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RADIOMETRIC AGES

OF

SELECTED HAWAIIAN CORALS

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN CHEMISTRY

DECEMBER 1971

Ву

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ABSTRACT

A new scheme for the separation of uranium and thorium from one another and from other interfering ions, especially calcium, aluminum and iron was developed using mixed solvent systems and Biorad AG-1 X8 resin. The complete separation takes place in one column operation after an initial precipitation procedure to reduce the ionic strength of the solution such that it will be soluble in the mixed solvent system.

An automatic elution and fraction collector was developed to further facilitate the ion exchange separation. This allows the entire separation to take place without operator attention after the initial set up. The elution system automatically changes elution reservoirs and controls the liquid level above the resin bed. The fraction collector allows collection in constant time, constant volume and constant number of drops modes and is especially convenient for ion exchange column developmental work. In the constant volume mode, provision is made to collect each elution fraction separately and with an absolute minimum of cross contamination.

These systems were applied to the separation of uranium and thorium from corals from the island of Oahu, Hawaii. Computer programs were developed to load the alpha spectrometric data of these analyses as outputed on Teletype

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8 level ascii code into a computer, plot a graph of the data, total the counts under each peak, and calculate the age of the sample. These resultant ages are discussed as to geologic implication.

DEDICATION

Dedicated to my wife Carol, and my children, whose love, support and faith kept me going through the difficulties encountered in this investigation.

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I. INTRODUCTION

A. Preface

Since the dawn of his existence on the earth, man has had an insatiable curiosity about the world in which he finds himself, and a drive to have dominion over it. In his quest to satisfy his curiosity, such questions as, "Why are there marine fossils in the tops of mountains?", "Why are there terrestrial fossils interbedding these marine fossils?", "How long ago did these events occur?" and "In what order did they occur?" have piqued his curiosity. For many years, answers to these types of questions could be obtained only on a relative basis. More recently, however, methods have been developed which give more absolute answers to these questions. However, the procedures developed thus far have required very laborious and tedious processes. Ιt has been the purpose of this research to improve and simplify these procedures and to make the answers to the above questions more readily available.

B. Historical Review and Background

 Review of Uranium and Thorium Separations from Coralline Materials

In 1956, Barnes <u>et al</u>. (1) demonstrated that the uranium-238 decay series in recent marine corals is systematically out of equilibrium, and that this disequilibrium gives rise to the possibility of determining the absolute age of these materials back to approximately 300,000 years, depending upon the individual sample. This gave rise to a proliferation of methods to isolate the uranium and thorium from these types of materials. Many of these methods have had only isolated use and acceptance, and will not be discussed here. Most of the methods use either a uranium-232 or -237 tracer and a thorium-228 (daughter of the uranium-232) or a thorium 234 tracer to determine the efficiencies of recovery of the respective elements. Most of them utilize an anion exchange separation of the uranium and thorium as an initial stage, followed by subsequent purification of the uranium and thorium either by solvent extraction techniques or anion or cation exchange systems.

The one method which seems to have gained the widest acceptance, with modifications by each worker to suit his needs seems to be that originally used by Barnes <u>et al</u>. and has come to be known as the Sackett method. This consisted of the procedure shown in Figure 1, which is given in detail to illustrate the prolonged and complicated steps that usually are involved in this work. This basic procedure, with minor modifications has been used and reported by Broecker (2), Thurber (3), Thurber <u>et al</u>. (4), Broecker and Thurber (5), Ku (6), Kaufman and Broecker (7), and Richards and Thurber (8).

Koide and Goldberg (9) reported a major modification of Sackett's method which is shown schematically in Figure 2.



fig. I General scheme of Sackett method.



fig. 2. Goldberg and Veeh modifications of Sackett's method.

Veeh reported a further modification upon this, using the method of Hyde (11, 12). This is included in Figure 2.

. Thorium-234 was used as a tracer for this system. Somayajulu and Goldberg (13) reported a variation of Veeh's method using natural sponges containing ferric hydroxide to extract uranium from sea water by towing the sponges. These sponges were then washed with 6 N hydrochloric acid to remove the adsorbed materials and treated for uranium by the method of Koide and Goldberg, and for thorium by the method of Hyde. Another minor variation of this was reported by Moore (14) where the sea water was pumped through a column containing sponges, rather than towing the sponges.

Another method was described by Osmond <u>et al</u>. (15) in which the sample was dissolved in 1 N hydrochloric acid, evaporated to dryness with perchloric acid, thorium and uranium separated on an anion exchanger in 10 N hydrochloric acid, and the uranium further purified by anion exchange in 8 N nitric acid. The thorium was separated from other impurities by anion exchange in 8 N nitric acid and then extracted into TTA in 2N nitric acid. Both elements were then electroplated from ammonium chloride solution.

Miyake <u>et al</u>. (16) described a procedure for separation of uranium from sea water by extraction with CDTA (1, 2cyclohexane-diaminetetraacetic acid) together with Dowex A-1 chelating resin at pH of 3. The uranium was subsequently eluted by 5 N hydrochloric acid.

Lalou and Mabuchi (17) reported a procedure in which the uranium and thorium were separated by anion exchange in 8 N hydrochloric acid, then each fraction was precipitated as iron hydroxide with ammonium hydroxide, filtered, dissolved in 6 N hydrochloric acid, extracted with diethyl ether, evaporated, taken up in concentrated nitric acid and evaporated on a planchet.

Blanchard (18), Blanchard and Oakes (19) and Blanchard <u>et al</u>. (20) reported a procedure in which the uranium was extracted into ethyl acetate from a nitric acid solution saturated with aluminum nitrate, the ethyl nitrate evaporated, the uranium taken up in nitric acid, fused with a flux and determined fluorometrically. A portion of this is then treated for α -spectrometry.

Two Japanese workers, Komura and Sakanoue (21), reported another procedure. They dissolved their samples in 6 N nitric acid and 0.5 N hydrofluoric acid solution, filtered, precipitated with ammonia gas, dissolved in 6 N hydrochloric acid or concentrated nitric and perchloric acids to dryness to remove organics, redissolved in 1 N hydrochloric acid, precipitated with ammonia gas, dissolved in 0.5 N oxalic acid and passed through an anion exchange resin. Thorium was eluted with 8 N hydrochloric acid and uranium with 6 N hydrochloric and 1 N perchloric acid solution. The uranium eluate was evaporated, taken up in 8 N hydrochloric acid and extracted with TIOA (Tri-iso-octyl amine) two times, washed two times with 8 N hydrochloric acid and stripped into 0.1 N hydrochloric acid. The thorium eluate was evaporated with concentrated nitric and perchloric acids to destroy the oxalic acid, taken up in 3 N hydrochloric acid and treated according to the method of Hyde previously described. Both thorium and uranium were electroplated.

Tatsumoto and Goldberg (22) reported using the method of Fisher and Kunin (23) for the isolation of uranium and thorium from calcareous materials and from manganese nodules. This method used 6% sulfurous acid in sulfuric acid adjusted to pH 1.0-1.5 with sodium hydroxide. Uranium was sorbed onto an anion exchange resin in the sulfate form. Undesired elements were removed from the column by washing with 0.1 M sodium sulfate containing 6% sulfurous acid, then with hot water. The uranium was eleuted with 1 M perchloric acid. The thorium was treated as previously described by Goldberg and Koide (24).

2. Deficiencies of Previous Methods

All of the above methods suffer from several deficiencies. First, there are a confusing variety of methods, all very complicated and involving many different critical steps. From the nature of the processes involved, it was believed that these deficiencies could be removed or reduced in number by the application of the right chemistry. Second, many of the methods involve either the use of chemicals not commonly available, or chemicals that are not

particularly desirable to work with. This in itself is not a condemnation of a method, but where it can be avoided by procedural changes, the newer method becomes preferable. Third, many of the methods require the meticulous adjustment of solution conditions, i.e., adjustment of pH for extraction, retention on the resin, or elution from the resin, careful evaporation, etc. Again, this in and of itself is not a condemnation of any method, but it would be preferable if it could be avoided. Fourth, none of these methods has a well defined one- or two-step procedure for isolating the uranium and thorium from each other and from other interfering elements.

3. Review of the Nature of the Problem under Investigation

A restatement of the purpose of this research will be helpful. The original intention of this research was to develop a less complicated method for isolation of uranium and thorium from each other and from other interfering ions from coralline materials. This would be tested in dating various exposed reefs found in the Hawaiian Islands. Additionally, since thorium-uranium ages are usable only back to about 300,000 years, and uranium-uranium ages are approximate and valid only to about 700,000 to 800,000 years, an attempt also was to be made to approach the late Pleistocene ages from the far end by the use of potassiumargon age dating techniques. This will be more thoroughly discussed later. As an adjunct to this, the possibility of uranium-helium age dating was examined later.

A 1951 quarterly of the Colorado School of Mines (25, no author listed) reported that in madreporarian corals the tabulae and dissepiments are formed of parallel crystals growing at right angles to the surface, and in the septa they form prismatic or cylindrical columns of tiny fibers radiating from the central axis. Clarke and Wheeler (26) gave analyses for thirty madreporarian corals from widely separated areas, all of them having remarkably similar compositions, being essentially 100% calcium carbonate, with magnesium carbonate, silica, calcium sesquiphosphate, ironaluminum oxides, and calcium sulfate all being less than 1%. They also reported that most warm shallow water corals are aragonitic, whereas those from the colder deeper seas tend to be calcitic. Thus, we are working mainly with aragonitic corals, and the problem reduces to the separation of uranium and thorium from each other and from calcium, magnesium, iron and aluminum. Most other metal ions generally will be absent.

It was initially decided that ion exchange techniques would give the most efficient and least time consuming procedure. Consequently, solvent extraction techniques were not investigated and will not be reviewed here.

4. Review of Literature on Ion-Exchange Separations

for Uranium, Thorium, Calcium, Iron and Aluminum There are a number of excellent treatises on ion exchange (27, 28, 29, 30) which give in-depth coverage to nearly all aspects of the topic. Consequently, the general points pertinent to an understanding of this work need not be reviewed here. The discussion of the essential points will be found in Helfferich (27).

A large amount of work has been done in the field of ion-exchange, particularly in the purification of uranium compounds due to its importance to the field of nuclear science. No attempt will be made to review all of this work. Only that work which seems particularly important to the purpose of this research will be discussed. The discussion will be divided into two main categories: a) work done with cation exchangers, and b) work done with anion exchangers.

a) Work done with cation exchangers. Korkisch and co-workers reported several schemes for the separation of uranium and thorium from each other and from selected other elements (31, 32, 33). They used Dowex 50W -X8 cation resin with mixed solvent systems, e.g., systems of aliphatic alcohols with mineral acids and complexing agents. They studied the effects of chain length, system pH, percent composition, and complexants, and present particular schemes for the separation of uranium from thorium in alcohol-nitric

acid systems, uranium from bismuth in an isopropyl alcoholhydrochloric acid system, and uranium and thorium from the rare earths in a methyl alcohol-nitric acid-trioctylphosphine oxide system.

Kraus and co-workers have done considerable work in an attempt to develop a general ion exchange analysis scheme using Dowex 50W -X8 and mineral acid systems. His results were summarized in the form of a periodic chart of graphs, plotting in a very interesting way the logarithm of the distribution coefficient as the ordinate versus molarity of the mineral acid as the abscisa (34, 35, 26). Only a few of their references have been mentioned here, and only their work relative to the elements important to this study will be discussed. Since iron presents the most problematic separation, discussion will be centered around this element.

In hydrochloric acid systems, iron shows a minimum distribution coefficient (K_d) of 0 at about 4 molar acid concentration. This of course is ideal, since it means there is no retention by the exchanger and the iron will move through the column as fast as the flow rate of the solvent system. Calcium and aluminum also show very low K_d 's at this concentration. However, the uranium shows a K_d of less than 10 at this concentration, indicating that very poor if any separation would be achieved. Good separation could be achieved of these elements from thorium, however, since thorium has a K_d of about 10³ at this

concentration. In perchloric acid systems, iron has a minimum of about 10 at 4 molar concentration, with calcium and aluminum being below this. Uranium has a K_d of a little over 10 at this concentration, and thorium is over 10⁴. Again, very poor separation would be achieved between uranium and the other elements, although good separation could be obtained between uranium and thorium. They reported a procedure for purifying microgram amounts of thorium-234 from hundred gram amounts of uranyl nitrate using hydrochloric-hydrofluoric acid systems. It was felt, however, that it would be desirable to avoid this system due to the problems of working with hydrofluoric acid.

Strelow <u>et al</u>. have investigated nitric and sulphuric acid systems (37). Here again, the distribution coefficients are such that good separations could be obtained between uranium and iron, or uranium and thorium, or iron and thorium, but not all three separately from each other and from calcium and aluminum. Strelow does in fact report a procedure for the separation of thorium from low grade ores (38). Many others have investigated mineral acid systems (39, 40, 41) for the ions investigated here, but with results similar to those reported above.

b) Work done with anion exchangers. A survey of the anion exchange literature gives much more promise of success. By far the most work in this area seems to have been done by Korkisch and his co-workers. Together they

have over twenty-five papers involving separations of uranium and thorium from each other and from other metal ions. Their work seemed to have concentrated quite heavily upon mixed solvent systems involving organic solvents of various types and various mineral and organic acids, sometimes using complexants to improve the separation. All of this work will not be reviewed here, but only those papers presenting summaries, and those presenting data important for this work will be discussed.

