
|---|---|---|
| Si | $4.55x10^5 \pm 4.60x10^4$ | $6.34x10^4 \pm 6.40x10^3$ |
| S | <MDC | $3.67x10^4 \pm 4.00x10^3$ |
| Cl | $6.07x10^3 \pm 6.10x10^2$ | $3.38x10^4 \pm 3.40x10^3$ |
| K | $1.11x10^5 \pm 1.20x10^4$ | $1.26x10^5 \pm 1.30x10^4$ |
| Ca | $3.23x10^3 \pm 3.25x10^2$ | $1.08x10^4 \pm 1.10x10^3$ |
| Ti | $2.06x10^3 \pm 2.10x10^2$ | $6.74x10^2 \pm 7.00x10^1$ |
| Cr | $4.68x10^5 \pm 4.70x10^4$ | $8.78x10^5 \pm 9.00x10^4$ |
| Fe | <MDC | <MDC |
| Cu | <MDC | <MDC |
| Zn | <MDC | <MDC |
| Br | $3.12x10^1 \pm 3.20$ | <MDC |
| Sr | <MDC | <MDC |

All concentrations in Appendix B are reported in ppm.

Left Flank

| Element | Type A | Type B |
|---|---|---|
| Si | <MDC | <MDC |
| S | <MDC | <MDC |
| Cl | <MDC | <MDC |
| K | $7.71 \times 10^5 \pm 8.00 \times 10^4$ | $2.53 \times 10^5 \pm 2.55 \times 10^4$ |
| Ca | $5.20 \times 10^3 \pm 5.30 \times 10^2$ | $1.27 \times 10^4 \pm 1.30 \times 10^3$ |
| Ti | <MDC | $2.31 \times 10^3 \pm 2.35 \times 10^2$ |
| Cr | <MDC | $5.48 \times 10^5 \pm 5.50 \times 10^4$ |
| Fe | <MDC | <MDC |
| Cu | <MDC | <MDC |
| Zn | <MDC | <MDC |
| Br | <MDC | $3.78 \times 10^1 \pm 3.80$ |
| Sr | <MDC | <MDC |

## Appendix C

## Trace Element Concentrations in Type A Swine Biopsies as Determined by NAA

| Element | Blood | Skin (right) |
|---|---|---|
| Ag | $2.21 \pm 9.40 \times 10^{-1}$ | $<1.54 \times 10^{-1}$ |
| Al | $<4.02 \times 10^{1} \pm 2.80 \times 10^{1}$ | $3.54 \pm 4.10 \times 10^{-1}$ |
| As | $<2.00 \times 10^{-2}$ | $1.48 \times 10^{-1} \pm 3.13 \times 10^{-2}$ |
| Au | $<4.00 \times 10^{-5}$ | $4.42 \times 10^{-3} \pm 2.30 \times 10^{-3}$ |
| Ba | $<8.00$ | $<3.98$ |
| Br | $2.28 \pm 1.23$ | $3.18 \pm 3.20 \times 10^{-1}$ |
| Ca | $<1.14 \times 10^{2}$ | $2.56 \times 10^{2} \pm 6.21 \times 10^{1}$ |
| Cd | $<2.00 \times 10^{-1}$ | $1.40 \pm 2.54 \times 10^{-1}$ |
| Ce | $<8.00 \times 10^{-3}$ | $<2.27 \times 10^{-1}$ |
| Cl | $3.57 \times 10^{3} \pm 4.00 \times 10^{2}$ | $<2.20 \times 10^{3} \pm 2.20 \times 10^{2}$ |
| Co | $1.4 \times 10^{-1} \pm 4.0 \times 10^{-1}$ | $2.87 \times 10^{-1} \pm 3.00 \times 10^{-2}$ |
| Cr | $<1.00 \times 10^{-2}$ | $<3.07 \times 10^{-1}$ |
| Cs | $<2.00 \times 10^{-4}$ | $<3.26 \times 10^{-2}$ |
| Cu | $<4.00$ | $3.84 \pm 1.03$ |
| Dy | $<1.00 \times 10^{-2}$ | $<8.15 \times 10^{-3}$ |
| Eu | $<6.00 \times 10^{-2}$ | $<2.84 \times 10^{-1}$ |
| Fe | $<9.00 \times 10^{-3}$ | $6.01 \times 10^{1} \pm 6.5$ |
| Hf | $<1.00 \times 10^{-3}$ | $<2.71 \times 10^{-2}$ |
| Hg | $<1.00 \times 10^{-2}$ | $4.73 \times 10^{-2} \pm 1.05 \times 10^{-2}$ |
| I | $<3.00 \times 10^{-1}$ | $<1.56 \times 10^{-1}$ |
| K | $<4.00 \times 10^{4}$ | $<1.35 \times 10^{2}$ |
| La | $<1.00 \times 10^{-2}$ | $2.07 \times 10^{-1} \pm 2.83 \times 10^{-2}$ |
| Lu | $<1.30 \times 10^{-3}$ | $<4.60 \times 10^{-3}$ |
| Mg | $<1.04 \times 10^{2}$ | $<5.79 \times 10^{1}$ |
| Mn | $1.35 \pm 5.00 \times 10^{-1}$ | $3.94 \times 10^{-1} \pm 5.83 \times 10^{-2}$ |
| Mo | $<4.00 \times 10^{-2}$ | $<1.89 \times 10^{-1}$ |
| Na | $3.49 \times 10^{2} \pm 3.45 \times 10^{1}$ | $1.45 \times 10^{3} \pm 1.50 \times 10^{2}$ |
| Ni | $<1.00$ | $<1.44 \times 10^{1}$ |
| Rb | $<6.00 \times 10^{-2}$ | $1.36 \pm 2.97 \times 10^{-1}$ |
| Ru | $<3.00 \times 10^{-2}$ | $2.20 \times 10^{2} \pm 3.65 \times 10^{1}$ |
| Sb | $4.10 \times 10^{-2} \pm 2.60 \times 10^{-2}$ | $1.53 \times 10^{-1} \pm 7.00 \times 10^{-2}$ |
| Sc | $<5.00 \times 10^{-5}$ | $<1.54 \times 10^{-3}$ |
| Se | $1.90 \times 10^{-1} \pm 2.00 \times 10^{-2}$ | $<1.97 \times 10^{-1}$ |
| Sm | $1.30 \times 10^{-2} \pm 1.70 \times 10^{-3}$ | $7.66 \times 10^{-2} \pm 2.98 \times 10^{-2}$ |
| Sn | $<6.00$ | $<3.04$ |
| Sr | $<2.00 \times 10^{1}$ | $<1.11 \times 10^{1}$ |
| Ta | $<1.00 \times 10^{-3}$ | $<2.43 \times 10^{-2}$ |
| Te | $<2.00 \times 10^{1}$ | $<1.07 \times 10^{1}$ |
| Th | $<2.00 \times 10^{-3}$ | $<8.21 \times 10^{-2}$ |
| Ti | $<5.00$ | $<2.64$ |
| U | $<1.00 \times 10^{-2}$ | $<4.83 \times 10^{-2}$ |
| V | $<5.00 \times 10^{-2}$ | $<2.82 \times 10^{-2}$ |
| W | $<5.00 \times 10^{-2}$ | $4.30 \times 10^{-1} \pm 5.78 \times 10^{-2}$ |
| Yb | $<1.00 \times 10^{-3}$ | $5.19 \times 10^{-2} \pm 1.86 \times 10^{-2}$ |
| Zn | $2.73 \pm 8.40 \times 10^{-1}$ | $5.86 \pm 6.00 \times 10^{-1}$ |
| Zr | $<7.00 \times 10^{-1}$ | $<1.27 \times 10^{1}$ |

All concentrations in Appendix C are reported in ppm.