Korkisch and Janauer (42) reported in a summary of a number of previous papers, detailed descriptions of the adsorption behavior of uranium and thorium in aliphatic alcohol-mineral acid solutions on Dowex 1 -X8 anion resin. They examined the aliphatic homologs from methyl to isoamyl alcohol in hydrochloric, nitric and sulphuric acids, and investigated the effect of chain length, acid normality, dielectric constant and percent alcohol composition. In all cases, the adsorption of both elements increased markedly with an increase of alcohol concentration. This is explained on the basis of increased tendency to form neutral or anionic complexes which can then enter the resin matrix and undergo sorption, enter into further complexation to be exchanged, or be exchanged directly if already anionic. The distribution coefficient increased with increasing chain length for uranium in hydrochloric and nitric acid systems, but had no effect in the sulphuric acid system. For

thorium, the distribution coefficient increased for the hydrochloric, decreased for the nitric and had no effect for the sulfuric acid systems with a change in chain length. The effect of dielectric constant was similar to the effect of chain length as would be expected. Increasing overall acid normality caused an increase in the distribution coefficient in nearly all cases for the hydrochloric and nitric acid systems, but a decrease in the sulphuric acid system. This is explained by the formation of neutral complexes of higher order, equivalent to hydrolysis of the thorium. A number of procedures are described for the separation of uranium and thorium based upon these investigations. As given, none of them are applicable to the separations desired in this work. Korkisch and Hazan (43) reported an investigation into systems involving hydrochloric acid and twelve organic solvents, namely, methyl alcohol through isobutyl alcohol, acetone, tetrahydrofuran, methyl and ethyl glycols, formic and acetic acids. The data were presented in the form of graphs with the distribution coefficient as the ordinate, and the various elements investigated as the abscisca, these being arranged by chemical group. The data will not be discussed in detail, but can be summarized as follows: In most of the systems investigated, the uranium distribution coefficient was near or above 10^3 whereas the thorium distribution coefficient was near or below 100. In those cases that were

favorable to the separation of iron, aluminum and calcium from the uranium and thorium, the thorium distribution coefficient was so low that it also would have been separated. Korkisch and Urubay (44) reported an investigation of formic, acetic, mono-, di-, and trichloroacetic and propionic acids with methyl through isobutyl alcohol, acetone and dioxane. For the conditions selected, similar results were obtained to those when using the mineral acids, i.e., hydrochloric, nitric and sulphuric acids, with these same solvents. Although no data was presented for thorium, the data presented for copper and lanthanum would indicate that thorium might hydrolize in many of these systems. Urubay et al. (45) reported investigations of hydrochloric and nitric acids with diethyl, di-isopropyl, and dioxane ethers. The distribution coefficients reported are such that good separation of uranium from thorium, iron and aluminum could be obtained, but not uranium and thorium from the others. Korkisch and Hazan (46) reported investigating oxalic malonic, succinic, glutaric, d, 1-tartaric and citric acids in methanol and water systems. Again, no combinations appeared which allowed separation of uranium and thorium from iron, calcium and aluminum, and in several of the systems, thorium hydrolized. Hazan and Korkisch (47) investigated thirteen different systems involving 5% formic or acetic and 95% various organic solvents with uranium and the lanthanides. Their results indicate very high

distribution coefficients with formic and acetic in these systems, but very low values (0.1) for the lanthanides. However, thorium hydrolyzes in these systems and, therefore, they are not applicable for this investigation. Korkisch and Arrhenius (48) reported a system involving 90% glacial acetic acid and 10% 5 N nitric acid in which uranium and thorium are retained on the exchanger, but iron, calcium and aluminum are not retained. Formic and propionic acids were also investigated, but found unsuitable.

Complexants sometimes can be very useful in effecting a separation that cannot otherwise be accomplished, as mentioned above. Huff and Kulpa (49) reported an investigation of 95% tri (2-ethylhexyl) phophate (TEHP) and 5% di (2-ethylhexyl) hydrogen phosphate (HDEHP) adsorbed onto Plaskon, type CTFE 2300. (A trifluorochloroethylene polymer) This was followed by a layer of anion exchanger. This gave good separations for plutonium, ziconium and uranium. Korkisch et al. (50) reported a modification of the extraction process using saturated ammonium nitrate, adapting it to column elution with good success in separating uranium from thorium and a number of other elements. Korkisch et al. (51, 52) reported using ascorbic acid to reduce and complex the iron in several hydrochloric acid methanol systems in order to separate iron from uranium. If ethers extract iron and alcohols enhance sorption of uranium and thorium, then glycols should be

effective in accomplishing both tasks at the same time. Korkisch and Hazan (53) reported investigations using methyl and ethyl glycols in hydrochloric acid systems. Separation of uranium from even gram amounts of iron are reported. Νo data for thorium are reported, however. Morie and Sweet (54) investigated the separation of iron (II) from iron (III) using a tartrate medium with very good success. Α large number of other investigators have examined separations involving one or more of the elements uranium, thorium iron, calcium and aluminum, a few of which are listed (55, 56, 57, 58, 59). In summary, it appears from the literature review that several reported procedures could be used in the separation of the iron, calcium and aluminum from the uranium and thorium, i.e., the 90% glacial acetic acid 10% 5 N nitric acid system reported by Korkisch and Arrhenius (48), the glycol-hydrochloric acid system reported by Korkisch and Hazan (53) and the methanol-hydrochloric acidascorbic acid systems reported by Korkisch et al. (51, 52). Separation of the uranium and thorium could then be achieved by switching to a different solvent system such as that reported by Korkisch and Janauer (42) consisting of alcoholnitric or -hydrochloric acid systems.

5. Review of Literature on Uranium-Thorium and Uranium-Uranium Dating Methods

In 1908, Joly (60) observed what appeared to be an excess of radium-226 in deep sea sediments and near bottom

ocean waters. Pettersson (61) proposed to explain this as the result of the decay of thorium-230 deposited in the sediments and originating from uranium in the oceans. In 1958, Sackett et al. (62) reported that thorium-230 in the ocean was less than 0.6% of the equilibrium amount, and probably even as low as 0.1%. In 1956, as mentioned previously, Barnes et al. (1) reported the possibility of dating coralline materials based on the disequilibrium between uranium and thorium in recent skeletons, and the observed regrowth towards equilibrium with time. Further investigations by Sackett (63) and Tatsumoto and Goldberg (22) indicated that the method was valid only for certain samples, the criterion of choice for which was then not yet understood, but at least required unrecrystallized corals. An extensive investigation by Broecker (2) to evaluate the possibility of determining the age of marine carbonates from their radium-226 to uranium-238 ratio proved futile, but did point out a few more useful criteria for determining valid samples. Based on the assumption that the system has remained closed, the results of recent and fossil investigations by Thurber et al. (4) indicate the following criteria for the selection of valid samples for dating by the thorium-uranium method:

a) The sample should contain less than a few percent calcite. Coral, as previously discussed, is deposited as pure aragonite, therefore, any calcite present would

indicate a violation of the close system assumption.

b) Sample uranium content should be about 2 to 3 ppm. Recrystallized corals are frequently lower than this value, and other empirical evidence (2, 64, 65) indicates that the ratio of uranium to calcium in corals is the same as that in sea water, and that this has not changed during Pleistocene times.

c) The uranium-234 to uranium-238 ratio corrected for age should be 1.15 \pm 0.03. This will be more thoroughly discussed later.

d) The radium-226 to thorium-230 ratio should be consistent with the age of the sample. Departure of the measured ratio from the predicted value indicates an open system within the last 7000 years. Chemical alternation occurring earlier than this will leave no record on this ratio.

e) The thorium-230 to thorium-232 ratio in the sample should exceed 20. (Preferably there should be no thorium-232 at all.) The presence of thorium-232 in corals is evidence of secondary addition.

f) The thorium-230 uranium-234 ages should be consistent with stratigraphic data. Concurrent and subsequent work by other investigators has confirmed these criteria (15, 19, 5, 18, 7, 8, 11).

An assumption made initially in several methods of radio-age dating involving uranium or its daughter products,

was that the uranium-234 was in equilibrium with its parent uranium-238. However, in 1955 Cherdyntsev (66) reported ratios greater than one in secondary minerals, and excess uranium-234 in leach solutions of uranium bearing minerals. This work was confirmed by others (67, 68, 69) who found not only excess uranium-234 in secondary minerals, but deficiencies in very weathered primary minerals. In 1962 Thurber (70) found a 15% excess of uranium-234 in recently formed marine carbonates, and suggested the possibility of using this as an additional method for age dating marine samples of carbonate composition, e.g., bottom sediments, corals, etc. Ku (6) studied this extensively with respect to bottom sediments and found that they do not form a closed system, i.e., post depositional migration of the uranium-234 in the sedimentary column occurs. Based on these studies, he suggested that a sizable amount of the excess uranium-234 in the sea must originate by diffusion from the bottom sediments. Rosholf et al. (71), however, present an argument for the origin of this excess to preferential leaching of uranium-234 due to the Szilard-Chalmers process. Blanchard (18) studied the uranium-234 to uranium-238 ratios in coastal marine waters and calcium carbonates and determined that all water samples, regardless of salinity or total uranium content, have a ratio of 1.15. This same ratio was found in all of the shells examined except two, which were collected in an estuary where they had been

exposed to fresh water silt. Koide and Goldberg (9) examined this ratio in sea waters collected from many places over the world, and at various depths, with the conclusion that an average value of 1.14 ± 0.014 was found. No variation was apparent within experimental error. However, Miyake et al. (16) found this ratio to vary from 1.05 to 1.20 for waters from the western North Pacific. Somayajulu and Goldberg (13) studied this ratio again, along with the ratio of thorium-230 to thorium-232 and thorium-228 to thorium-232 in sea water and bottom sediments of the Pacific Ocean. They found no significant variation over that which they observed before, and additionally determined that the thorium concentration in sea water was of the order of n x 10^{-10} g/1. This gives additional support for the assumption in the thorium-uranium method that no thorium is deposited with the coral. Several investigators have used this 15% uranium-234 excess to date marine coralline materials with apparently good results (4, 11).

6. Derivation of Pertinent Equations

The solution for the general differential equation describing the decay of parent and the growth and decay of daughter in a system where both parent and daughter are radioactive is given in several texts, (72, 73) and will not be presented here. However, the application of this solution to calculating the age of a sample given present activities

of daughter and parent is important to a complete understanding of this method, and will be derived. As the coral is deposited, disequilibrium between the uranium and daughter thorium-230 is established, there being no thorium deposited in the coral. With this assumption, the solution for the Bateman equation for this system takes the form of

$$N_{Th230} = \frac{\lambda_{U234}}{\lambda_{Th230} - \lambda_{U234}} N_{U234}^{0} (e^{-\lambda}U234^{t} - e^{-\lambda}Th230^{t})$$
(1)

where N represents the number of atoms at some time t and N^0 the initial number of atoms. The observed activity can be related to the number of atoms by the expression

 $A = c\lambda N$ or $N = A/c\lambda$

where A is the observed activity (in cpm) and c is the detection coefficient. Since all of the emanations we are dealing with here are alphas, the detection coefficients can be assumed equal. The expression then converts to

$$\frac{A_{Th230}}{\lambda_{Th230}} = \frac{\lambda_{U234}}{\lambda_{Th230} - \lambda_{U234}} \times \frac{A_{U234}^{0}}{\lambda_{U234}} (e^{-\lambda}U234^{t} - e^{-\lambda}Th230^{t})$$
(2)

This can now be divided by A_{U238}/λ_{U238} to get the ratio that is useful in calculating the age of the sample. Doing this, and dividing by λ_{U238} and multiplying by λ_{Th230} to obtain the simple ratio on the left hand side of the equation gives

$$\frac{A_{\rm Th230}}{A_{\rm U238}} = \frac{\lambda_{\rm Th230}}{\lambda_{\rm Th230} - \lambda_{\rm U234}} \times \frac{A_{\rm U234}^{0} (e^{-\lambda}U_{\rm U234}^{t} - e^{-\lambda}Th_{\rm U230}^{t}}{A_{\rm U238}^{0} e^{-\lambda}U_{\rm U238}^{t}}$$
(3)

This expression gives the exact relationship between the variables. However, in practical application, the initial uranium activities are not available to us. Therefore, approximations become necessary. This is best accomplished by looking at two different cases. That where thorium-230 is being generated by the two uranium isotopes in equilibrium with each other, and that where the excess uranium-234 is generating thorium-230 by decay only.

In the equilibrium case, since the decay constant for uranium-238 is very much smaller than that for uranium-234, the situation known as transient equilibrium obtains, and the whole system decays with the half life of the parent, i.e., uranium-234 appears to have the same half life as uranium-238, and λ_{U238} may be substituted for λ_{U234} in the above equation. But since the decay constant of uranium-238 is so small, then $e^{-\lambda}U238^{t}$ approaches one for the times under consideration here. Lastly, since we have taken the equilibrium case, then the ratio of the uranium activities must be equal to 1 by definition. Incorporating these into equation (3) results in

$$\frac{A_{Th230}}{A_{U238}} = 1 - e^{-\lambda} Th230^{t}$$
(4)

This expression can be explicitly solved for t to give

$$t = \frac{-1}{\lambda_{\rm Th}^2 230} \ln \left(1 - \frac{A_{\rm Th}^2 230}{A_{\rm U}^2 238}\right)$$
(5)

where the negative sign with the numerator is inserted to give a positive value to the age.

For the case of the decay of the excess, the amount of excess is rigorously given by

$$A_{U234} ex. = A_{U234}^{0} - A_{U238}^{0}$$
 (6)

But, the initial activities of the uranium are not known. However, evidence presented above indicates that for marine samples, this initial excess is of the order of 0.15. Additionally, for the times involved here, the uranium-238 has had essentially no change in its activity, due to its very long half life. Consequently, the present uranium-238 activity can be substituted for the initial activity. Incorporating these into equation (3) results in

$$\frac{{}^{A}\text{Th}230}{{}^{A}\text{U}238} = \frac{{}^{\Lambda}\text{Th}230}{{}^{\lambda}\text{Th}230} \frac{\text{x}}{{}^{\lambda}\text{U}234} = \frac{0.15}{{}^{A}\text{U}234} \left(e^{-\lambda}\text{U}234^{t} - e^{-\lambda}\text{Th}230^{t}\right)$$
(7)

which represents the thorium-230 contribution to the ratio from uranium-234 in excess of the equilibrium amount. Thus, the total thorium-230 generated, and the ratio of the activities, will be given by the sum of equation (4) and (7) as
$$\frac{A_{\text{Th}230}}{A_{\text{U}238}} = (1 - e^{-\lambda} \text{Th}230^{\text{t}}) + (\frac{\lambda_{\text{Th}230}}{\lambda_{\text{Th}230}^{-\lambda} \text{U}234})$$

$$\times \frac{0.15}{A_{\text{U}238}} (e^{-\lambda} \text{U}234^{\text{t}} - e^{-\lambda} \text{Th}230^{\text{t}})$$
(8)

This expression cannot be explicitly solved for t, and thus one either obtains the age from a graph of the equation such as that given by Thurber (3) or one uses an iterative technique with computers. In this work, iterative solutions are obtained and checked against the graph cited above.

The above equation was derived using the uranium-238 as the comparator, and is evaluated assuming an initial 15% uranium-234 excess. This was felt by some to be too arbitrary, and not applicable to non-oceanic systems. To alleviate this, Kaufman and Broecker (7) derived an additional equation in which the excess correction is made in terms of the present uranium-234 activity, and is given as follows:

$$\frac{A_{Th230}}{A_{U234}} = \frac{A_{U238}}{A_{U234}} (1 - e^{-\lambda}Th230^{t}) + (1 - \frac{A_{U238}}{A_{U234}})$$

$$\left(\frac{\lambda_{\text{Th}230}}{\lambda_{\text{Th}230} - \lambda_{\text{U}234}}\right) (1 - e^{-(\lambda_{\text{Th}230} - \lambda_{\text{U}234})t})$$

This can be derived from the Bateman equation discussed previously, using the same assumptions and approximations, but by substituting

$$A_{U234}^{0} = \frac{A_{U234}}{e^{-\lambda_{U234}t}}$$

and by multiplying the whole equation through by A_{U238}/A_{U234} . Again, this equation cannot be solved explicitly for t, and must be converged upon iteratively. However, this assumes no arbitrary initial uranium-234 excess, and thus would not bias the determined age.

7. Review of Mass Spectrometer Principles and

Applications

Probably the earliest investigation of uranium-helium ratios in carbonate materials was by Fanale and Kulp (80) who investigated helium in limestone and marble, and observed that the limestone had less than the expected amount of helium. They attributed this to the uranium being external to the lattice. This conclusion is also born out in results of other studies of calcitic limestones (2, 7, 20). However, they found greater than expected amounts in the marble, and attributed this to the presence of gaseous inclusions within these materials.

Fanale and Schaeffer (81) investigated uranium-helium ratios for Pleistocene and Tertiary fossil aragonites with quite good success, finding that the helium geochronometer appears to yield reliable minimum ages when used in conjunction with other isotopic and geologic information. They conclude that in the absence of recrystallization, the helium content of aragonitic materials is equal to their total alpha-flux since their formation, for at least back to 10 million years, and that no significant helium is contributed to the total reservoir by primary helium present at the time of deposition of the skeleton.

Turekian <u>et al</u>. (82) investigated bones of Oligocene and Pleistocene or Pliocene age for their uranium-helium ratios and concluded that the dating of fossil bones or other apatite deposits was not possible due to the apparent continuous loss of helium from the samples.

These studies would indicate that at least for carbonate materials, only aragonitic carbonates would be suitable for uranium-helium dating.

II. EXPERIMENTAL WORK

A. Description of Instrumentation

1. Automatic Elution and Fraction Collector System

Early in this work, it was found that a comparative characterization of the various systems under investigation was a very tedious process, involving drop counting, catching successive small volumes, collecting for successive constant time periods, etc. To alleviate this tedious labor, an automatic system was constructed (see Fig. 3) which was unique with features not found in any commercially available system. This consists of six solvent reservoirs each feeding into a common catchment through glass solenoid operated valves. The ion exchange column immediately follows this catchment with a small reservoir above the resin. At two levels along this reservoir are placed two photocell sensors. The upper sensor controls the solvent level within the column reservoir by opening the "on" switched glass solenoid valve when the liquid level drops below the sensor level. Thus, the liquid level above the resin column remains relatively constant until the feed reservoir becomes emptied. The liquid level then drops to below the second photocell sensor, which switches to the next solvent reservoir solenoid valve. This fills the column reservoir to the first photocell sensor level, and continues oscillating about this level until the feed





reservoirs are all emptied, at which time the second photocell turns the entire instrument off.

The column effluent can be handled in a number of ways. In the drop counting mode, a photo-cell sensor is placed just below the tip of the column and the counter set for the desired number of drops between 2 and 99. Collection planchets are placed on the fraction collector table. This table then rotates bringing a fresh collection planchet under the column outlet after the preset number of drops have been collected. In the constant time mode, the turntable rotates at any present time which is an evenly divisible multiple of 60, i.e., 30 seconds, 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, 30 and 60 minutes. In the constant volume mode, the effluent may either be collected directly into collection tubes placed in the fraction collector table, or collected into a separate reservoir which rotates the table and dumps the collected liquid into a collection tube at the preset volume. In the first instance, the volume is controlled by a photo-cell sensor placed at the desired volume level on the collection tube (see Fig. 3), the turntable being activated when the liquid level reaches this photo-cell sensor. In the second instance, the volume is controlled by the placement of a thermistor at the proper level in the collection reservoir (see Fig. 4). In either case, whenever the lower photo-cell switches to a new reservoir, these systems are activated to collect anew.



fig. 4 thermistor actuated constant volume reservoir.

This instrument has several unique features. No commercial unit examined has the ability to control the elution solution level, nor to change elution solutions automatically. Similarly, no commercial unit examined has the ability to dispense the effluent directly into individual collection tubes and control the solution level within these tubes. All units examined dispense the effluents into a collection reservoir which then dumps a preset volume into the collection tubes. This allows cross contamination from one fraction to another. The incorporation of the unique features of this system allows it to be set up initially and operate entirely unattended for the whole separation with an absolute minimum of cross contamination of effluents. Those developments which are unique to this system will be described in more detail whereas those common to most systems will be briefly reviewed in Appendix A accompanied by their schematics.

The schematic for the automatic elution system is given in Figure 5. Symbols are defined as follows: A is a bridge rectified RC filtered 12 V power supply for photocells 1 and 2 amplifier circuits and lamps. B is a set of 110 V auxiliary outlets. F is a 1 ampere fuse. FSS is a pair of female banana outlets for a solenoid valve to be added at the effluent of the column to shut off the column flow when the power is shut off. (This is a supplemental device and need not be used unless desired.) PC 1 and PC 2











FIG. 7 PHOTO CELL 2 SCHEMATIC

are normally open relays activated by the photo-cell circuits to enable the glass solenoid valves or the reservoir selection switch to operate. MA is a pushbutton to manually activate PC 2 relay in order to manually advance the reservoir selection switch. R is a pushbutton to manually reset the reservoir selection switch to position 1. This also closes SS solenoid. RSS is the reservoir selection switch. SS is the shut-off switch and solenoid, automatically activated as the reservoir selection switch is cycled into 7th position. T is a 12 V 1 ampere power transformer. TS is a microswitch attached to the turntable to automatically shut down the system if a number of collection tubes are exceeded. V1 through V6 are the solenoids which open the reservoir glass valves. The backto-back diodes associated with these solenoids were necessary to reduce inductance interferences with the sensitive drop counting circuit.

As can be seen from the schematic and the above discussion, when the liquid level in the column reservoir activates photo-cell 1, PC 1 relay enables the RSS "on" switched solenoid, opening the valve to that particular reservoir until the photo-cell circuit is disabled by the rising liquid level. This cycle is repeated until photocell 2 is activated, enabling the relay of RSS to switch to the next setting, activating a new solenoid valve and thus allowing a new reservoir to be tapped. As RSS reaches

position 7, SS solenoid is activated, opening the normally closed SS switch and shutting off power to the circuits. The circuit for photo-cell 2 differs from that of photocell 1 in that there is a time delay before activation in photo-cell circuit 2 (see Figs. 6 and 7). This is a variable delay inserted to allow the liquid level above the column resin to drain near the resin level. The photo-cell sensor itself cannot be placed at this level because as the new solution enters the column, some resin is stirred up, which clamps the circuit from disabling. Photo-cell circuit 2 is better stabilized than photo-cell circuit 1, and also causes turntable rotation when PC 2 relay is activated, resulting in a fresh collection site for the new elution solution. The remainder of the circuitry is discussed in Appendix A.

The solenoids used to enable the reservoir glass valves were similar to those found in any automatic washing machine. These were dismantled, bored out with 7/64" bit, and mounted on a support in the configuration shown in Figure 8. This configuration was chosen such that six - 125 ml separatory funnels could be utilized in a minimum of space. An analogous mount was constructed to support the separatory funnels immediately above the solenoid valve support. The six inlets to the common catchment were also constructed in this same configuration. The glass valves were constructed according to Figure 4.



FIG. 8 RESERVOIR and VALVE CONFIGURATION.



FIG. 9ª TOP VIEW, TURNTABLE ASSEMBLY.



FIG. 96 SIDE VIEW, TURNTABLE ASSEMBLY.

Since each glass valve proved to be just a little different, and since each solenoid also was just a little different, it was necessary to have a short section of tygon tubing between the bottom of each valve, and the ball and socket connection of the catchment in order to be able to adjust the position of the valve within the solenoid for best operation.

It was found necessary to use screw locked clamps for the ball and socket joints as the system was operated under a positive pressure to control the flow rate through the column to the desired value. These were constructed from regular spring action No. 12 ball and socket clamps in which a hole was drilled through one of the handles and a No. 10 brass nut soldered over this hole. In this way, a No. 10 stainless steel screw could be used to positively lock the clamps after they had been applied to the ball and socket joints.

The fraction collector turntable was constructed according to Figure 9. There are three rows of 30 collection sites, each site consisting of a recessed hole 1-inch in diameter and 0.1 inch in depth, and a hole 0.75 inches in diameter centered in the above recess and all the way through the 0.5 inch thick Micarta. Thus, each collection site can hold a 1-inch planchett, or a 2 x 15 cm collection tube. (Volume about 25 ml.) When it was necessary to use more than 30 collection sites, guides were placed on the

table and a movable funnel placed under the column such that the column effluent could be directed into the second row of collection sites after completion of the first, and into the third after completion of the second.

The symbols in Figure 9 are defined as follows: A is a microswitch to properly position the turntable. The turntable requires 5 seconds to rotate from one position to Three seconds of this time are under the control the next. of the electronics. This enables the roller of the microswitch to ride out of the driving gear notch in which it normally sits, turning on the microswitch. The turntable continues to rotate after the electronics have shut off until it is properly positioned by the roller of the microswitch dropping into the driving gear notch, thus turning off the microswitch. B is a locking solenoid and plunger. As the turntable is activated, this solenoid is activated, withdrawing the plunger from the driving gear notch and releasing it for motion. As the turntable is deactivated, this deactivates the locking solenoid, releasing the plunger into the driving gear notch and locking the turntable from further motion. C denotes the commutators for the turntable switch discussed above. D is the synchronous motor which drives the turntable through a peg and gear arrangement. E is a ball thrust bearing. The entire weight of the turntable assemblage rests on this steel ball. This allows easy removal of the turntable

assemblage when necessary, but firm long wearing roller action during operation. F is the upper bearing made of nylon. G is the polished stainless steel shaft which supports the entire turntable assemblage and is the center of rotation. H is the driving gear. This is 5 inches in diameter and has 30 notches at an angle of 12 degrees to each other. I is the collection turntable previously described.