| Element | Skin (left) | Bristles (right) |
|---|---|---|
| Ag | $<3.53\times10^{-1}$ | $<3.31\times10^{-1}$ |
| Al | $1.21\times10^{1} \pm 4.45$ | $2.93\times10^{1} \pm 7.69$ |
| As | $2.05\times10^{-1} \pm 3.54\times10^{-2}$ | $<1.29\times10^{-1}$ |
| Au | $9.17\times10^{-3} \pm 3.26\times10^{-3}$ | $9.47\times10^{-3} \pm 5.21\times10^{-3}$ |
| Ba | $<4.36$ | $<3.93$ |
| Br | $2.67 \pm 7.93\times10^{-1}$ | $3.10 \pm 4.98\times10^{-1}$ |
| Ca | $2.50\times10^{2} \pm 1.10\times10^{2}$ | $1.47\times10^{3} \pm 1.70\times10^{2}$ |
| Cd | $3.18 \pm 3.69\times10^{-1}$ | $<8.00\times10^{-1}$ |
| Ce | $<4.77\times10^{-1}$ | $<4.25\times10^{-1}$ |
| Cl | $2.25\times10^{3} \pm 2.30\times10^{2}$ | $7.33\times10^{2} \pm 7.5\times10^{1}$ |
| Co | $5.58\times10^{-1} \pm 3.39\times10^{-1}$ | $4.23\times10^{-1} \pm 7.46\times10^{-2}$ |
| Cr | $<4.64\times10^{-1}$ | $4.41 \pm 5.20\times10^{-1}$ |
| Cs | $<7.83\times10^{-2}$ | $<7.06\times10^{-2}$ |
| Cu | $7.94 \pm 1.25$ | $1.27\times10^{1} \pm 1.47$ |
| Dy | $1.46\times10^{-2} \pm 3.57\times10^{-3}$ | $<1.46\times10^{-1}$ |
| Eu | $<2.53\times10^{-1}$ | $<4.15\times10^{-1}$ |
| Fe | $7.90\times10^{1} \pm 1.46\times10^{1}$ | $5.77\times10^{1} \pm 8.87$ |
| Hf | $<5.43\times10^{-2}$ | $<5.80\times10^{-2}$ |
| Hg | $1.13\times10^{-1} \pm 1.99\times10^{-2}$ | $1.67\times10^{-1} \pm 3.70\times10^{-2}$ |
| I | $3.86\times10^{-1} \pm 5.44\times10^{-2}$ | $1.59 \pm 1.60\times10^{-1}$ |
| K | $4.13\times10^{2} \pm 1.27\times10^{2}$ | $6.33\times10^{3} \pm 6.50\times10^{2}$ |
| La | $5.27\times10^{-2} \pm 1.19\times10^{-2}$ | $<5.44\times10^{-2}$ |
| Lu | $1.07\times10^{-2} \pm 2.07\times10^{-3}$ | $<6.98\times10^{-3}$ |
| Mg | $<7.09\times10^{1}$ | $4.62\times10^{2} \pm 4.60\times10^{1}$ |
| Mn | $8.43\times10^{-1} \pm 5.79\times10^{-1}$ | $1.87 \pm 2.00\times10^{-1}$ |
| Mo | $<2.81\times10^{-1}$ | $4.47\times10^{-1} \pm 5.44\times10^{-2}$ |
| Na | $1.42\times10^{3} \pm 1.50\times10^{2}$ | $1.28\times10^{3} \pm 1.30\times10^{2}$ |
| Ni | $<3.29\times10^{1}$ | $<3.08\times10^{1}$ |
| Rb | $<1.80$ | $2.98 \pm 1.06$ |
| Ru | $<8.98\times10^{1}$ | $<7.59\times10^{1}$ |
| Sb | $2.20\times10^{-1} \pm 3.97\times10^{-2}$ | $2.58\times10^{-1} \pm 5.88\times10^{-2}$ |
| Sc | $3.41\times10^{-3} \pm 7.85\times10^{-4}$ | $<3.63\times10^{-3}$ |
| Se | $<4.12\times10^{-1}$ | $5.08\times10^{-1} \pm 1.01\times10^{-1}$ |
| Sm | $6.80\times10^{-2} \pm 1.47\times10^{-2}$ | $5.45\times10^{-2} \pm 6.00\times10^{-3}$ |
| Sn | $<3.68$ | $<4.05$ |
| Sr | $<1.21\times10^{1}$ | $<1.05\times10^{1}$ |
| Ta | $7.20\times10^{-2} \pm 1.52\times10^{-2}$ | $<4.44\times10^{-2}$ |
| Te | $<1.23\times10^{1}$ | $<1.16\times10^{1}$ |
| Th | $<8.85$ | $<1.79\times10^{-1}$ |
| Ti | $5.50 \pm 1.09$ | $<3.90$ |
| U | $<6.98\times10^{-2}$ | $<6.44\times10^{-2}$ |
| V | $<3.69\times10^{-2}$ | $5.60\times10^{-2} \pm 1.76\times10^{-2}$ |
| W | $<1.91\times10^{-1}$ | $2.93\times10^{-1} \pm 6.77\times10^{-2}$ |
| Yb | $<8.64\times10^{-2}$ | $<6.09\times10^{-2}$ |
| Zn | $1.41\times10^{1} \pm 1.86$ | $1.45\times10^{2} \pm 1.50\times10^{1}$ |
| Zr | $<2.95\times10^{1}$ | $<2.73\times10^{1}$ |

| Element | Bristles (left) | Thyroid |
|---|---|---|
| Ag | $<4.64\times10^{-1}$ | $<2.26\times10^{-1}$ |
| Al | $9.58 \pm 1.63$ | $6.63\times10^{1} \pm 2.17\times10^{1}$ |
| As | $<9.94\times10^{-2}$ | $3.96\times10^{-1} \pm 8.31\times10^{-2}$ |
| Au | $9.56\times10^{-3} \pm 1.00\times10^{-3}$ | $5.93\times10^{-3} \pm 6.00\times10^{-3}$ |
| Ba | $<3.10$ | $9.96\times10^{1} \pm 2.28\times10^{1}$ |
| Br | $6.49 \pm 6.66\times10^{-1}$ | $4.61 \pm 1.18$ |
| Ca | $9.92\times10^{2} \pm 1.00\times10^{2}$ | $<1.55\times10^{2}$ |
| Cd | $<7.24\times10^{-1}$ | $<1.07$ |
| Ce | $<5.67\times10^{-1}$ | $<3.09\times10^{-1}$ |
| Cl | $1.55\times10^{3} \pm 1.72\times10^{2}$ | $1.13\times10^{3} \pm 1.00\times10^{2}$ |
| Co | $6.33\times10^{-1} \pm 1.29\times10^{-1}$ | $1.59\times10^{-1} \pm 2.33\times10^{-2}$ |
| Cr | $2.15 \pm 5.91\times10^{-1}$ | $1.80 \pm 1.47\times10^{-1}$ |
| Sc | $1.44\times10^{-1} \pm 2.00\times10^{-2}$ | $<4.80\times10^{-2}$ |
| Cu | $1.08\times10^{1} \pm 2.41$ | $<7.92$ |
| Dy | $<1.27\times10^{-2}$ | $<6.72\times10^{-2}$ |
| Eu | $<1.90\times10^{-1}$ | $<9.60\times10^{-1}$ |
| Fe | $6.38\times10^{1} \pm 2.38\times10^{1}$ | $4.92\times10^{1} \pm 8.12$ |
| Hf | $<7.71\times10^{-2}$ | $<4.05\times10^{-2}$ |
| Hg | $1.62\times10^{-1} \pm 3.47\times10^{-2}$ | $6.00\times10^{-2} \pm 1.49\times10^{-2}$ |
| I | $6.66\times10^{-1} \pm 7.00\times10^{-2}$ | $2.29\times10^{3} \pm 3.74\times10^{2}$ |
| K | $3.30\times10^{2} \pm 1.87\times10^{2}$ | $7.23\times10^{3} \pm 7.00\times10^{2}$ |
| La | $4.65\times10^{-2} \pm 9.98\times10^{-3}$ | $1.88\times10^{-1} \pm 2.52\times10^{-2}$ |
| Lu | $<1.10\times10^{-2}$ | $<8.56\times10^{-3}$ |
| Mg | $2.78\times10^{2} \pm 3.00\times10^{1}$ | $<2.42\times10^{2}$ |
| Mn | $6.16\times10^{-1} \pm 6.20\times10^{-2}$ | $2.08 \pm 1.20$ |
| Mo | $5.48\times10^{-1} \pm 8.60\times10^{-2}$ | $<3.64\times10^{-1}$ |
| Na | $3.22\times10^{2} \pm 1.33\times10^{2}$ | $5.51\times10^{3} \pm 6.00\times10^{2}$ |
| Ni | $<4.70\times10^{1}$ | $<2.14\times10^{1}$ |
| Rb | $<1.88$ | $2.30 \pm 3.25\times10^{-1}$ |
| Ru | $<6.36\times10^{1}$ | $<6.30\times10^{2}$ |
| Sb | $1.95\times10^{-1} \pm 2.42\times10^{-2}$ | $2.45\times10^{-1} \pm 1.01\times10^{-1}$ |
| Sc | $<4.42\times10^{-3}$ | $<2.04\times10^{-3}$ |
| Se | $1.01 \pm 1.74\times10^{-1}$ | $<2.74\times10^{-1}$ |
| Sm | $6.44\times10^{-2} \pm 6.50\times10^{-3}$ | $6.84\times10^{-2} \pm 1.54\times10^{-2}$ |
| Sn | $<2.57$ | $<3.03\times10^{1}$ |
| Sr | $<8.54$ | $<1.09\times10^{2}$ |
| Ta | $<5.73\times10^{-2}$ | $<3.01\times10^{-2}$ |
| Te | $2.46 \pm 5.79\times10^{-1}$ | $<9.82\times10^{1}$ |
| Th | $<2.24\times10^{-1}$ | $<1.18\times10^{-1}$ |
| Ti | $4.45 \pm 1.10$ | $<2.60\times10^{1}$ |
| U | $<6.27\times10^{-2}$ | $<9.48\times10^{-2}$ |
| V | $4.42\times10^{-2} \pm 1.10\times10^{-2}$ | $<7.65\times10^{-2}$ |
| W | $<1.56\times10^{-1}$ | $<3.46\times10^{-1}$ |
| Yb | $<8.57\times10^{-2}$ | $<7.95\times10^{-2}$ |
| Zn | $1.59\times10^{2} \pm 1.60\times10^{1}$ | $1.50\times10^{1} \pm 2.50$ |
| Zr | $<3.93\times10^{1}$ | $<1.96\times10^{1}$ |