2. The Electroplating System

The next critical part of the separation system was the electroplating unit used to deposit the uranium and thorium as a pure thin layer on the surface of a metal planchet. This then serves as the source for the alpha spectrometry. The power supply used for the electroplating was a constant potential instrument constructed at the University of Hawaii and capable of up to 28 volts and 3 amperes. It was not operated in the constant potential mode for this application. The electroplating cell is illustrated in Figure 10, and consists of a small glass bottle with the bottom cut off and the inside of the mouth ground to a 24/40 taper. A teflon insert fits snugly into this taper and against the polished flat of the lip to form a liquid tight seal. The teflon insert is milled to give a plating surface 0.5 inch in diameter. The stainless steel planchet resides in a small recess centered to and behind this



fig.10 Electroplating cell.

•

plating area, and is tightly pressed against the teflon insert by the screw cap assemblage. This consists of the regular screw cap with a teflon gasket and the copper disc and wire for the electrical connection as illustrated in the figure.

The electroplating system finally adopted was that of Kim <u>et al</u>. (74). There are several "intricacies" involved in obtaining clear platings at maximum efficiencies. Two of the most important of these were acquired by personal communication with two persons. Dr. John Noakes suggested that the residue to be plated be picked up in a small volume of strong electrolyte such as 8 N hydrochloric acid and then transferred to the plating cell. Dr. Herbert Veeh suggested that the planchets be washed with water and then acetone after plating. Although the residue to be plated and the plating solution are quite clean and, therefore, this step would seem unnecessary, it makes a remarkable difference in the resolution of the spectra.

3. Alpha Spectrometry System

The initial alpha spectrometric analyses in this work were done on a system consisting of a Nuclear Diodes model SL5-35-14 surface barrier detector operated in a vacuum chamber pumped through a liquid nitrogen trap to insure no back diffusion of oil vapors from the pump. The detector had an active surface of 150 mm² and a rated resolution of

35 Kev. This was operated through an Ortec 101-201 amplifier system which consists of a separate preamplifier and a combined amplifier and biased post amplifier. This allowed the biasing out of all noise with no change in the linearity of the amplification, and sufficient post bias amplification to get adequate resolution. The output of this was then fed to a Nuclear Data model 110 - 128 channel analyzer. The readout device for this was a teletype model 33 with Nuclear Data interfacing boards. The theory of operation of surface barrier detectors in conjunction with multichannel analyzers is sufficiently well understood and referenced (76) that this will not be discussed here. Near the end of this work, a second system was established which consisted of an Ortec model A-045-450-100 surface barrier detector operated in a vacuum system through the same This detector had an active surface area pumping system. of 450 mm², and a rated resolution of 45 Kev. This was biased by a battery operated system and operated through a Tennelec FET preamplifier, model TC 133, a Nuclear Data amplifier, model ND 534, and an Ortec Biased amplifier, mode1 408, all housed in a Tennelec Nim Bin, model Tennebin 3. The output of this system was fed into a Nuclear Data model 180 F and 180 M - 512 channel analyzer, of which initially only 128 channels was used to conform with the computer program developed to analyze the data.

Calibration of these systems for uranium and thorium was done by the use of precisely prepared standards. The uranium standard contained 65.086 micrograms of uranium-238 per gram of solution. This value was determined mass spectroscopically at Australian National University (77). The thorium standard was prepared in this laboratory from a sample of thorium nitrate and analyzed by the standard gravimetric procedure (in triplicate). This was calculated to contain 82.3951 \pm 0.000696 micrograms of thorium-232 per gram of solution.

B. Description of Chemical Separation Scheme

A schematic outline of the separation scheme is given in Figure 13. However, since details of procedure are of the utmost importance in this work (sometimes referred to as an "art"), a description of all steps is included. We have arrived at most of these the hard way, through many experiments and failures. Also, the advice of experts in this field has been invaluable, and due acknowledgment must be made, especially to Dr. Herbert Veeh.

1. Preparation of Samples

All samples that were personally collected were carefully examined in the field at the time of collection for any signs of recrystallization (original aragonite to calcite). This can often be detected by tiny flashes of reflected light from the faces of the recrystallized calcite

as the sample is rotated back and forth at the proper angle to the sun. All samples were carefully cleaned in the laboratory, removing with a small grinding tool all traces of material in any way suspect, e.g., crumbly, very dirty, marled worm encrustations, etc. The samples were then cut into small pieces about 4 mm square and about 8 to 10 mm long and washed in an ultrasonic bath either until the wash solution remained clean, or for about six washings. This latter limit was necessary with only a few of the older samples due to their tendency to break apart into tiny particles. The samples were then dried in an oven at 110°C overnight and placed into clean labeled containers. A random sampling of these pieces were taken for x-ray analysis. The pieces were crushed in an iron motar, ground in a porcelain mortar, and fine ground in an agate mortar to a fine powder less than 200 mesh. Some samples were fine ground in a carborundum container placed in a Spex mixer/mill, catalog number 5000. After each sample, all equipment was rinsed with dilute hydrochloric acid to remove any trace of coral, and rinsed well with water. The finely ground samples were then packed to infinite thickness and analyzed on a Tim-Press Research, Inc. (State College, Penn.) x-ray machine. Standards of 1, 3, 5, and 10% calcite were analyzed simultaneously and the data plotted as the ratio of calcite to aragonite peak heights versus percent

calcite. The percent calcite in the samples were then obtained from this standard graph (see Fig. 11).

The different curves in Figure 11 represent calibration curves of standards which were obtained at different times, and indicate the variability due to packing of the powder, instrument settings, etc. Since a calibration curve was obtained for each different determination of unknowns, and no attempt was made to identically reproduce operating conditions from one determination to another, the variation between the curves on Figure 11 should not be interpreted as an error range on the results. The various curves are shown merely to demonstrate that there is some variability, but that this does not markedly affect the percent calcite of the sample.

2. Dissolution and Precipitation

About 25 grams of sample was carefully transferred to a 1-liter volumetric flask and the sides washed down with de-ionized water. One-hundred lambdas each of uranium-232 and thorium-234 tracer were added, and the sides of the flask again carefully washed down with de-ionized water. A stirring bar was then added, and 35 ml of concentrated nitric acid (DuPont) was added dropwise from a funnel. Addition of the acid and complete dissolution of the coral generally required about 20 to 30 minutes. The use of a 1-liter volumetric flask was to reduce spattering loss during the



dissolution stage. In an attempt to develop a sample pretreatment procedure which would give the best results for the majority of samples, three different sample pretreatment procedures were investigated.

After transfer of the solution from the volumetric flask to a 400 ml beaker with at least three rinsings, 5 ml of concentrated perchloric acid (DuPont) was added along with an iron carrier of 5 to 10 mg, and the solution evaporated to dryness on the sandbath. It was found helpful, especially in the case of corals containing very much organic matter (e.g., recent corals or those containing considerable algae) to use one or two rinsings of concentrated nitric acid. This seemed most effective in transferring the most material to the beaker. Evaporation to dryness was intended to assure complete removal of the organic material present and to insure equilibration of the tracer with the natural isotopes. This residue was then dissolved in concentrated nitric acid while still warm, and diluted to about 150 ml. Dissolution was frequently very difficult at this point, and one or two samples never did go completely back into solution. Some of the more difficult samples would finally go into solution if allowed to sit for periods sometimes up to two weeks.

A second procedure involved evaporating the solution directly to dryness after transfer to the beaker and addition of the iron carrier, without the addition of the

perchloric acid. This residue was also dissolved in concentrated nitric acid while still warm and diluted to about 150 ml. Again, dissolution of the residue was sometimes difficult, but not as frequently so as with the first procedure.

The third procedure involved transferring to the beaker, addition of the iron carrier, and addition of the 5 ml of perchloric acid, but not evaporating to dryness. Rather, the sample was cooked for 1-2 hours on a sandbath to wet digest the organic matter present.

To evaluate which of these procedures resulted in the best data, a recent coral (which would contain considerable organic matter) was processed through each, and the results will be discussed with the conclusions.

All samples were next precipitated with concentrated ammonium hydroxide (DuPont) and digested on the sandbath for 15 minutes. This suspension was then centrifuged and the supernate discarded. Initially, the precipitate was redissolved with 5 N nitric acid, diluted to about 150 ml, reprecipitated with 6 N sodium hydroxide to a pH greater than 10, and digested for 15 minutes on the sandbath. This was then centrifuged, the supernate discarded and the precipitate dissolved in 5 N nitric acid. This step in the procedure was inserted to help remove much of the aluminum that might be present, and also to eliminate as much of the silica as possible in the form of soluble sodium silicates.

The resultant solution of the precipitate was again diluted to about 150 ml, reprecipitated with concentrated ammonium hydroxide, centrifuged, and the precipitate redissolved in a minimum of 5 N nitric acid. This further purified the system of calcium, and the sodium introduced in the previous precipitation. The last few samples were processed with a modification of this procedure. After the first ammonium hydroxide precipitation, the precipitate, rather than being redissolved in 5 N nitric acid, was washed with very hot 3 N sodium hydroxide, stirred well in this solution in the centrifuge tubes, and recentrifuged. The supernate was discarded, and the precipitate was washed with de-ionized water. (Dilute ammonium nitrate or ammonium hydroxide might be better here.) This precipitate was then redissolved in a minimum of 5 N nitric acid. The resultant minimum solutions of either of these treatments was then evaporated to near dryness on the sandbath.

3. Ion Exchange Separation

Since this particular type of work was a pioneering effort in this laboratory, in the progress of the major portion of this work, it was not realized that there was such a discrepancy between what theory predicted and what practice was able to achieve. Consequently, much time was wasted in trying to achieve separations that theoretically looked very feasible, but practically just would not produce. It

was not until Dr. Herbert Veeh arrived on the staff, and suggested a mini-column final stage separation just prior to the plating step that any real success was noted in the desired separations (77). In retrospect, several of the systems that were investigated and discarded at the time as not adequate would possibly be adequate with the present methodology. These will briefly be discussed under proposals for future work. The remainder of this section will be devoted to discussing the separation scheme as it is presently developed.

In the review of the ion exchange literature pertinent to the separation of uranium and thorium from each other and from iron, calcium and aluminum, it was seen that many systems had been developed that allowed separation of iron from uranium, of uranium from thorium, of uranium from other elements, etc., but not with the purity and completeness of separation needed in this work. It was felt that the best procedure would be to attempt to modify several existing procedures in a way that would allow the desired separations. To this end, the work of Korkisch and co-workers was selected as presenting the best opportunity for modification due mainly to the large number of systems which he and his co-workers have investigated and reported. The work reported by Korkisch and Hazan (53) and Korkisch and Janauer (42) was finally adopted with modifications to achieve the desired separations.

The major separation of iron, aluminum and calcium from the uranium and thorium is achieved in a 90% glacial acetic acid - 10% 5 N nitric acid system (90-10) on a Biorad AG 1 -X8 anion resin column 8 mm O.D. and 10 to 12 cm long. Proper preparation and pretreatment of this column is essential to a clean separation of the iron, calcium and aluminum in the first stage from the uranium and thorium. The resin bed was formed on a small wad of cotton in the bottom of the column by swirling and pouring presoaked resin into the column filled to the upper reservoir with water. The stopcock was then opened and the resin settled into the column by gravity and current flow as the water drained from the column. After the water level had reached the top of the resin bed, the sides were washed down with 5 N nitric acid and the column conditioned with at least 30 ml of 5 N nitric acid to convert the resin to the nitrate form. Complete conversion is essential for complete separation of The column was then conditioned with 20 ml of the iron. the 90-10 sorbtion solution in final preparation for addition of the sample.

In the 90-10 sorbtion solution the distribution coefficient of uranium is 100 and that of thorium is 160,000. That of uranium is not as high as would be preferred, but is sufficiently high for good separations if the column is kept long. The distribution coefficients of iron, calcium and aluminum are 0.1, 7.1, and 0.1 respectively. Thus, good separation of these elements from uranium and thorium are readily achieved by maintaining the sample solution volume at about 50 ml, and using 25 to 50 ml of the pure sorbtion solution as a wash to selectively displace the last of the sample solution.

With the uranium and thorium remaining on the column, essentially purified of all other undesirable elements, it was then desired to separate these two from each other. This could be done by continued elution with the wash solution, since the distribution coefficient of the two elements are greatly different in this medium. However, this would be very time consuming and require large volumes of solvent, i.e., this would not give a clean separation due to the high distribution coefficient of uranium. Consequently, a new solvent system must be used to achieve the desired separation cleanly. This introduces an additional problem, however. The degree of swelling of the resin is a function of the dielectric constant of the solvent system, and in particular, in mixed solvent systems involving water, the percentage of water in the total solvent system. Radical changes in the composition with respect to the amount of water present will cause a marked change in the degree of swelling of the resin, and may result in one of two deleterious effects. First, if the percentage of water is markedly increased, the resultant increased swelling of the resin can, in extreme cases,

burst open the column explosively. In less extreme cases, uneven swelling usually occurs, with resultant channeling within the resin bed. This in turn results in uneven solvent flow through the column and thus poor development or resolution of the desired separation. Second, if the percentage of water is markedly decreased, the resin will undergo considerable shrinkage, creating void spaces in the resin bed. This again will result in channeling, with the above discussed problems.