| Element | Liver | Brain |
|---|---|---|
| Ag | $<5.69\times10^{-1}$ | $<3.59\times10^{-1}$ |
| Al | $7.07 \pm 1.30$ | $5.13 \pm 5.45\times10^{-1}$ |
| As | $3.41\times10^{-1} \pm 4.00\times10^{-2}$ | $<1.03\times10^{-1}$ |
| Au | $<1.26\times10^{-3}$ | $<8.09\times10^{-4}$ |
| Ba | $<4.44$ | $<4.39$ |
| Br | $1.74 \pm 2.00\times10^{-1}$ | $8.84\times10^{-1} \pm 9.00\times10^{-2}$ |
| Ca | $1.22\times10^{2} \pm 1.06\times10^{1}$ | $<7.45\times10^{1}$ |
| Cd | $1.46 \pm 2.50\times10^{-1}$ | $<5.08\times10^{-1}$ |
| Ce | $<6.46\times10^{-1}$ | $<3.66\times10^{-1}$ |
| Cl | $1.25\times10^{3} \pm 2.00\times10^{2}$ | $1.61\times10^{3} \pm 2.00\times10^{2}$ |
| Co | $1.56\times10^{-1} \pm 2.00\times10^{-2}$ | $1.11\times10^{-1} \pm 2.65\times10^{-2}$ |
| Cr | $1.31 \pm 3.18\times10^{-1}$ | $7.05\times10^{-1} \pm 1.69\times10^{-1}$ |
| Cs | $<1.23\times10^{-1}$ | $<6.39\times10^{-2}$ |
| Cu | $1.13\times10^{2} \pm 1.00\times10^{1}$ | $7.17 \pm 7.00\times10^{-1}$ |
| Cy | $<1.18\times10^{-2}$ | $<2.59\times10^{-2}$ |
| Eu | $<6.48\times10^{-1}$ | $<6.71\times10^{-1}$ |
| Fe | $4.16\times10^{2} \pm 4.00\times10^{1}$ | $3.49\times10^{1} \pm 8.75$ |
| Hf | $<1.05\times10^{-1}$ | $<5.18\times10^{-2}$ |
| Hg | $1.46\times10^{-1} \pm 2.76\times10^{-2}$ | $<4.56\times10^{-2}$ |
| I | $1.96 \pm 7.00\times10^{-1}$ | $4.94\times10^{-1} \pm 3.48\times10^{-1}$ |
| K | $3.17\times10^{3} \pm 3.00\times10^{2}$ | $3.35\times10^{3} \pm 3.00\times10^{2}$ |
| La | $<5.25\times10^{-2}$ | $<3.56\times10^{-2}$ |
| Lu | $<6.67\times10^{-3}$ | $<4.16\times10^{-3}$ |
| Mg | $2.37\times10^{2} \pm 3.00\times10^{1}$ | $1.48\times10^{2} \pm 4.00\times10^{1}$ |
| Mn | $3.02 \pm 3.00\times10^{-1}$ | $<4.70\times10^{-1}$ |
| Mo | $9.01\times10^{-1} \pm 1.49\times10^{-1}$ | $<1.81\times10^{-1}$ |
| Na | $1.10\times10^{3} \pm 1.00\times10^{2}$ | $1.17\times10^{3} \pm 1.00\times10^{2}$ |
| Ni | $<3.81\times10$ | $<2.65\times10^{1}$ |
| Rb | $7.26 \pm 9.34\times10^{-1}$ | $2.60 \pm 2.86\times10^{-1}$ |
| Ru | $<9.04\times10^{1}$ | $2.81\times10^{2} \pm 6.38\times10^{1}$ |
| Sb | $6.01\times10^{-2} \pm 6.25\times10^{-3}$ | $3.45\times10^{-2} \pm 1.52\times10^{-2}$ |
| Sc | $<4.22\times10^{-3}$ | $<2.23\times10^{-3}$ |
| Se | $9.51\times10^{-1} \pm 1.44\times10^{-1}$ | $<3.49\times10^{-1}$ |
| Sm | $3.49\times10^{-2} \pm 9.20\times10^{-3}$ | $1.96\times10^{-2} \pm 6.58\times10^{-3}$ |
| Sn | $<3.52$ | $<3.19$ |
| Sr | $2.82\times10^{1} \pm 5.24$ | $<1.22\times10^{1}$ |
| Ta | $1.07\times10^{-1} \pm 1.90\times10^{-2}$ | $3.05\times10^{-2} \pm 7.88\times10^{-3}$ |
| Te | $<1.21\times10^{1}$ | $<1.18\times10^{1}$ |
| Th | $<2.87\times10^{-1}$ | $<1.68\times10^{-1}$ |
| Ti | $4.37 \pm 9.24\times10^{-1}$ | $5.39 \pm 1.45$ |
| U | $<6.57\times10^{-2}$ | $<4.20\times10^{-2}$ |
| V | $<2.87\times10^{-2}$ | $<2.79\times10^{-2}$ |
| W | $<2.41\times10^{-1}$ | $<1.81\times10^{-1}$ |
| Yb | $<4.77\times10^{-2}$ | $<3.45\times10^{-2}$ |
| Zn | $4.87\times10^{1} \pm 4.41$ | $1.29\times10^{1} \pm 2.79$ |
| Zr | $<5.00\times10^{1}$ | $<2.77\times10^{1}$ |

| Element | Heart | Spleen |
|---|---|---|
| Ag | $<3.92\times10^{-1}$ | $<3.47\times10^{-1}$ |
| Al | $6.14 \pm 1.93$ | $4.98 \pm 1.28$ |
| As | $<1.55\times10^{-1}$ | $<7.73\times10^{-2}$ |
| Au | $6.50\times10^{-3} \pm 8.58\times10^{-4}$ | $<1.00\times10^{-3}$ |
| Ba | $<7.73$ | $<3.13$ |
| Br | $2.42 \pm 6.55\times10^{-1}$ | $2.87 \pm 3.00\times10^{-1}$ |
| Ca | $<8.33\times10^{1}$ | $7.18\times10^{1} \pm 1.57\times10^{1}$ |
| Cd | $1.96 \pm 3.97\times10^{-1}$ | $<5.73\times10^{-1}$ |
| Ce | $<4.18\times10^{-1}$ | $<3.99\times10^{-1}$ |
| Cl | $9.32\times10^{2} \pm 0.00\times10^{1}$ | $1.29\times10^{3} \pm 1.30\times10^{2}$ |
| Co | $2.03\times10^{-1} \pm 3.46\times10^{-2}$ | $1.28\times10^{-1} \pm 1.36\times10^{-2}$ |
| Cr | $<5.70\times10^{-1}$ | $2.75 \pm 2.80\times10^{-1}$ |
| Cs | $<7.28\times10^{-2}$ | $<6.93\times10^{-2}$ |
| Cu | $7.65 \pm 8.00\times10^{-1}$ | $3.21 \pm 6.84\times10^{-1}$ |
| Dy | $<1.16\times10^{-2}$ | $<7.65\times10^{-3}$ |
| Eu | $<7.48\times10^{-1}$ | $3.79\times10^{-1} \pm 5.10\times10^{-2}$ |
| Fe | $7.21\times10^{1} \pm 9.04$ | $2.19\times10^{2} \pm 2.25\times10^{1}$ |
| Hf | $<6.16\times10^{-2}$ | $<6.21\times10^{-2}$ |
| Hg | $1.06\times10^{-1} \pm 2.26\times10^{-2}$ | $<4.81\times10^{-2}$ |
| I | $1.01 \pm 3.31\times10^{-1}$ | $4.07 \pm 9.90\times10^{-1}$ |
| K | $3.80\times10^{3} \pm 4.10\times10^{2}$ | $5.29\times10^{3} \pm 5.35\times10^{2}$ |
| La | $1.36\times10^{-1} \pm 1.90\times10^{-2}$ | $<3.68\times10^{-2}$ |
| Lu | $<6.67\times10^{-3}$ | $<5.86\times10^{-3}$ |
| Mg | $2.32\times10^{2} \pm 2.00\times10^{1}$ | $2.03\times10^{2} \pm 5.50\times10^{1}$ |
| Mn | $3.42\times10^{-1} \pm 1.50\times10^{-1}$ | $<2.84\times10^{-1}$ |
| Mo | $<2.86\times10^{-1}$ | $<2.09\times10^{-1}$ |
| Na | $9.10\times10^{2} \pm 9.12\times10^{1}$ | $8.15\times10^{2} \pm 8.20\times10^{1}$ |
| Ni | $<3.10\times10^{1}$ | $<2.91\times10^{1}$ |
| Rb | $4.65 \pm 5.0\times10^{-1}$ | $7.13 \pm 1.06$ |
| Ru | $<1.35\times10^{2}$ | $4.03\times10^{1} \pm 1.03\times10^{1}$ |
| Sb | $1.76\times10^{-1} \pm 6.17\times10^{-2}$ | $4.38\times10^{-2} \pm 1.05\times10^{-2}$ |
| Sc | $<3.19\times10^{-3}$ | $<2.72\times10^{-3}$ |
| Se | $6.35\times10^{-1} \pm 1.23\times10^{-1}$ | $5.66\times10^{-1} \pm 1.17\times10^{-1}$ |
| Sm | $4.09\times10^{-2} \pm 1.04\times10^{-2}$ | $1.43\times10^{-2} \pm 3.18\times10^{-3}$ |
| Sn | $<4.87$ | $<2.22$ |
| Sr | $<1.87\times10^{1}$ | $<8.31$ |
| Ta | $<3.95\times10^{-2}$ | $<2.76\times10^{-2}$ |
| Te | $<1.66\times10^{1}$ | $<7.88$ |
| Th | $<1.81\times10^{-1}$ | $<1.75\times10^{-1}$ |
| Ti | $5.87 \pm 1.02$ | $1.31\times10^{1} \pm 1.35$ |
| U | $1.53\times10^{-1} \pm 3.15\times10^{-2}$ | $<4.97\times10^{-2}$ |
| V | $7.68\times10^{-2} \pm 1.22\times10^{-2}$ | $5.12\times10^{-2} \pm 9.45\times10^{-3}$ |
| W | $4.26\times10^{-1} \pm 9.68\times10^{-2}$ | $<1.22\times10^{-1}$ |
| Yb | $<5.95\times10^{-2}$ | $<4.86\times10^{-2}$ |
| Zn | $2.42\times10^{1} \pm 2.50$ | $3.71\times10^{1} \pm 4.41$ |
| Zr | $<3.06\times10^{1}$ | $<2.79\times10^{1}$ |