To avoid these effects, it was necessary to condition the resin bed by an intermediate solvent system which will allow a change of the resin swelling to proceed in the desired direction, but without the undesirable effects described above. It is necessary, however, that this conditioning step retain the desired elements on the column. To this end, a solution was developed which consisted of 84% ethanol, 8% 6 N hydrochloric acid, and 8% 5 N nitric acid. This was found to have sufficiently high distribution coefficients for the uranium and thorium and yet to adequately condition the resin for the subsequent separation.

Conditions are now established for the final separation of the uranium and thorium. This was accomplished by the use of two alcohol-mineral acid solvent mixtures. The uranium was selectively displaced in a solution of 80% ethanol and 20% 3.5 N nitric acid. In this system, uranium

has a distribution coefficient of 9, whereas the value for thorium is 700. The thorium was selectively displaced in a solution of 80% methanol and 20% 6 N hydrochloric acid. In this system the thorium has a distribution coefficient of 3 whereas that of uranium is 867. On the basis of these distribution coefficients alone, the order in which these displacements occur is immaterial. However, since the uranium had a rather low distribution coefficient in the initial stages, and thus has moved down the column farther than the thorium, it was felt that displacement of the uranium first would give the most satisfactory results.

Each of these solvent systems was collected separately, as described in the section concerning the automatic elution and fraction collector. The uranium and thorium fractions were then evaporated to dryness on a rotary evaporator system attached to a water aspirator (see Fig. 12). Use of this rotary evaporator is essential. The uranium displacement solution, as previously described, contains an organic solvent-nitric acid mixture. As this system approaches a final evaporation volume, the esters previously formed in the evaporation react with the remaining concentrated nitric acid, causing small explosive "pops" bumping the solution from the beaker. Evaporation under reduced pressure in the rotary evaporator not only eliminates this loss of solution with its resultant laboratory contamination problems, but considerably speeds up this stage of the analysis. The



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fig. 12 Rotary evaporator system.

intermediate trap in the evaporator is designed to prevent any backcontamination of the evaporating solution, and still allow rapid evaporation.

4. Final Preparation for Electroplating and Alpha Spectrometry

The flasks from the previous evaporation of the uranium and thorium solutions were then placed on the sandbath, 1-2 ml of concentrated nitric acid and 3 drops of concentrated perchloric acid added, and refluxed until the sides of the flask drain clean, i.e., no drops of solution adhered to the sides of the flask upon swirling. At this point, it was assumed that all the organics were reacted from the glass surface, and that clean transfer to a 10 ml beaker could be This solution was then transferred with a effected. minimum of three rinses with small volumes of 5 N nitric acid. One or two more drops of perchloric acid were then added, and solution evaporated to dryness on the sandbath. This assured complete removal of the organics originating either from the displacement solutions, or removed from the column resin. At this stage, there generally was a barely perceptible residue remaining in the beaker.

As mentioned previously, Dr. Veeh suggested that just prior to the electroplating, better results could be obtained by a final cleanup of the element using a very small ion exchange column. This consisted of a column 4 mm O.D. and about 2.5 to 3 cm long. For the uranium, AG1-X8 anion exchange resin was used, using the same sorbtion, wash and conditioning solutions, but then using 8 N hydrochloric acid to strongly adsorb the uranium to the resin and remove all other elements that might remain after the previous treatment. The uranium was then developed from the column by de-ionized water. The thorium was treated according to the method of Hyde as previously discussed. The thorium, contained in a solution of 3 N perchloric acid, was added to a mini-column of AG50W-X8 cation exchange resin of the previously described dimensions, washed 5 times with 1 ml of 3 N hydrochloric acid, and the thorium displaced with 0.75 M oxalic acid. This oxalic acid was then destroyed by taking to perchloric acid fumes 3 times, rinsing the sides of the beaker each time with 5 N nitric acid. Both the uranium and thorium solutions were then taken to dryness with nitric and perchloric acids.

Each of these residues were then taken up in two small drops of 8 N hydrochloric acid, the beaker warmed slightly to affect better dissolution, the beaker rotated so as to wet the lower sides and bottom of the beaker, and rinsed into the electroplating cell with 95% ethanol. A diagram of the electroplating cell is given in Figure 10. Each element was plated onto stainless steel planchets at 110 ma. The uranium was plated at a temperature of 65°C for 2 hours, and the thorium at room temperature for 4 hours. Although

Kim <u>et al</u>. designate 2 hours on platinum, better results were obtained at 4 hours with the stainless steel. The planchets were then washed with de-ionized water and acetone as previously discussed, and flamed to convert the hydroxides to the more stable oxides. These planchets were then counted on the alpha spectrometer, being placed about 6 mm from the surface of the detector.

5. Summary of Final Methodology

Figure 13 gives in schematic form, the final overall methodology recommended for analyses of coral materials. Although there still seems to be a large number of steps, a closer examination of them will indicate that almost onehalf of the steps do not require the continuous presence of the investigator, merely a check now and then to evaluate the extent of progress. This considerably alleviates the problem of tedious laboratory separations experienced in other procedures. In particular, the main column separation can be left to run overnight with the use of the automatic fraction collector system previously described.

C. Description of Computer Processing Programs

1. Introduction to the Wang Computer

The use of a modified Wang 720B computer was kindly permitted by Dr. Wilton A. Hardy of the Department of Oceanography. The Wang 720B is a programmable desktop computer with a 1983 program step capability. There are 247

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hand picked, cleaned samples
                             dissolve in c HNO3
                              c HClO<sub>4</sub> to fumes
                            NH, OH precipitation
                               hot NaOH wash
                                  ₩<sub>2</sub>0,wash
                            dissolve in 5N HNO3
                              dilute to 150 ml
                           repeat NaOH & H<sub>2</sub>O wash
                            dissolve in 5N HNO.
                        to dryness w/ HNO3 & HClO4
                    diss. in 5N HNO<sub>3</sub> + 9 vol. gl. HOAc
                              sorb onto column
                          wash w/ 50 ml 90-10 soln
                            15 ml EtOH-HC1-HNO
                              -75 ml U eluate
                              75 ml Th eluate -
       dryness in rot. evap.
                                                        dryness in rot. evap.
       reflux w/ HNO3 & HC104
                                                        reflux w/ HNO3 & HClO4
      dryness in 10 ml beaker
                                                       dryness in 10 ml beaker
3 drops 5N HNO3 + 27 drops gl. HOAc
                                                         dissolve in 3N HCl
   sorb onto mini-column (AG1-X8)
                                                   sorb onto mini-column (AG50W-X8)
           5 ml 90-10 soln
                                                             1 m1 3N HC1
                                                           repeat total of 5X
         2 ml EtOH-HC1-HNO3
                                                        2 ml 0.75 M oxalic acid
             5 ml 8N HCl
              5 m1 H<sub>2</sub>0
                                                        fumes w/ HNO3 & HC10,
      dryness w/ HNO3 & HC104
                                                        rense sides w/ 5N HNO3
           2 drops 8N HCl
                                                       repeat above 2 steps 2X
         E.P., wash & count
                                                       dryness w/ HNO3 & HClo4
                                                            2 drops 8N HCl
                                                          E.P., wash & count
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FIG. 13 FINAL METHODOLOGY

storage registers, of which a varying number are used for program step storage. Thus, the number of storage registers available for data storage is dependent upon the length of the program, each 2 registers containing 16 program steps.

The Wang 720B computer normally has the option of reading or recording data from or onto magnetic tape cassettes, and can read, or "load program" under program control. Printed output is through an IBM Selectric typewriter. The computer as modified by Dr. Hardy's group accepts input from a teletype printer-reader through a hard wired interface board. This same interface also allows recording from memory under program control. It was these two modifications which made the computer processing of this data possible and desirable on the Wang computer.

The 60 programmable operations of the Wang 700 series are listed in Table 1 along with the numerical codes assigned each. Programming the Wang consists of sequentially coding the operations desired. The branching of programs is achieved by the MARK and SEARCH commands in the following manner. The destination of the branching is "flagged" by a MARK command associated with one additional number. This number may be any of the 60 programmable operations, or any of the other numbers between 0000 and 1500 in blocks of 15, i.e., 0000 to 0015, 0100 to 0115, etc., the only restriction being that each number be "flagged" only once in any program. The sequential program
TABLE | 700 PROGRAM CODES

CODE	КЕҮ	CODE	KEY
0400	+ DIRECT	0600	+
0401	- DIRECT	0601	-
0402	x DIRECT	0602	x
0403	÷DIRECT	0603	÷
0404	STORE DIRECT	0604	†
0405	RECALL DIRECT	0605	↓
0406	CDIRECT	0606	()
0407	SEARCH	0607	X
0408	MARK	0608	INTEGER X
0409	GROUP 1	0609	π
0410	GROUP 2	0610	Log ₁₀ X
. 0411	WRITE	0611	Log _e X
0412	WRITE ALPHA	0612	\sqrt{X}
0413	END ALPHA	0613	10 ^x
0414	STORE Y*	0614	e ^x
0415	RECALL Y*	0615	$\frac{1}{X}$
0500	+ INDIR	0700	0
0501	- INDIR	0701	1
0502	x INDIR	0702	2
0503	÷INDIR	0703	3
0504	STORE INDIR	0704	4
0505	RECALL INDIR	0705	5
0506		0706	6
0507	SKIP if Y≥X	0707	7
0508	SKIP if Y < X	0708	8
0509	SKIP if Y = X	0709	9
0510	SKIP if ERROR	0710	SET EXP
0511	RETURN	0711	CHANGE SIGN
0512	END PROG	0712	DECIMAL POINT
0513	LOAD PROG	0713	X ²
0514	GO	0714	RECALL RESIDUE
0515	STOP	0715	CLEAR X

***ENTERED BY TOGGLE SWITCHES**

is caused to branch by a SEARCH command, followed by the unique number of the MARK command, e.g., a SEARCH 1400 in a sequential program listing would cause branching of the program at that point and re-entry at the point where MARK 1400 was found. Subroutine operations are also possible, and for the 720B these may be up to five levels deep. Both of these operations serve essentially to reset the program step counter.

When a program is either loaded into or recorded from the memory, the program step counter always returns to the program step immediately following the "LOAD PROGRAM" or "RECORD PROGRAM" step to continue its operation. Ordinarily, this "LOAD PROGRAM" step would be placed near the beginning of the program, so that as many program steps as possible would be available to the in-loading program. Analogously, the "RECORD PROGRAM" command, when utilized under program control, would be placed near the end of the program so that only the desired information be loaded onto the cassette.

Since a large amount of data was to be accumulated, it was desirable to condense the data as much as possible. Once each data tape had been processed, only the peak maxima and minima, the areas under the peaks, the number of channels between peaks, and the cumulation time was needed for further calculation. Hence, in recording this data, it would be desirable to place it all together and just record

that small portion of the memory. To achieve this, it became necessary to use some legal operations in a somewhat illegal manner. The RECALL DIRECT operation recalls into the X register any of the 247 registers whose number immediately follows it. This is ordinarily used to manipulate data. However, it may also recall a register which contains program steps, although this is usually a meaningless operation. Similarly, the STORE DIRECT operation stores into any of the 247 register whatever is in the X register. Thus, by recalling those registers which contain the LOAD PROGRAM, or the RECORD PROGRAM codes, and re-storing them in the desired location, it becomes possible to load into or record from any desired portion of the memory from any other point in the memory. Thus, essentially we are resetting the program step counter under program control both in the LOAD PROGRAM and RECORD PROGRAM modes. This latter capability is unique to this particular installation of the Wang, and considerably facilitated the computer analysis.

2. Description of Programs

For the data acquisition systems used in this work, 131 registers were required for data storage, plus 5 registers for scratch computation and storage. Thus, only sufficient memory remained for 879 program steps. It, therefore, became necessary to divide the processing into two programs. The detailed listing of these programs, together with a

brief program operation description page for each is given in Appendix C. Flow diagrams and a brief discussion will be given here.

A flow diagram of Program 1 is given in Figure 14a and 14b. The program is divided into four main routines to accommodate four basic needs. Since only 879 program steps are available, considerable use of subroutine was necessitated in order to maximize the program efficiency so that it could be contained within this limitation. After the data has been loaded into storage and the data type determined by the computer, one of three options is available. The raw data may be plotted, all data being normalized to the maximum channel on a variable inch plot, or the data may be analyzed via the uranium or thorium routine to obtain the desired information, and this information recorded automatically onto the data tape cassette. At the same time, hard copy of this information is printed out on the Selectric typewriter. A typical output for each sample analyzed is contained in Appendix B. Each sample is assigned a unique cue number of subsequent magnetic tape storage and search purposes.