| Element | Lungs | Kidneys |
|---|---|---|
| Ag | $<5.28\times10^{-1}$ | $<4.10\times10^{-1}$ |
| Al | $2.54\times10^{1} \pm 1.29\times10^{1}$ | $3.16 \pm 3.20\times10^{-1}$ |
| As | $<1.81\times10^{-1}$ | $4.40\times10^{-1} \pm 9.51\times10^{-2}$ |
| Au | $<8.07\times10^{-3}$ | $2.42\times10^{-3} \pm 5.92\times10^{-4}$ |
| Ba | $<6.74$ | $<5.46$ |
| Br | $5.18 \pm 5.20\times10^{-1}$ | $4.12 \pm 4.06\times10^{-1}$ |
| Ca | $<1.05\times10^{2}$ | $2.02\times10^{2} \pm 2.75\times10^{1}$ |
| Cd | $1.51 \pm 3.37\times10^{-1}$ | $<7.47\times10^{-1}$ |
| Ce | $<6.18\times10^{-1}$ | $<4.45\times10^{-1}$ |
| Cl | $2.18\times10^{3} \pm 2.15\times10^{2}$ | $1.65\times10^{3} \pm 1.69\times10^{2}$ |
| Co | $3.55\times10^{-1} \pm 4.00\times10^{-2}$ | $1.76\times10^{-1} \pm 3.36\times10^{-2}$ |
| Cr | $2,38 \pm 2.40\times10^{-1}$ | $8.83\times10^{-1} \pm 2.03\times10^{-1}$ |
| Cs | $<1.03\times10^{-1}$ | $1.61\times10^{-1} \pm 3.41\times10^{-2}$ |
| Cu | $<3.35$ | $6.26 \pm 1.01$ |
| Dy | $<1.26\times10^{-1}$ | $<1.03\times10^{-2}$ |
| Eu | $<3.41$ | $<3.74$ |
| Fe | $1.77\times10^{2} \pm 2.74\times10^{1}$ | $6.61\times10^{2} \pm 6.25\times10^{1}$ |
| Hf | $<9.04\times10^{-2}$ | $<6.71\times10^{-2}$ |
| Hg | $<8.02\times10^{-2}$ | $1.19\times10^{-1} \pm 2.83\times10^{-2}$ |
| I | $1.28 \pm 2.08\times10^{-1}$ | $3.87\times10^{-1} \pm 4.13\times10^{-2}$ |
| K | $3.82\times10^{3} \pm 4.11\times10^{2}$ | $3.06\times10^{3} \pm 3.10\times10^{2}$ |
| La | $<6.80\times10^{-2}$ | $<5.33\times10^{-2}$ |
| Lu | $<9.69\times10^{-2}$ | $<5.08\times10^{-3}$ |
| Mg | $2.04\times10^{2} \pm 4.41\times10^{1}$ | $<6.19\times10^{1}$ |
| Mn | $<7.72\times10^{-1}$ | $4.56\times10^{-1} \pm 4.60\times10^{-2}$ |
| Mo | $5.72\times10^{-1} \pm 1.10\times10^{-1}$ | $5.65\times10^{-1} \pm 9.00\times10^{-2}$ |
| Na | $1.54\times10^{3} \pm 1.60\times10^{2}$ | $1.51\times10^{3} \pm 1.55\times10^{2}$ |
| Ni | $5.41\times10^{1} \pm 1.48\times10^{1}$ | $<3.30\times10^{1}$ |
| Rb | $5.30 \pm 6.33\times10^{-1}$ | $3.45 \pm 5.88\times10^{-1}$ |
| Ru | $<1.34\times10^{2}$ | $<1.10\times10^{2}$ |
| Sb | $6.53\times10^{-2} \pm 1.93\times10^{-2}$ | $3.17\times10^{-2} \pm 6.41\times10^{-3}$ |
| Sc | $4.36\times10^{-3} \pm 1.40\times10^{-3}$ | $<3.28\times10^{-3}$ |
| Se | $<5.57\times10^{-1}$ | $1.50 \pm 1.17\times10^{-1}$ |
| Sm | $4.50\times10^{-2} \pm 7.88\times10^{-3}$ | $3.38\times10^{-2} \pm 3.40\times10^{-3}$ |
| Sn | $<4.99$ | $1.05\times10^{1} \pm 1.36$ |
| Sr | $2.91\times10^{1} \pm 8.65$ | $<1.47\times10^{1}$ |
| Ta | $<5.06\times10^{-2}$ | $<3.89\times10^{-2}$ |
| Te | $<1.75\times10^{1}$ | $4.58 \pm 8.51\times10^{-1}$ |
| Th | $<2.64\times10^{-1}$ | $<1.96\times10^{-1}$ |
| Ti | $<4.24$ | $<3.55$ |
| U | $<8.92\times10^{-2}$ | $<5.99\times10^{-2}$ |
| V | $1.27\times10^{-1} \pm 2.12\times10^{-2}$ | $<3.30\times10^{-2}$ |
| W | $<3.43\times10^{-1}$ | $<3.54\times10^{-1}$ |
| Yb | $<8.41\times10^{-2}$ | $<4.35\times10^{-2}$ |
| Zn | $2.52\times10^{1} \pm 4.38$ | $2.22\times10^{1} \pm 2.25$ |
| Zr | $<4.27\times10^{1}$ | $<3.24\times10^{1}$ |