In determining the area under the peaks, it was essential that each peak be treated as nearly identical as possible, particularly for the uranium-238 and -234 peaks, since their ratio is particularly sensitive to variations in either peak, and is an important evaluator (see Fig. 17 for

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store words sequentially

a11 words read

& stored

YES

test

data

type ł

U

ł print "U data" ŧ STOP

FIG. 14A

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print data"

STOP

FLOW DIAGRAM FOR PROGRAM I

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(NO)

LOAD ROUTINE



PLOT ROUTINE

URANIUM ROUTINE



THORIUM ROUTINE



FIG 14B FLOW DIAGRAM FOR PROGRAM I (CONTINUED)

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sample spectrum). To obtain the lower summing limit for the uranium-238 peak, the number of channels between the uranium-238 and -234 peaks was subtracted from the channel number of the minimum for the uranium-238 peak. Thus, the uranium-238 and -234 peaks were both summed over the same number of channels. The uranium-238 sum was then obtained by summing from this lower limit up to and including the minimum for the uranium-238 peak. The uranium-234 initial sum was obtained by summing from one greater than the uranium-238 minimum up to and including the minimum for the uranium-234 peak. However, this sum contains a small but non-negligible contribution from the uranium-235 naturally present, and it was necessary to correct the uranium-234 sum for this amount.

A graph of the distribution of the alphas for uranium-238, -235, -234 and -232 is given in Figure 15. It will be seen that there are two different energy alphas for each of uranium-238, -234 and -232, but that there are a large number of different energy alphas for uranium-235. The lowest energy alpha is so close to the uranium-238 high energy alpha that it is included under the uranium-238 peak. Similarly, the higher energy uranium-235 alphas are sufficiently close to the uranium-234 alphas that they are included under the tailing of the uranium-234 peak. For best results, provision must be made to compensate for each of them. It was decided that the easiest way to make each



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compensation was to determine the percentage of total uranium-235 included under each of the peaks, determine the difference between the uranium-235 under the uranium-238 peak and that under the uranium-234 peak, apply this correction to the sum of the uranium-235 counts, and then subtract this from the initial uranium-234 sum to obtain the corrected uranium-234 sum. This was accomplished by first determining the number of MEV's per channel between the uranium-238 and -234 peaks. An examination of Figure 15 will disclose a slight gap in the uranium-235 energies at 4.450 MEV. This was chosen as the cut-off point, the channel number corresponding to this MEV was calculated, and the sum one greater than the uranium-238 minimum to this cut-off channel was obtained and labeled uranium-235 sum. Under these conditions, there are 9.5% of the uranium-235 theoretical counts under the uranium-234 peak, and 5.7% under the uranium-238 peak, for a difference of 3.8% more under the uranium-234 than under the uranium-238. It is this difference that must be added to the uranium-235 count. This may be approximated closely enough by multiplying the uranium-235 count by 1.038, this product then being subtracted from the uranium-234 count to obtain the corrected results. In practice, this factor was varied from 1.000 to above 1.050, and 1.038 was found to give the best results for both a uranium standard known to be in

equilibrium, and a recent coral known to have a uranium-234 to uranium-238 ratio of 1.15.

The uranium-232 sum was obtained by summing from one greater than the uranium-234 minimum up to and including the minimum for this peak. An additional problem developed in that thorium-228 is the daughter of uranium-232, and cannot be resolved from the uranium-232 with the present analyzer Therefore, if the uranium is not counted system. immediately after separation and plating, then an increasing percentage of the counts under the uranium-232 peak are due to the ingrowth of thorium-228. This was critical since the uranium-232 sum was used to determine both the percent efficiency of the uranium recovery, and the parts per million of the uranium in the sample. Thus, in this program, the data was summed to the observed minimum which includes the thorium-228, and this was corrected for the thorium-228 after all of the data had been collated in Program 2.

The thorium-230 sum was obtained in exactly the same manner as the uranium-238 sum, using the channel difference between the thorium-230 and 228 peaks, no corrections being necessary here, however.

After the data had been calculated as desired, and stored in registers 6 through 18, the program rearranges itself to place a RECORD PROGRAM command into registers 20 and 21, a STOP, END PROGRAM command into registers 0 and 1, records the data onto the cassette, and then restores

itself to the original format ready for the next block of data.

A flow diagram of Program 2 is given in Figure 16 and is self explanatory. The only unusual part of this program is again the rearrangement of the program under program control so that the data blocks from the data cassette are stored in their original format in registers 6 through 18. After all of the data with the same cue number has been collated, the program again rearranges itself back to its original format in preparation for a new cue search.

Later in this work, for reasons that will subsequently be discussed, it was decided to write a third program with the age calculations based upon the uranium-234 age correction equation. The resultant Program 3 is basically the same as Program 2, except in that section of the program where the corrected age is calculated, where there are two major differences in addition to the difference in the equation used to calculate the corrected age.

First, in lieu of multiplying the uncorrected age and approaching the corrected age from above, Program 3 divides the uncorrected age by 2 and approaches the corrected age iteratively by multiplying by 1.01. This method is not as efficient of computer time as approaching the corrected age from above since the corrected age is usually closer to the uncorrected age than to one-half the corrected age. However, it was felt that comparison of the corrected ages



FIG.16 FLOW DIAGRAM FOR PROGRAM 2

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as calculated by the two methods might give some additional insight into problems being encountered at the time.

Second, two corrected ages are calculated via two different approaches to the basic age correcting equation. As discussed previously, the uranium-234 age correction equation does not assume any initial uranium-234 to uranium-238 (U4/U8) ratio. Empirical evidence gathered to date suggests, as previously discussed, that the current 15% excess of uranium-234 in sea water has existed over at least the past time over which the method is capable of indication. It was felt that additional insight to this relationship might be obtained by calculating a theoretical age bases on an exact initial U4/U8 ratio of 1.15. Thus, 1.00 is used wherever the activity of the uranium-238 is required. .15 $e^{-\lambda}$ U234^t is used wherever the activity of uranium-234 is required, and iterative comparison is made to the observed ThO/U4 ratio. All data associated with this calculation in the printout are denoted by (T). In addition, the printout format of both Programs 2 and 3 were changed so that the DPM values and the thorium-230 to uranium-234 (Th0/U4) or thorium-230 to uranium-238 (Th0/U8) ratios are printed out, since valuable information can be obtained by examination and comparison of these values.

Two supplementary programs were also written to facilitate cumulative error calculations on the thorium-234 beta tracer efficiencies, and on the error for the

thorium-232 standard prepared during this work. The first is a cumulative error for difference-quotient combinations, and the second is a cumulative error for product-quotient combinations. The detailed listing of these programs, together with a brief program operation description page for each is also given in Appendix C.

The program as described here is applicable only to the Wang 720-B programmable desk top calculator. However, the same operation has been programmed in Basic language, and can be used on any computer utilizing the Basic language.

D. Description of Samples

- R-V A recent coral identified as <u>Acropora</u>, but of unknown species, collected from the Great Barrier Reef of Australia from Wreck Island reef flat and separated by H. H. Veeh in 1969.
- R-1 A recent unidentified coral used mostly for developmental work. Collected at Mokuleia Beach, Oahu, by this investigator.
- R-2 A recent coral identified as <u>Montipora verrucosa</u>, collected by S. Smith from the lagoon of Kaneohe Bay, Oahu, Hawaii.
- R-3 A recent coral identified as <u>Acropora</u>, but of unknown species, collected by S. Smith from the lagoon of Fanning Island.

- GBR-V A young coral identified as <u>Galaxea</u> <u>clavus</u>, collected by J. J. Veevers at a depth of 175 m off the Great Barrier Reef of Australia. Separated by H. H. Veeh in 1969 (see (85) for greater detail).
- GBR-H A portion of the above sample separated in this investigation.
- BP-1 A coral sample identified as <u>Porites lobata</u>, collected by H. T. Stearns at Black Point, Honolulu, Hawaii. Elevation, 5 ft.
- DH-1 A coral sample identified as <u>Porites lobata</u>, collected by H. T. Stearns at Diamond Head, Honolulu, Hawaii. Elevation, 5 ft.
- NAS-A A coral sample identified as to genus <u>Porites</u>, species unknown. Collected from a coral pit at 10 ft. above sea level one-half mile to the east of the big curve in Coral Sea Road, Barbers Point Naval Air Station.
- WAIMEA A coral sample identified as <u>Porites</u> <u>lobata</u>, collected about one-half mile east of the Waimea store on Kamehameha Highway, Oahu, Hawaii. Elevation, 18 ft.
- EWA-4 A coral sample identified as <u>Porites</u> <u>lobata</u>, collected on the road south of Ewa town, west of Puuloa Road and just outside to the east of Barbers Point Naval Air Station. Elevation slightly over 30 ft.

- FH-PH A coral sample identified as to genus <u>Cyphastrea</u>, but species unknown. Collected by this investigator along Farrington Highway near Campbell Industrial Park. Original location unknown, but collection elevation about 70 ft.
- KH-1 A coral sample identified as to genus <u>Porites</u>, but species unknown. Collected by this investigator imbedded in a tuff pillar at Koko Head, Honolulu, Hawaii. Original elevation unknown.
- BC A sample of uranium ore taken from the then Belgian Congo uranium mines. Separated and prepared by H. H. Veeh.
- SPERGEN A sample of limestone from St. Genevieve, Missouri of Mississippian age, prepared for interlaboratory comparison by W. H. Sackett. This particular sample was separated and prepared by H. H. Veeh.

These samples were chosen on the following basis: those designated by -V were prepared elsewhere and used in this investigation for interlaboratory comparison. The recent samples were chosen to show the lack of initial thorium-230 and to test the initial uranium-234/uranium-238 ratio of 1.15 hypothesis. Both BP-1 and DH-1 were investigated in an attempt to corroborate H. T. Stearns' hypothesis of an 80,000 year horizon (to be discussed in greater detail later). KH-1 was chosen because of its unique history relative to the other samples. NAS-A, WAIMEA, EWA-4, and FH-PH samples were chosen in an attempt to gain a broad spectrum of the various horizons found on Oahu.

E. Description of Uranium-Helium Work

A discussion of the essential features of mass spectrometers may be found in the work by Dalrymple and Lanphere (78). The instrument used for this work utilized a Reynolds type 60° mass spectrometer constructed at the University of Hawaii and discussed elsewhere (79, 80). This was modified slightly by the insertion of a liquid nitrogen cup-trap between the furnace extraction system and the gas clean-up system in such a manner that any gases exchanging between the two systems must contact the LN temperature In this manner, nearly all of the carbon dioxide surface. liberated in the descrepitation of the carbonate samples was solidified onto the internal surfaces of this trap. This greatly facilitated chemical clean up of the helium gas for analysis. Decrepitation was accomplished utilizing a Lepel 12.5 KVA high frequency induction system.

One interesting feature of the instrument, which is particularly important for the work done here is the use of a helium-3 tracer system. This was first described by Damon and Kulp (81). The system as utilized in this work consisted of a metal bulb containing the helium-3 tracer attached to the pipette system consisting of two Nupro valves welded together with a volume of about 0.7 cc between them. The system is attached to the gas extraction system of the mass spectrometer by one-half-inch stainless steel tubing. With a bulb pressure of 3.51 microns, one pipette of tracer gave a signal on the same order of magnitude as the samples. The volume of the tracer was calibrated using a standard mica from Massachusetts Institute of Technology, No. R-1659 from Renfrew County, Ontario, Canada, containing 740 x 10^{-5} cc of helium-4 per gram. This volume was then used to determine the constants in the exponential equation given in Dalrymple and Lanphere for calculating the volume of successive tracer spikes.

III. RESULTS AND DISCUSSION

A. Spectrometry

1. Spectrum Analysis

A sample multichannel analyzer spectrum for a typical uranium sample is given in Figure 17. For recent coral, the uranium-234 peak should contain 15% more counts than the uranium-238 peak, and therefore, is generally higher. It should be noted that the uranium-238, -235 and -234 peaks are nearly completely resolved, whereas there is a shoulder peak of thorium-228 with the uranium-232. This shoulder peak represents the ingrowth of thorium-228 daughter and must be corrected for in analyzing the data. As discussed under computer program, the uranium-234 peak is corrected for the small but non-negligible uranium-235 that is summed into it.

The uranium-232 peak serves as a calibrator to determine the activities of the uranium-238 and -234 and the PPM of uranium in the sample. This is accomplished by multiplying the uranium-238/-232 (U8/U2) ratio by a calibration factor (21.840) which represents the disintegrations per minute contained in the uranium-232 tracer added. The uranium-234 peak is similarly treated to obtain its activity. The PPM of uranium is obtained by multiplying the U8/U4 ratio by another calibration factor (29.508) which represents the micrograms of uranium equivalent of the uranium-232 tracer



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added, and dividing this product by the sample weight. These calibration factors were obtained from the uranium-238 sample standardized mass spectrometrically as described previously.

An example of the multichannel analyzer spectrum for a typical thorium spectrum is given in Figure 18. If thorium-232 were present in the sample, it would appear in the position marked on the figure. Were this to be the case, the sample would be invalid for dating purposes. The thorium-230 peak is converted into activity by dividing by the analysis time and the overall thorium efficiency. This efficiency in turn is obtained by multiplying the thorium-234 beta efficiency by the efficiency of the alpha detector system.

These activity values are then substituted into the equations given earlier to obtain the uncorrected and corrected ages. Since this information is obtained through the use of a computer, many other parameters are calculated at the same time which give valuable information about the sample. An example of this final print out and the information ined thereon for each program is shown in Figure 19.