| Element | Lymph Nodes |
|---|---|
| Ag | $<3.01\times10^{-1}$ |
| Al | $3.77 \pm 6.74\times10^{-1}$ |
| As | $<2.21\times10^{-1}$ |
| Au | $<6.38\times10^{-3}$ |
| Ba | $<3.37$ |
| Br | $1.88 \pm 2.00\times10^{-1}$ |
| Ca | $<5.28\times10^{1}$ |
| Cd | $<6.55\times10^{-1}$ |
| Ce | $<3.63\times10^{-1}$ |
| Cl | $1.15\times10^{3} \pm 1.20\times10^{2}$ |
| Co | $1.86\times10^{-1} \pm 3.26\times10^{-2}$ |
| Cr | $5.38\times10^{-1} \pm 1.36\times10^{-1}$ |
| Cs | $<5.98\times10^{-2}$ |
| Cu | $<1.70$ |
| Dy | $1.60\times10^{-2} \pm 2.56\times10^{-3}$ |
| Eu | $<1.04\times10^{1}$ |
| Fe | $6.56\times10^{1} \pm 6.60$ |
| Hf | $<5.31\times10^{-2}$ |
| Hg | $<5.73\times10^{-2}$ |
| I | $2.45\times10^{-1} \pm 5.19\times10^{-2}$ |
| K | $3.15\times10^{3} \pm 3.30\times10^{2}$ |
| La | $1.22\times10^{-1} \pm 2.57\times10^{-2}$ |
| Lu | $<3.85\times10^{-3}$ |
| Mg | $1.05\times10^{2} \pm 2.21\times10^{1}$ |
| Mn | $2.13\times10^{-1} \pm 8.41\times10^{-2}$ |
| Mo | $<2.26\times10^{-1}$ |
| Na | $9.60\times10^{2} \pm 1.01\times10^{2}$ |
| Ni | $<2.51\times10^{1}$ |
| Rb | $2.50 \pm 4.56\times10^{-1}$ |
| Ru | $2.04\times10^{2} \pm 4.62\times10^{1}$ |
| Sb | $3.11\times10^{-2} \pm 3.15\times10^{-3}$ |
| Sc | $<2.33\times10^{-3}$ |
| Se | $4.31\times10^{-1} \pm 9.13\times10^{-2}$ |
| Sm | $5.14\times10^{-2} \pm 1.57\times10^{-2}$ |
| Sn | $<2.43$ |
| Sr | $<9.12$ |
| Ta | $<3.38\times10^{-2}$ |
| Te | $<8.74$ |
| Th | $3.78\times10^{-1} \pm 6.14\times10^{-2}$ |
| Ti | $<2.17$ |
| U | $<5.20\times10^{-2}$ |
| V | $3.98\times10^{-2} \pm 8.70\times10^{-3}$ |
| W | $<4.34\times10^{-1}$ |
| Yb | $<3.33\times10^{-2}$ |
| Zn | $1.17\times10^{1} \pm 1.33$ |
| Zr | $<2.49\times10^{1}$ |

## Appendix D

## Trace Element Concentrations in Type B Swine Biopsies as Determined by NAA

| Element | Liver | Brain |
|---|---|---|
| Ag | $<3.45\times10^{-1}$ | $<2.81\times10^{-1}$ |
| Al | $8.95 \pm 2.97$ | $9.60 \pm 1.20$ |
| As | $<9.91\times10^{-2}$ | $<7.43\times10^{-2}$ |
| Au | $<1.03\times10^{-3}$ | $<9.57\times10^{-4}$ |
| Ba | $<3.57$ | $<3.42$ |
| Br | $2.15 \pm 2.20\times10^{-1}$ | $9.47\times10^{-1} \pm 1.21\times10^{-1}$ |
| Ca | $<6.81\times10^{1}$ | $<5.54\times10^{1}$ |
| Cd | $<6.16\times10^{-1}$ | $<5.53\times10^{-1}$ |
| Ce | $<3.65\times10^{-1}$ | $<2.92\times10^{-1}$ |
| Cl | $1.85\times10^{3} \pm 2.00\times10^{2}$ | $1.57\times10^{3} \pm 1.60\times10^{2}$ |
| Co | $1.54\times10^{-1} \pm 3.25\times10^{-2}$ | $1.26\times10^{-1} \pm 1.30\times10^{-2}$ |
| Cr | $<5.16\times10^{-1}$ | $<7.10\times10^{-1}$ |
| Cs | $<7.16\times10^{-2}$ | $<5.81\times10^{-2}$ |
| Cu | $1.73\times10^{1} \pm 4.71$ | $2.02\times10^{1} \pm 3.25$ |
| Dy | $<7.84\times10^{-3}$ | $<7.61\times10^{-3}$ |
| Eu | $<2.69\times10^{-1}$ | $<1.64\times10^{-1}$ |
| Fe | $2.40\times10^{2} \pm 3.30\times10^{1}$ | $3.39\times10^{1} \pm 5.00$ |
| Hf | $<5.94\times10^{-2}$ | $<4.84\times10^{-2}$ |
| Hg | $<4.89\times10^{-2}$ | $<4.19\times10^{-2}$ |
| I | $<1.64\times10^{-1}$ | $<1.35\times10^{-1}$ |
| K | $3.13\times10^{3} \pm 3.20\times10^{2}$ | $3.42\times10^{3} \pm 3.50\times10^{2}$ |
| La | $<4.12\times10^{-2}$ | $<3.57\times10^{-2}$ |
| Lu | $<5.37\times10^{-3}$ | $<5.48\times10^{-3}$ |
| Mg | $<6.10\times10^{1}$ | $<5.03\times10^{1}$ |
| Mn | $1.98 \pm 3.78\times10^{-1}$ | $<3.60\times10^{-1}$ |
| Mo | $3.61\times10^{-1} \pm 5.73\times10^{-2}$ | $<2.00\times10^{-1}$ |
| Na | $1.18\times10^{3} \pm 1.20\times10^{2}$ | $1.27\times10^{3} \pm 1.49\times10^{2}$ |
| Ni | $<3.00\times10^{1}$ | $<2.41\times10^{1}$ |
| Rb | $5.02 \pm 1.10$ | $2.95 \pm 3.88\times10^{-1}$ |
| Ru | $<8.54\times10^{1}$ | $<6.88\times10^{1}$ |
| Sb | $3.05\times10^{-2} \pm 5.48\times10^{-3}$ | $<1.38\times10^{-2}$ |
| Sc | $<2.82\times10^{-3}$ | $<2.27\times10^{-2}$ |
| Se | $<5.97\times10^{-2}$ | $<2.77\times10^{-1}$ |
| Sm | $<7.53\times10^{-3}$ | $<6.55\times10^{-3}$ |
| Sn | $<3.15$ | $<2.60$ |
| Sr | $<1.15\times10^{1}$ | $<9.28$ |
| Ta | $<2.75\times10^{-2}$ | $<2.01\times10^{-2}$ |
| Te | $<1.11\times10^{1}$ | $<8.87$ |
| Th | $<1.67\times10^{-1}$ | $<1.30\times10^{-1}$ |
| Ti | $<2.74$ | $<2.26$ |
| U | $<5.19\times10^{-2}$ | $<4.88\times10^{-2}$ |
| V | $<2.67\times10^{-2}$ | $<2.24\times10^{-2}$ |
| W | $<1.66\times10^{-1}$ | $<1.24\times10^{-1}$ |
| Yb | $<4.71\times10^{-2}$ | $<4.62\times10^{-2}$ |
| Zn | $2.46\times10^{1} \pm 3.20$ | $1.07\times10^{1} \pm 2.21$ |
| Zr | $<2.89\times10^{1}$ | $<2.28\times10^{1}$ |

All concentrations in Appendix D are reported in ppm.

| Element | Heart | Spleen |
|---|---|---|
| Ag | $<2.56\times10^{-1}$ | $<3.71\times10^{-1}$ |
| Al | $5.50 \pm 1.29$ | $1.04\times10^{1} \pm 6.91$ |
| As | $<8.18\times10^{-2}$ | $<2.73\times10^{-1}$ |
| Au | $<9.03\times10^{-4}$ | $<9.74\times10^{-4}$ |
| Ba | $<3.40$ | $<3.29$ |
| Br | $2.06 \pm 2.10\times10^{-1}$ | $2.49 \pm 3.66\times10^{-1}$ |
| Ca | $1.12\times10^{2} \pm 1.41\times10^{1}$ | $<5.70\times10^{1}$ |
| Cd | $<5.40\times10^{-1}$ | $<7.37\times10^{-1}$ |
| Ce | $<3.10\times10^{-1}$ | $<4.07\times10^{-1}$ |
| Cl | $1.20\times10^{3} \pm 1.80\times10^{2}$ | $1.60\times10^{3} \pm 2.00\times10^{2}$ |
| Co | $1.72\times10^{-1} \pm 2.84\times10^{-2}$ | $1.47\times10^{-1} \pm 4.40\times10^{-2}$ |
| Cr | $<4.13\times10^{-1}$ | $<5.33\times10^{-1}$ |
| Cs | $<4.97\times10^{-2}$ | $<7.96\times10^{-2}$ |
| Cu | $<5.69$ | $<1.59$ |
| Dy | $<6.27\times10^{-3}$ | $<6.04\times10^{-3}$ |
| Eu | $<2.29\times10^{-1}$ | $<1.60\times10^{1}$ |
| Fe | $6.97\times10^{1} \pm 7.27$ | $1.73\times10^{3} \pm 3.04\times10^{2}$ |
| Hf | $<4.47\times10^{-2}$ | $<6.05\times10^{-2}$ |
| Hg | $<4.36\times10^{-2}$ | $<6.55\times10^{-2}$ |
| I | $<9.85\times10^{-1}$ | $<1.31\times10^{-1}$ |
| K | $3.23\times10^{3} \pm 3.25\times10^{2}$ | $3.56\times10^{3} \pm 6.50\times10^{2}$ |
| La | $<3.60\times10^{-2}$ | $<7.84\times10^{-2}$ |
| Lu | $<5.10\times10^{-3}$ | $<4.26\times10^{-3}$ |
| Mg | $2.28\times10^{2} \pm 8.28\times10^{1}$ | $2.90\times10^{2} \pm 3.85\times10^{1}$ |
| Mn | $3.14\times10^{-1} \pm 5.20\times10^{-2}$ | $2.52\times10^{-1} \pm 3.61\times10^{-2}$ |
| Mo | $<1.97\times10^{-1}$ | $<2.56\times10^{-1}$ |
| Na | $1.21\times10^{3} \pm 1.20\times10^{2}$ | $9.08\times10^{2} \pm 1.12\times10^{2}$ |
| Ni | $<2.18\times10^{1}$ | $<3.07\times10^{1}$ |
| Rb | $4.00 \pm 1.02$ | $4.36 \pm 1.91$ |
| Ru | $<7.00\times10^{1}$ | $<6.64\times10^{1}$ |
| Sb | $<1.50\times10^{-2}$ | $7.80\times10^{-2} \pm 1.34\times10^{-2}$ |
| Sc | $<1.95\times10^{-3}$ | $<2.93\times10^{-3}$ |
| Se | $<6.35\times10^{-1}$ | $<7.09\times10^{-1}$ |
| Sm | $<6.49\times10^{-3}$ | $1.80\times10^{-2} \pm 2.00\times10^{-3}$ |
| Sn | $<2.60$ | $<2.44$ |
| Sr | $<9.59$ | $<9.11$ |
| Ta | $<2.45\times10^{-2}$ | $<3.48\times10^{-2}$ |
| Te | $<9.28$ | $<8.64$ |
| Th | $<1.28\times10^{-1}$ | $<1.73\times10^{-1}$ |
| Ti | $<2.21$ | $<3.91$ |
| U | $<4.81\times10^{-2}$ | $<5.78\times10^{-2}$ |
| V | $<2.15\times10^{-2}$ | $<2.13\times10^{-2}$ |
| W | $<1.38\times10^{-1}$ | $<5.51\times10^{-1}$ |
| Yb | $<4.21\times10^{-2}$ | $<3.46\times10^{-2}$ |
| Zn | $1.86\times10^{1} \pm 2.95$ | $2.18\times10^{1} \pm 5.65$ |
| Zr | $<2.07\times10^{1}$ | $<2.96\times10^{1}$ |