2. Spectrometer Malfunction

To insure the obtaining of valid data, the spectrometer system was initially carefully calibrated using single



Fig. 18 Sample thorium spectrum from multichannel analyzer.

TOTALED DATA FUR Great Barrier Reef-Hammond. U-234 program. URANIU:: U238= 11969.0 ± 109.4 U234= J3684.9 ± 116.9 U232= 4585.1 ± 67.7 R= 1.14836<u>+</u> 1.4809ex -2 T in min= 4329.364 THORIUM Th232= 98.0 ± 9.8 Th230= 2918.8 ± 54.0 Th228= 2616.0 ± 51.1 T in min= 7069.052 U EFF= 4.84% U238 PPN= 3.071 Th EFF= 2.69% Th230 PPM= 1.3375ex -5 U-Th AGE(T)= 31.14 K YRS U-Th AGE(C)= 31.14 K YRS U-Th AGE(U) = 31.14 + 1.0659 ex 1 K YRS UNCORR. AGE = 30.96 K YRS U-U AGE= 16.10 K YRS BACK CALC. U-U RATIO= 1.15647 U 238 dpm= 57.011 U234 dpm(0)= 65.184 U234 dpm(C)= 60.069 Th230 dpm= 15,330 Th230/U234(0)= 2.3519ex -1 Th230/U234(C)= 2.5521ex -1 TOTALED DATA FOR Great Barrier Reef-Hanmond. U-238 program. URANIUM U238= 11969.0 ± 109.4 U234= 13684.9 ± 116.9 U232= 4585.1 ± 67.7 $R = 1.14336 \pm 1.4309 \text{ ex} -2$ T in min= 4329.864 THORIUM Th232= 98.0 ± 9.8 Th230= 2918.8 ± 54.0 Th228= 2616.0 ± 51.1 T in min= 7069.052 U238 PPM= 3.071 U EFF= 4184% Th EFF= 2.69% Th230 PPM= 1.3375 ex -5 U-Th AGE= 13.44+ 4.6016 ex K YRS U-U AGE= 16.10 K YRS UNCORR. AGE= 30.96 K YRS BACK CALC. U-U RATIO= 1,148 U238 dpm= 57.011 U234 dpm= 65.184 Th230 dpm= 15.330 Th230/U238= 2.6890 ex -1

Fig. 19 Sample totaled data print out.

isotope planchets of uranium-234 and thorium-230 obtained through the coutesy of Dr. John Noakes of the Oak Ridge National Laboratory. These were used to calibrate the pulse generator on the Ortec 201 directly in MEV's. This in turn was used to determine the linearity of the analyzer system, which showed complete linearity. Additional checks were done using a sample of a Belgian Congo uranium ore known to be in radioactive equilibrium with respect to the uranium decay activities, and a sample of a Mississippian limestone also known to be in equilibrium. Both of these samples were supplied through the courtesy of Dr. Herbert H. Veeh of the University of Hawaii, Hawaii Institute of Geophysics. Both of these samples gave a U4/U8 ratio of 1.000 \pm .006, and it was assumed that the analyzer was functioning correctly.

Since the data were to be analyzed by computer, a fair body of unanalyzed data were obtained before the completion of the computer program. Upon compiling and collating these data through the computer, it was determined that the data were not coming out as expected. In particular, the U4/U8 ratio of the recent corals which should have a value of $1.15 \pm .03$, was coming out consistently low. In addition, the ages that were obtained for these samples did not fit into the pattern established by previous geological evidence. To insure the correctness of the computer program, several samples were carefully processed by hand

calculation, each time obtaining values very close to those obtained by the computer program.

At this point the spectrometer system was again checked out by setting the pulse generator at the MEV settings for uranium-238 and -234 and accumulating counts for 1 minute intervals. The ratio of these accumulated counts was consistently 1.00 within the counting statistics. The pulse generator was a mercury wetted relay operating at a line frequency of 3600 cpm. All of the 1 minute counts averaged 3594.8 ± 21.4 , indicating there was no short term malfunction within the spectrometer system.

The output of the spectrometer system is formatted on a model 33 Teletype printer and puncher. This was tested for malfunction by printing 10 consecutive printouts from the ND 180 spectrometer and checking each successive printout against the first for any change. The first printout was additionally checked by advancing the memory readout manually and reading the value for each channel from the binary coded decade panel readout of the spectrometer. In no case was a deviation observed.

Since the uranium-238, -235 and -234 peaks are not totally resolved, it was thought there might be a distortion in the data due to tailing effects, although the computer program had been designed to minimize such effects. Consequently, these data were investigated to determine if there was some factor by which all of the uranium-234 data

for the recent samples could be multiplied to obtain a value which would then be subtracted from the uranium-234 peak and added to the uranium-238 to give a U4/U8 of 1.15. Not only was there no constant factor, but the quantity calculated to be necessary to make this adjustment was larger than the total amount of uranium-235 present in the samples, indicating that the distortion did not arise from the uranium-235 correction nor from tailing effects.

Since two spectrometer systems were available, interinstrument comparison of the same sample was made, the results being essentially identical. For example, a recent sample on the ND 110 system gave a U4/U8 ratio of 1.088, whereas it gave a ratio of 1.099 on the ND 180 system. To further test whether the resolution was an interference, a sample was analyzed on the ND 180 using first 128 channels and then the full 512 channels. The 128 channels gave a U4/U8 ratio of 1.125 and the 512 channels a ratio of 1.110.

At this point the spectrometer system was again very carefully checked out by our electronics technician, carefully recalibrated and checked for linearity, all of which showed no obvious defects.

Finally, by a combination of changing one of the electronic modules in the ND 180 system, raising the voltage of this detector to the maximum rated for that detector, and replacing the detector on the ND 110 system with a totally new one, it appeared that proper U4/U8 ratios were being

obtained on both instruments. Thus, a recent sample on the ND 110 system gave a U4/U8 ratio of 1.147 and on the ND 180 a ratio of 1.157. This was checked with an additional sample which gave 1.147 and 1.149 respectively. Consequently, data were again accumulated on equilibrium standards, recent samples and unknown samples.

Again, however, after sufficient data had been obtained, it became apparent that the problem still had not been solved. The equilibrium standards still gave U4/U8 ratios of $1.00 \pm .01$, but the recent samples were again giving low results. It appeared as though the effect was proportional to the extent of disequilibrium when it occurred. This discrepancy was investigated by alternating a recent sample and an equilibrium standard randomly for 12-hour periods of time and examining each individual spectrum for any apparent trends, and the overall U4/U8 ratios for the final result. The recent sample gave a U4/U8 ratio of 1.127 and the equilibrium standard a ratio of 0.984 \pm 0.14. The latter is low, but is just on the edge of the counting statistical limit. There were no apparent trends in the individual blocks of data obtained.

If the solid angle subtended by the source to detector geometry is too large, distortion can occur due to detector edge effects. This is caused by a fraction of the ionizing radiation exiting the sensitive volume of the detector before giving up all of its energy, thus registering an

event of lesser energy in the spectrometer. This is frequently one of the major causes of scattering in the accumulated data. Although the peak shapes of the data being discussed here did not show evidence of such a problem, an investigation of the effect of changing the source to detector distance was carried out. There was no detectable difference in the ratio of an equilibrium sample when counted at source to detector distances of 3 mm or 7 mm, the ratio being $1.003 \pm .01$ and $1.000 \pm .01$ respectively.

In the process of this work, an interlaboratory check had been arranged through Dr. Veeh. A sample of Great Barrier Reef coral which he had analyzed while at the Australian National University was obtained and processed through the separation scheme described in this work. In addition, the planchets which he had counted an ANU were also obtained and counted here. It is the information obtained from these samples which finally delineates the problem to be in the spectrometry and not in the planchets, i.e., it does not seem to be due to some impurity on the planchets, or to some problem associated with the chemical separations. The data obtained from these samples is summarized in Table 2.

The original data that Veeh obtained at ANU is given in the first row. The age of 17 thousand years was interpolated from a graph of the uranium-234 corr. eq. using the

	Sample		OBSERVED COUNTS			U238		AGES (K YRS)	
		U238	V234	U232	<u>v238</u>	<u>U232</u>	r m	238	
1	GBR-V Veeh's orig data	22042	25386	9884	1.152	2.23	3.01	17	
3	GBR-V MD110 data 798d	20630	23426	8418 (c)	1.136	2.45	3.31	15.1	
2	GER-V Vech's data, prog calc	55045	25386	9884	1.152	2.23	3.01	17.5	
• 4	GER-V ND130 data, V calib 77 days	14304	16420	5913 (c)	1.148	2.42	3.27	14.5	
5	GBR-H ND110 data 46 days	11969	13685	4385	1.143	2.73	3.27	27.5	
6	GBR-H MD110 data 41 days	11969	13685	4405	1.143	2 .7 2 '	3.196	27.5 .	
10	R-3 computer 66 d	21169	24101	10759	1.139	1.97	2.32	0	
11	R-3 hand pr∝ 66 d	21174	24064	10632	1.137	1.97	2.33		
9	R-3 total hand, ≠ peaks	31507	35364		1.122	1.97	2.33		
7	R-3 total computer 66 d	31473	35450	15527 15875	1.126				
8	R-3 total hand	31225	35364		1.133				

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SUMMARY OF DATA ON GER-V, H, & R-3

TABLE 2

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thorium-230 to uranium-234 ratio of 0.143. The data obtained for this sample by this investigator on the previously described ND 110 spectrometry system is given in Row 2. It is of particular importance to note the decreases in the U4/U8 ratio, and the increase in thorium-238 to uranium-232 ratio. Both of these changes indicate a discrimination of the higher energy alphas by the spectrometer system. Data for this same sample counted on the ND 180 spectrometry system is given in Row 4, but in this instance the discrimination towards the higher energies is not so pronounced, i.e., the U4/U8 ratio is higher and the U8/U2 ratio is lower. In both of these instances, the PPM values are too high, again indicating that the uranium-232 values are too low. The results of Veeh's original results processed through the computer programs are given in Row 3. It can be seen that the ages compare very favorably with that initially obtained by Veeh from a graph.

The data obtained for the Great Barrier Reef sample processed through the chemical scheme of this investigation are given in Row 5. These data were obtained on the ND 110 spectrometer system, and shows a trend similar to that of Veeh's sample on this spectrometer system, but is not as pronounced. The fact of the U8/U2 ratio being relatively considerably higher than that for Veeh's sample is not significant due to the uranium-232 tracer addition system was not identical. The fact, however, that the PPM is 3.27,

almost identical to that obtained from Veeh's sample on these spectrometry systems is significant, and again seems to indicate a discrimination within the system.

In part, this apparent discrimination of the uranium-232 may be due to the method of correcting the uranium-232 for the thorium-228 daughter ingrowth. The present method of correction consists of calculating the percent activity of the daughter thorium-228 present at a time that is the end of the counting time, multiplying this percent fraction by the total counts for uranium-232 and thorium-228, and subtracting this from the total counts to give the resultant uranium-232 counts. This is rigorously valid if the counting time is a relatively small fraction of the total The correction method was initially time since separation. designed to operate under these conditions, i.e., the planchets were to be counted within 10 days after separation, in which case the correction would be relatively insignificant but rigorous. In the case of the GBR-V sample, the sounting time of 1.5 days with a time since separation of 799 days would also be a very close approximation to the rigorous situation. However, a counting time of 10 days with 30 days since time of separation would overcompensate for the amount of thorium-228 that had grown in since time of separation. To test the applicability of this correction to the data involved to this investigation, corrections were made for the time since separation to the beginning of

counting, and to the end of the counting period. Using the beginning of the counting period too small a correction was involved, and to the end of the counting period too large a correction was involved. This test was applied to the GBR-H data, with the results found in rows 5 and 6. The PPM value has been reduced, but still is not down to the proper value even when the uranium-232 is undercorrected. In fact, the best PPM value (3.07) is obtained when no correction at all is made to the uranium-232 counts. This again indicates a discrimination of the spectrometer system towards the higher energy alphas.

On an examination of only the U4/U8 ratios listed in Table 2 discussed thus far, it might be argued that this discrimination is more apparent than real, except that in the more than 10 spectrometer analyses of recent corals which should average a U4/U8 ratio of 1.15 ± 0.03 , only two of the final averages were over 1.15, and only one of these was as high as 1.157. The final averaged values consistently tended to be low.

The data for one of these are given in line 7 of Table 2. The same data processed by hand are given in line 8. The difference between the uranium-238 counts of the two is 248, which is almost the same value as the statistical error of 189 associated with these counts. Thus, statistical error alone can produce variations of the order between these two. In this case, however, the hand data are biased

in favor of the higher ratio. This arises because the uranium-234 data were summed down to the minimum between the uranium-234 and -235 peaks, but still contains about 3% more of the uranium-235 alphas than the 238 peak does. The uranium-238 peak is summed over the same number of channels and therefore contains fewer counts. Thus, there is too large a uranium-234 count relative to the uranium-238 count. By including the lower 5 - 10 channels of the uranium-238 data not initially included in the hand treatment, the ratio is brought very close to the initial ratio listed for the computer processing of this data as shown in line 9. Ιn this respect, if the analyzer system is functioning properly, the computer processed ratios are the more accurate ones because of the equal treatment of uranium-238 and -234 peaks, along with the compensation for the uranium-235 present based on equilibrium data.