| Element | Lungs | Kidneys |
|---|---|---|
| Ag | $<2.71\times10^{-1}$ | $<2.21\times10^{-1}$ |
| Al | $3.22 \pm 1.24$ | $5.05 \pm 1.85$ |
| As | $<8.41\times10^{-2}$ | $<9.80\times10^{-2}$ |
| Au | $<1.07\times10^{-3}$ | $3.59\times10^{-3} \pm 3.60\times10^{-4}$ |
| Ba | $<5.07$ | $<5.78$ |
| Br | $3.56 \pm 4.00\times10^{-1}$ | $3.76 \pm 3.80\times10^{-1}$ |
| Ca | $<9.40\times10^{1}$ | $<9.94\times10^{1}$ |
| Cd | $<6.23\times10^{-1}$ | $<6.85\times10^{-1}$ |
| Ce | $<2.75\times10^{-1}$ | $<2.88\times10^{-1}$ |
| Cl | $2.48\times10^{3} \pm 2.50\times10^{2}$ | $2.73\times10^{3} \pm 3.75\times10^{2}$ |
| Co | $1.65\times10^{-1} \pm 5.51\times10^{-2}$ | $1.61\times10^{-1} \pm 1.89\times10^{-2}$ |
| Cr | $<3.54\times10^{-1}$ | $<6.25\times10^{-1}$ |
| Cs | $<4.57\times10^{-2}$ | $<4.87\times10^{-2}$ |
| Cu | $<2.76$ | $<2.93$ |
| Dy | $<1.39\times10^{-2}$ | $<1.07\times10^{-2}$ |
| Eu | $<2.34\times10^{-1}$ | $<2.49\times10^{-1}$ |
| Fe | $3.71\times10^{2} \pm 4.00\times10^{1}$ | $1.71\times10^{2} \pm 5.37\times10^{1}$ |
| Hf | $<3.89\times10^{-2}$ | $<3.98\times10^{-2}$ |
| Hg | $<4.81\times10^{-2}$ | $<5.29\times10^{-2}$ |
| I | $<2.02\times10^{-1}$ | $<2.31\times10^{-1}$ |
| K | $3.50\times10^{3} \pm 3.50\times10^{2}$ | $2.39\times10^{3} \pm 2.40\times10^{2}$ |
| La | $<4.03\times10^{-2}$ | $<4.58\times10^{-2}$ |
| Lu | $<6.13\times10^{-3}$ | $<6.43\times10^{-3}$ |
| Mg | $1.67\times10^{2} \pm 2.82\times10^{1}$ | $<8.42\times10^{1}$ |
| Mn | $<5.42\times10^{-1}$ | $6.70\times10^{-1} \pm 1.17\times10^{-1}$ |
| Mo | $<2.25\times10^{-1}$ | $<2.48\times10^{-1}$ |
| Na | $1.25\times10^{3} \pm 1.25\times10^{2}$ | $1.81\times10^{3} \pm 1.90\times10^{2}$ |
| Ni | $<1.95\times10^{1}$ | $<2.05\times10^{1}$ |
| Rb | $4.55 \pm 7.44\times10^{-1}$ | $3.22 \pm 7.88\times10^{-1}$ |
| Ru | $<1.02\times10^{2}$ | $<1.19\times10^{2}$ |
| Sb | $<1.71\times10^{-2}$ | $<1.93\times10^{-2}$ |
| Sc | $<1.96\times10^{-3}$ | $<1.95\times10^{-3}$ |
| Se | $<2.53\times10^{-1}$ | $8.09\times10^{-1} \pm 2.08\times10^{-1}$ |
| Sm | $<7.27\times10^{-3}$ | $<8.14\times10^{-3}$ |
| Sn | $<3.99$ | $<4.41$ |
| Sr | $<1.41\times10^{1}$ | $<1.64\times10^{1}$ |
| Ta | $<2.48\times10^{-2}$ | $<2.51\times10^{-2}$ |
| Te | $<1.38\times10^{1}$ | $<1.53\times10^{1}$ |
| Th | $<1.61\times10^{-1}$ | $<1.17\times10^{-1}$ |
| Ti | $<3.60$ | $<3.74$ |
| U | $<5.56\times10^{-2}$ | $<6.18\times10^{-2}$ |
| V | $<3.77\times10^{-2}$ | $<3.73\times10^{-2}$ |
| W | $<1.37\times10^{-1}$ | $<1.74\times10^{-1}$ |
| Yb | $<5.20\times10^{-2}$ | $<5.53\times10^{-2}$ |
| Zn | $1.14\times10^{1} \pm 1.20$ | $1.22\times10^{1} \pm 2.86$ |
| Zr | $<1.83\times10^{1}$ | $<1.80\times10^{1}$ |

| Element | Lymph Nodes |
|---|---|
| Ag | $<8.31\times10^{-1}$ |
| Al | $8.04 \pm 3.22$ |
| As | $<1.08\times10^{-1}$ |
| Au | $<6.58\times10^{-3}$ |
| Ba | $<4.72$ |
| Br | $1.87 \pm 5.30\times10^{-1}$ |
| Ca | $3.04\times10^{2} \pm 1.66\times10^{2}$ |
| Cd | $<7.83\times10^{-1}$ |
| Ce | $<4.96\times10^{-1}$ |
| Cl | $1.30\times10^{3} \pm 1.65\times10^{2}$ |
| Co | $2.72\times10^{-1} \pm 4.66\times10^{-2}$ |
| Cr | $<2.79$ |
| Cs | $<8.05\times10^{-2}$ |
| Cu | $1.10\times10^{1} \pm 6.51$ |
| Dy | $<8.67\times10^{-3}$ |
| Eu | $<1.77\times10^{-1}$ |
| Fe | $1.32\times10^{2} \pm 3.76\times10^{1}$ |
| Hf | $<7.05\times10^{-2}$ |
| Hg | $<1.82\times10^{-1}$ |
| I | $5.48 \pm 9.10\times10^{-1}$ |
| K | $1.88\times10^{3} \pm 4.68\times10^{2}$ |
| La | $<5.10\times10^{-2}$ |
| Lu | $<6.37\times10^{-2}$ |
| Mg | $2.36\times10^{2} \pm 2.40\times10^{1}$ |
| Mn | $8.68\times10^{-1} \pm 4.23\times10^{-1}$ |
| Mo | $<2.91\times10^{-1}$ |
| Na | $1.04\times10^{3} \pm 2.63\times10^{2}$ |
| Ni | $<3.03\times10^{1}$ |
| Rb | $3.08 \pm 9.77\times10^{-1}$ |
| Ru | $<8.99\times10^{1}$ |
| Sb | $7.88\times10^{-2} \pm 1.00\times10^{-2}$ |
| Sc | $<3.21\times10^{-3}$ |
| Se | $<4.57\times10^{-1}$ |
| Sm | $<2.14\times10^{-2}$ |
| Sn | $<3.41$ |
| Ar | $<1.23\times10^{1}$ |
| Ta | $<3.98\times10^{-2}$ |
| Te | $<1.12\times10^{1}$ |
| Th | $<2.00\times10^{-1}$ |
| Ti | $<2.94$ |
| U | $<7.09\times10^{-2}$ |
| V | $4.64\times10^{-2} \pm 1.55\times10^{-2}$ |
| W | $<1.78\times10^{-1}$ |
| Yb | $<6.51\times10^{-2}$ |
| Zn | $1.24\times10^{1} \pm 3.89$ |
| Zr | $<3.19\times10^{1}$ |

## Appendix E

## Trace Element Concentrations in Swine Skin Biopsies as Determined by NAA

Left Flank

| Element | Type A | Type B |
|---|---|---|
| Ag | $<9.51\times10^{-2}$ | $<8.42\times10^{-2}$ |
| Al | $1.76\times10^{1} \pm 2.00$ | $6.46 \pm 7.00\times10^{-1}$ |
| As | $<1.09\times10^{-1}$ | $<1.20\times10^{-1}$ |
| Au | $<3.68\times10^{-4}$ | $<4.02\times10^{-4}$ |
| Ba | $<4.09$ | $<4.13$ |
| Br | $2.33 \pm 2.50\times10^{-1}$ | $3.14 \pm 3.50\times10^{-1}$ |
| Ca | $2.91\times10^{2} \pm 3.60\times10^{1}$ | $<7.06\times10^{1}$ |
| Cd | $<2.68\times10^{-1}$ | $<2.92\times10^{-1}$ |
| Ce | $<1.29\times10^{-1}$ | $<1.22\times10^{-1}$ |
| Cl | $2.12\times10^{3} \pm 2.20\times10^{2}$ | $2.18\times10^{3} \pm 2.20\times10^{2}$ |
| Co | $1.15\times10^{-1} \pm 1.25\times10^{-2}$ | NA* |
| Cr | $<1.52\times10^{-1}$ | $<1.49\times10^{-1}$ |
| Cs | $<2.08\times10^{-2}$ | $<2.00\times10^{-2}$ |
| Cu | $<1.84$ | $<1.95$ |
| Dy | $<5.98\times10^{-3}$ | $<5.96\times10^{-3}$ |
| Eu | $<1.10\times10^{1}$ | $<1.38\times10^{1}$ |
| Fe | $<1.68\times10^{1}$ | $3.25\times10^{1} \pm 5.07$ |
| Hf | $<1.64\times10^{-2}$ | $<1.38\times10^{-2}$ |
| Hg | $<2.09\times10^{-2}$ | $<2.26\times10^{-2}$ |
| I | $<1.55\times10^{-1}$ | $9.42\times10^{-1} \pm 1.00\times10^{-1}$ |
| K | $<1.26\times10^{3}$ | $<1.25\times10^{3}$ |
| La | $<2.27\times10^{-2}$ | NA* |
| Lu | $<1.39\times10^{-3}$ | $<1.50\times10^{-3}$ |
| Mg | $<5.51\times10^{1}$ | $<5.65\times10^{1}$ |
| Mn | $1.34 \pm 1.50\times10^{-1}$ | $4.05\times10^{-1} \pm 5.02\times10^{-2}$ |
| Mo | $<8.95\times10^{-2}$ | $<9.74\times10^{-2}$ |
| Na | $1.48\times10^{3} \pm 1.50\times10^{2}$ | $1.34\times10^{3} \pm 1.40\times10^{2}$ |
| Ni | $<8.04$ | $<7.38$ |
| Rb | $1.48 \pm 2.83\times10^{-1}$ | $1.12 \pm 2.47\times10^{-1}$ |
| Ru | $<8.15\times10^{1}$ | $<8.44\times10^{1}$ |
| Sb | NA* | $5.12\times10^{-2} \pm 5.62\times10^{-3}$ |
| Sc | $2.14\times10^{-3} \pm 5.39\times10^{-4}$ | $<9.63\times10^{-4}$ |
| Se | $<1.12\times10^{-1}$ | $1.56\times10^{-1} \pm 4.60\times10^{-2}$ |
| Sm | $1.83\times10^{-2} \pm 2.00\times10^{-3}$ | $1.38\times10^{-2} \pm 2.09\times10^{-3}$ |
| Sn | $<2.98$ | $<3.08$ |
| Sr | $<1.12\times10^{1}$ | $<1.15\times10^{1}$ |
| Ta | NA* | $<1.35\times10^{-2}$ |
| Te | $3.39 \pm 7.46\times10^{-1}$ | $<1.07\times10^{1}$ |
| Th | $<4.91\times10^{-2}$ | $<4.79\times10^{-2}$ |
| Ti | $<2.52$ | $<2.57$ |
| U | $<2.21\times10^{-2}$ | $<2.36\times10^{-2}$ |
| V | $<2.50\times10^{-2}$ | $7.79\times10^{-2} \pm 1.18\times10^{-2}$ |
| W | $<2.16\times10^{-1}$ | $<2.37\times10^{-1}$ |
| Yb | $<1.21\times10^{-2}$ | $<1.28\times10^{-2}$ |
| Zn | $1.08\times10^{1} \pm 1.10$ | $6.19 \pm 6.91\times10^{-1}$ |
| Zr | $<7.87$ | $<7.57$ |

All concentrations in Appendix E are reported in ppm.
*NA--Not Available

Left Flank

| Element | Type C |
|---|---|
| Ag | $<1.13\times10^{-1}$ |
| Al | $3.65\times10^{1} \pm 4.00$ |
| As | $<1.51\times10^{-1}$ |
| Au | $1.14\times10^{-3} \pm 2.48\times10^{-4}$ |
| Ba | $<5.08$ |
| Br | $4.00 \pm 4.00\times10^{-1}$ |
| Ca | $<9.55\times10^{1}$ |
| Cd | $<3.49\times10^{-1}$ |
| Ce | $<1.45\times10^{-1}$ |
| Cl | $2.56\times10^{3} \pm 2.60\times10^{2}$ |
| Co | $1.07\times10^{-1} \pm 1.39\times10^{-2}$ |
| Cr | $1.84 \pm 2.00\times10^{-1}$ |
| Cs | $<2.38\times10^{-2}$ |
| Cu | $7.25 \pm 1.24$ |
| Dy | $<7.98\times10^{-3}$ |
| Eu | $<1.65\times10^{1}$ |
| Fe | $6.74\times10^{1} \pm 6.65$ |
| Hf | $<1.91\times10^{-2}$ |
| Hg | $<2.72\times10^{-2}$ |
| I | $2.30 \pm 2.50\times10^{-1}$ |
| K | $<1.56\times10^{3}$ |
| La | $<3.02\times10^{-1}$ |
| Lu | $<1.74\times10^{-3}$ |
| Mg | $1.67\times10^{2} \pm 3.26\times10^{1}$ |
| Mn | $2.47 \pm 2.50\times10^{-1}$ |
| Mo | $2.96\times10^{-1} \pm 6.14\times10^{-2}$ |
| Na | $2.00\times10^{3} \pm 2.00\times10^{2}$ |
| Ni | $<1.06\times10^{1}$ |
| Rb | $<6.01\times10^{-1}$ |
| Ru | $<1.03\times10^{2}$ |
| Sb | $5.86\times10^{-2} \pm 6.00\times10^{-3}$ |
| Sc | $<1.18\times10^{-3}$ |
| Se | $<1.30\times10^{-1}$ |
| Sm | $1.90\times10^{-2} \pm 2.51\times10^{-3}$ |
| Sn | $9.44 \pm 1.73$ |
| Sr | $<1.38\times10^{1}$ |
| Ta | $<1.30\times10^{-2}$ |
| Te | $<1.32\times10^{1}$ |
| Th | $<5.90\times10^{-2}$ |
| Ti | $<3.24$ |
| U | $<2.79\times10^{-2}$ |
| V | $<3.33\times10^{-2}$ |
| W | $<3.06\times10^{-1}$ |
| Yb | $<1.57\times10^{-2}$ |
| Zn | $2.95\times10^{1} \pm 3.00$ |
| Zr | $<9.43$ |

Abdomen

| Element | Type A | Type B |
|---|---|---|
| Ag | $<2.04\times10^{-1}$ | $<1.05\times10^{-1}$ |
| Al | $1.95\times10^{2} \pm 2.00\times10^{1}$ | $3.07\times10^{1} \pm 3.00$ |
| As | $<2.10\times10^{-1}$ | $<1.42\times10^{-1}$ |
| Au | $<7.21\times10^{-4}$ | $1.01\times10^{-3} \pm 2.48\times10^{-4}$ |
| Ba | $<8.73\times10^{1}$ | $<4.81$ |
| Br | $2.66 \pm 3.00\times10^{-1}$ | $3.62 \pm 4.00\times10^{-1}$ |
| Ca | $<1.89\times10^{3}$ | $<8.22\times10^{1}$ |
| Cd | $<5.56\times10^{-1}$ | $<3.62\times10^{-1}$ |
| Ce | $<2.99\times10^{-1}$ | $<1.43\times10^{-1}$ |
| Cl | $5.69\times10^{4} \pm 6.00\times10^{3}$ | $2.22\times10^{3} \pm 2.00\times10^{2}$ |
| Co | NA* | $1.11\times10^{-1} \pm 1.47\times10^{-2}$ |
| Cr | $<3.60\times10^{-1}$ | $<1.69\times10^{-1}$ |
| Cs | $<4.62\times10^{-2}$ | $<2.21\times10^{-2}$ |
| Cu | $<6.52\times10^{1}$ | $<2.21$ |
| Dy | $<7.12\times10^{-1}$ | $<7.65\times10^{-3}$ |
| Eu | $<1.92\times10^{1}$ | $<1.41\times10^{1}$ |
| Fe | $7.30\times10^{1} \pm 7.00$ | $<1.56\times10^{1}$ |
| Hf | $<3.64\times10^{-2}$ | $<1.61\times10^{-2}$ |
| Hg | $8.92\times10^{-2} \pm 9.00\times10^{-3}$ | $<3.08\times10^{-2}$ |
| I | $<3.62$ | $6.18 \pm 6.00\times10^{-1}$ |
| K | $<1.97\times10^{3}$ | $<1.70\times10^{3}$ |
| La | $<4.34\times10^{-2}$ | $<3.05\times10^{-2}$ |
| Lu | $<3.05\times10^{-3}$ | $<2.02\times10^{-3}$ |
| Mg | $3.38\times10^{3} \pm 3.00\times10^{2}$ | $1.28\times10^{2} \pm 2.68\times10^{1}$ |
| Mn | $<9.71$ | $1.28 \pm 1.14\times10^{-1}$ |
| Mo | $<1.92\times10^{-1}$ | $<1.24\times10^{-1}$ |
| Na | $1.83\times10^{3} \pm 2.00\times10^{2}$ | $1.63\times10^{3} \pm 2.00\times10^{2}$ |
| Ni | $<2.05\times10^{1}$ | $<9.86$ |
| Rb | $<1.26$ | $<5.62\times10^{-1}$ |
| Ru | $<1.79\times10^{3}$ | $<9.47\times10^{1}$ |
| Sb | $2.38\times10^{-1} \pm 2.00\times10^{-2}$ | $4.93\times10^{-2} \pm 5.00\times10^{-3}$ |
| Sc | $5.29\times10^{-3} \pm 5.00\times10^{-4}$ | $<9.23\times10^{-4}$ |
| Se | $<2.61\times10^{-1}$ | $<1.28\times10^{-1}$ |
| Sm | $2.76\times10^{-2} \pm 4.55\times10^{-3}$ | $1.48\times10^{-2} \pm 2.64\times10^{-3}$ |
| Sn | $<8.01\times10^{1}$ | $<3.47$ |
| Sr | $<2.40\times10^{2}$ | $<1.30\times10^{1}$ |
| Ta | $<3.02\times10^{-2}$ | $<1.53\times10^{-2}$ |
| Te | $<2.50\times10^{2}$ | $<1.22\times10^{1}$ |
| Th | $<1.14\times10^{-1}$ | $<5.50\times10^{-2}$ |
| Ti | $<7.94\times10^{1}$ | $9.57 \pm 1.33$ |
| U | $<4.54\times10^{-2}$ | $<2.96\times10^{-2}$ |
| V | $<9.56\times10^{-1}$ | $7.94\times10^{-2} \pm 8.00\times10^{-3}$ |
| W | $<4.14\times10^{-1}$ | $<3.03\times10^{-1}$ |
| Yb | $<2.57\times10^{-2}$ | $<1.71\times10^{-2}$ |
| Zn | $2.52\times10^{1} \pm 2.09$ | $4.23 \pm 6.70\times10^{-1}$ |
| Zr | $<1.83\times10^{1}$ | $<7.60$ |

*NA--Not Available

Abdomen

| Element | Type C |
|---|---|
| Ag | $<1.46\times10^{-1}$ |
| Al | $5.35\times10^{1} \pm 5.00$ |
| As | $4.25\times10^{-1} \pm 8.38\times10^{-2}$ |
| Au | $1.30\times10^{-3} \pm 2.74\times10^{-4}$ |
| Ba | $<5.40$ |
| Br | $3.56 \pm 4.00\times10^{-1}$ |
| Ca | $3.03\times10^{2} \pm 4.83\times10^{1}$ |
| Cd | $<4.31\times10^{-1}$ |
| Ce | $<1.94\times10^{-1}$ |
| Cl | $2.58\times10^{3} \pm 3.00\times10^{2}$ |
| Co | $1.63\times10^{-1} \pm 1.77\times10^{-2}$ |
| Cr | $<2.44\times10^{-1}$ |
| Cs | $<2.81\times10^{-2}$ |
| Cu | $5.44 \pm 1.25$ |
| Dy | $<8.99\times10^{-2}$ |
| Eu | $<1.79\times10^{1}$ |
| Fe | $<1.81\times10^{1}$ |
| Hf | $<2.44\times10^{-2}$ |
| Hg | $5.91\times10^{-2} \pm 1.51\times10^{-2}$ |
| I | $9.24 \pm 9.00\times10^{-1}$ |
| K | $<1.87\times10^{3}$ |
| La | $<3.64\times10^{-2}$ |
| Lu | $<2.37\times10^{-3}$ |
| Mg | $<7.33\times10^{1}$ |
| Mn | $2.02 \pm 1.83\times10^{-1}$ |
| Mo | $<1.53\times10^{-1}$ |
| Na | $1.54\times10^{3} \pm 2.00\times10^{2}$ |
| Ni | $<1.34\times10^{1}$ |
| Rb | $1.34 \pm 4.07\times10^{-1}$ |
| Ru | $<1.07\times10^{2}$ |
| Sb | $9.76\times10^{-2} \pm 1.00\times10^{-2}$ |
| Sc | $<1.62\times10^{-3}$ |
| Se | $<1.72\times10^{-1}$ |
| Sm | $2.23\times10^{-2} \pm 3.24\times10^{-3}$ |
| Sn | $<3.88$ |
| Sr | $<1.46\times10^{1}$ |
| Ta | $<1.97\times10^{-2}$ |
| Te | $<1.41\times10^{1}$ |
| Th | $<7.61\times10^{-2}$ |
| Ti | $1.46\times10^{1} \pm 1.67$ |
| U | $<3.54\times10^{-2}$ |
| V | $<3.48\times10^{-2}$ |
| W | $<3.64\times10^{-1}$ |
| Yb | $2.83\times10^{-2} \pm 6.04\times10^{-3}$ |
| Zn | $1.83\times10^{1} \pm 2.00$ |
| Zr | $1.54\times10^{1} \pm 4.66$ |

## Appendix F

## Trace Element Concentrations in USGS Rock Standards

| Element | BCR-1 | AGV-1 | GSP-1 | G-2 |
|---|---|---|---|---|
| Br | 0.15 | 0.5 | - | 0.3 |
| Ca | 49,400 | 35,000 | 14,400 | 13,900 |
| Cl | 50 | 110 | 300 | 50 |
| Cr | 17.6 | 12.2 | 12.5 | 7 |
| Cu | 18.4 | 59.7 | 30.3 | 11.7 |
| Fe | 94,100 | 47,500 | 30,300 | 18,800 |
| K | 14,100 | 24,000 | 45,900 | 37,400 |
| S | 392 | 10 | 162 | 24 |
| Si | 255,000 | 276,000 | 315,000 | 323,000 |
| Sr | 330 | 657 | 233 | 479 |
| Ti | 13,200 | 6,240 | 4,000 | 3,000 |
| Zn | 120 | 84 | 98 | 85 |

All concentrations reported in ppm.

Data obtained from Descriptions and Analyses of Eight New USGS Rock Standards compiled and edited by F. J. Flanagan, Geological Survey Professional Paper 840, United States Government Printing Office, Washington, DC, 1976.

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TRACE ELEMENT CONCENTRATIONS

IN MELANOTIC SWINE

by

Roseanne Marie Sherman

(ABSTRACT)

It is believed that the presence of certain trace elements in the skin may play an important role in the formation of melanomas. In this work, neutron activation analysis and x-ray fluorescence analysis were used to determine trace element concentrations in cancerous, non-cancerous and normal swine skin samples and in non-cancerous and normal swine tissue samples. In-vivo x-ray fluorescence analysis was also used to determine trace element concentrations in cancerous, non-cancerous, and normal swine skin. Data on forty-eight trace elements in each sample were obtained and correlated. The limited number of cancerous samples made definitive conclusions about trace element imbalances uncertain. Nevertheless, the in-vivo XRFA method was shown to be a very useful method for trace element determination. Additionally, good base line data were obtained for trace element concentrations in a variety of organs of Sinclair miniature swine.