When an examination is made of the individual blocks of data from which the averaged results are obtained, a disturbing pattern appears. Line 1 of Table 3 lists chronologically the U4/U8 ratios for 12 blocks of data taken for R-3 at three different time periods. Asterisks indicate the beginning of a new counting period. Line 2 lists the same data in decreasing order. The block of data for which the U4/U8 ratio is denoted by a ! consisted of doublet peaks, indicating a shift in the gain at some time during that analysis period, and this block of data can

R-3 Chronological order	1	*1.138:	1.148	1.161	1.107	1.079	*1.165
		1.163	1.123	*1.152	1.156	1.086	1.159
R-3 Decreasing order	2	1.165	1.163	1.161	1.159	1.156	1.152
		1.148	1.138!	1.123	1.107	1.086	1.079
Eva-4 Chronological order	3	1.031	1.016	1.056	1.041	1.032	1.089
		1.066	1.037	1.074	1.056		
Ewa=4 Decreasing order	14	1.089	1.074	1.066	1.056	1.056	1.041
		1.037	1.032	1.031	1.016		

TABLE 3 SUMMARY OF INDIVIDUAL BLOCK DATA

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immediately be discarded. Examination of these ratios show that the low values are much lower from the accepted ratio of 1.15 than the high ratios are higher than this value. None of these data are rejectable by any of the usual statistical rejection tests because none of them are really "outlying" relative to its nearest neighbor. If, however, we take the deviation of 0.03 as the nearest neighbor, then the two lowest results can be dropped with 95% confidence. This brings the final results to those given in lines 10 and 11 of Table 2, which is much better, but still too low.

This procedure is not really valid, however, as it was performed with a biased opinion, i.e., we know what we want the resultant average to be because it is a recent coral. A similar listing of an "old" coral with unknown ratio is given in lines 3 and 4 of Table 3. Again it will be seen that there is a random pattern to the low values, but in this case it is impossible to reject any of them as outlying and yet the final ratio of 1.049 is surely too low as this gives a U-U age of 400 years.

All of the results thus far presented are strongly indicative of an indeterminate but biased error occurring in the data, and originating with the spectrometry phase of the total analyses. However, since both spectrometers seem to be effected, although not equally, it would seem that the disturbing influence must be external to the spectrometers themselves.

An attempt was made to correlate the low values for R-3 with their time of analysis from the analyzer log book, but no apparent pattern could be discerned. Additionally, the noise on the input line was examined with a current probe sensitive from 30 Hz to 100 MegHz and an oscilloscope. Although noise was observed, it was not possible to correlate it with spectrometer effects at that time, mainly due to the fact that it would require long term monitoring of the total noise spectrum simultaneously with sample analysis in order to effect any correlation of noise changes with U4/U8 ratio variations.

B. Results of the Chemical Separation Scheme

Table 4 gives a summary of the chemical treatment and results for each of the samples analyzed in this investigation. It will be noted that both the uranium and thorium efficiencies are rather low, the highest being less than 14% in both cases. The major reason for this is the efficiency of the electroplating procedure used. As initially worked out by Kim <u>et al</u>. (74) and as initially developed for use in this investigation, the plating substrate was platinum foil, which gave plating efficiencies in the 70% to 95% range. However, with the advent of the interlaboratory comparisons and calibrations, it was deemed important to use the same plating base on which the interlaboratory comparison was plated, namely stainless
Sample	Chemical Pretreatment	Sorb. Vol.	PPT	R	РРМ	U eff.	Th eff. (overall)	Th 228 eff.	Theor Th228 dpm	U resol KEV	Th resol KEV	% calc.
R-1	5ml HClO4-dryness, diss 5N HNO3, 3 OH pptns	30	N	1.107	2.52	2.11			17.80	141		?
R-2	HENO3→ dryness, diss 5N HNO3, 3 OH pptns	30	N	1.142	1.15	3.96			18.01			< 1
R-3	2ml HClO ₄ -digest 30 min, 30H [™] pptns HClO ₄ - dryness 3X	30	N	1.136	2.38	5.54			18.15	93		< 1
GBR-H	HEЮ3→ dryness, diss 5N HHO3, 3 OH" pptns fine ppt formed in flask & on column	100	У	1.143	3.27 3.00	4.55	2.69	2.04	18.17 16.65	78	152	< 1
BP-1	HENO3→ dryness, diss 5N HENO3, 3 OM [™] pptns	30	N	1,095	2.28	5.07	5.80	5.30 5.78	18.00 16.50	100	130	2
DH-1	HClO ₃ → dryness, diss 31 HNO ₃ , 3 OH" pptns	50	N	1.095	2.99	4.46	11.44	10.40 11.34	18.01 16.51	80	95	> 10
Eva	5ml HClO ₄ → dryness, diss 5N HNO ₃ , Let s t ¹ 4 hrs & cent pptn	30	Y	1.049	1.49	6.74	10.46	9.72 10,66	17.96 16.37			2
nas-a	δal HClO _{4→} dryness, diss 5N HBNO ₃ , 3 OH [™] pptns	3 20 ml		1.090	2.54	4.78	8.67	8.06 8.83	17.81 16.26	77	148	1
Waimea	5ml HClO _{4→} dryness, diss 5N HNO ₃ , 3 OH [*] pptns cent ppt, lost small amount soln	30 ml	Y	1.093	1,33	7.93	4.12	4.34 4.78	17.96 16.37	96	95	< 1
гн-рн	5nl HClo _{l→} dryness, diss 5N HNO ₃ , 3 OH" pptns	40 ml	N	1.146	1.64	• 52	13.89	13.05 14.22	18.14 16.65	77-V.B.	95	< 1
KH-1	5rl HClO ₄ dryness, diss 5N HNO ₃ , 3 OH [®] pptns Set sevrl hrs - cent & wash ppt	30 ml	Y	1.056	2.73	2.12	11.48	10.82 11.80	17.94 16.45	93	111	< 5
Blank	5ril HC103- dryness, dies 5N HD03, 3 OH pptns	30 ml				13.78	4.58	4.04 4.40	17.95 16.46			

TABLE 4

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SUMMARY OF CHEMICAL RESULTS

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steel. With the introduction of the stainless steel planchets, the plating efficiencies dropped to much lower values. An example of this can be seen in the uranium calibration standard prepared in this investigation, in which only 19.7% efficiency was obtained, in comparison with about 25% overall efficiency if the plating efficiency were near 100%. The blank determination represents the best possible situation, in which there are no interfering ions present either in the separation procedure or in the plating procedure. The 13.78% efficiency obtained here probably represents a plating efficiency of about 50%, with the other samples ranging downward from there. Thorium plating efficiencies ranged from a low of 11% to a high of 61% as determined from the Th-234 beta tracer added. Veeh (77) reports similar types of variations in studies with other electroplating systems. Consequently, it is felt that essentially 100% recovery is obtained in the ion-exchange and precipitation procedures involved in the separation scheme developed in this investigation.

Since there is known to be a problem with the spectrometer system, both the uranium and thorium efficiencies reported here can only be relied upon to give approximate values. As an example of this, since the uranium-232 tracer carries a built-in thorium calibrator as well, the thorium efficiencies were checked using this. The disintegrations per minute (DPM) of thorium-228 was calculated for each

sample based upon the time at which the thorium-228 was separated from its parent uranium-232 in the initial ionexchange separation. The values obtained for this are given in column 10 of Table 4. Two values are given based upon two different spectrometer calibrations using the same uranium calibration standard. Values of 20.034 and 21.840 were obtained for the uranium-232 dpm for these calibrations.

This in itself is another evidence for the variability of the spectrometer system. Using the theoretical thorium-228 dpm values, thorium efficiencies were calculated on the basis of the observed thorium-228 counts in the sample. A comparison of columns 8 and 9 show how these theoretically calculated efficiencies compare with the efficiencies obtained through the beta tracer. They are reasonably close, but do not follow a consistent pattern. Both calculated efficiencies may be below the observed efficiency, as with GBR-H, both calculated efficiencies may be above the observed efficiency, as with WAIMEA, or the calculated efficiencies may bracket the observed efficiency, as with NAS-A.

Probably of greater importance than efficiency of recovery is the completeness of separation of uranium and thorium from each other and from other interfering ions. This can be evaluated in two ways. First, any uranium that carries over with the thorium will immediately show in the

thorium spectrum. Any peaks showing in the thorium-232 region of the spectrum are either thorium-232 or uranium-238 which was not cleanly separated. These can be distinguished by determining the energy separation of their peaks with the thorium-230 or -228 peaks, the uranium-238 having less energy separation than the thorium-232. In either case, the sample is invalidated for dating purposes. This was not observed in the samples discussed here.

Secondly, the separation from interfering ions of other elements can be evaluated by the spread or scatter of the peaks, i.e., the resolution of the peak. This is generally evaluated in terms of the full width at half maximum (FWHM). These values are listed in columns 11 and 12 for the uranium and thorium spectra respectively. There is an inherent width to each peak due to there being at least two alphas of different energy emitted from each isotope. Calculated on the basis of the separation of the two nearest major alphas, the uranium spectra would have an average spread of 52 KEV as an absolute minimum, and the thorium-230 peak an absolute minimum of 67 KEV if there were no noise introduced by the electronics, or scatter due to absorptive energy loss in the sample or in the chamber. Figure 17 and 18 represent very clean separations and are 12% and 22% above the FWHM minima respectively. The average resolution for the uranium peaks, omitting the R-1 and FH-PH extremes is 88. This is only about 70% greater than the minimum, and

represents clean separations in general. R-1, with its FWHM of 141 represents a rather unclean separation and is 176% above the absolute minimum. The average for the thorium-230 spectra is 118. This is only about 75% greater than the minimum and again represents clean separations. Thus, the separation scheme developed in this investigation appears to perform as designed, giving clean separations with good recovery of the uranium and thorium.

A correlation of these FWHM resolutions with the U4/U8 ratios is of some interest. For example, the low ratio for R-1 might be attributable to the poor resolution, since the PPM value is not unreasonable. For the FH-PH sample, the U4/U8 ratio is unreasonably high, since this is felt to be a very old sample. This is undoubtedly due to the wide variability of the peak resolution, ranging from 77 to very bad. (Another support for spectrometry malfunction.) In some of the blocks of data, the peaks were spread so badly they were hardly recognizable, whereas in others, the resolution was very good. Nothing can be said about the correlation of the resolution and the U4/U8 ratios of the other samples.

In the discussion of the chemical procedures, it was noted that three different pretreatment procedures were used in an attempt to obtain one that could be more generally applied. The first of these, evaporation to dryness with perchloric acid is used extensively in other laboratories,

but as noted previously, tends to give insoluble residues. The purpose of this evaporation is to destroy any organic matter present that might bind up the uranium in complexes that would interfere with the separation procedure, and to make sure that all of the uranium is in the maximum oxidation state. This is very important since uranium (IV) has a chemistry very similar to that of thorium (IV) and would not give clean separations. The presence of organically complexed uranium would not give equilibration between the naturally occurring uranium and the uranium-232 tracer added for calibration. This then would result in the loss of the complexed uranium during separation, decreasing the U8/U2 ratio and giving proportionately low PPM values. This might be used as an explanation for the low PPM value of R-2. However, GBR-H and DH-1 were both processed by this same procedure and evidence the right PPM value when the spectrometer discrimination is considered. But, there undoubtedly was considerably more organic matter present in R-2 than in the others, and it may be that one evaporation to dryness with nitric acid was insufficient to destroy all of the organic matter present.

Destruction of the organic matter cannot be the whole problem, however, since Ewa-4 and Waimea samples were both evaporated to dryness with perchloric acid, and they evidence very low PPM values. R-3 was not taken to dryness, but digested with perchloric acid for one-half hour at

steaming temperature. The PPM value for this sample is somewhat low, and it is unfortunately not possible to determine whether this is a result of the spectrometer or of incomplete removal of the organic matter. Thus, due to spectrometry difficulties, it is not presently possible to evaluate which of the three procedures is the preferred one.

As the final pretreatment residue was taken up in 5 N nitric acid and glacial acetic acid added to produce the 90-10 sorbion solution, some of the samples formed a fine white precipitate. Attempts were made to eliminate this by evaporation, reprecipitation, etc. with some of the samples, mostly to no avail. Subsequently, each time this occurred, the solution was centrifuged, the residue washed carefully, and the solution processed through the remainder of the procedure. The presence or absence of such a precipitate is indicated in column 4. Examination of this factor together with the U4/U8 ratio and the PPM values evidences no apparent correlation. Comparison with the thorium and uranium efficiencies also seems to give no apparent correlation, there evidently being no significant loss of either uranium or thorium due to the presence of this precipitate.

Each sample was examined by x-ray diffraction for the presence of calcite before processing. This factor is listed in column 13 of Table 4. Comparison of this factor with the uranium PPM values might be useful in determining

if the system had or had not remained closed. Unfortunately there is no correlation between the low PPM values and the presence of calcite. In fact, DH-1, which showed the largest percent calcite present, also gives the best PPM value of all the samples collected on Oahu. It is not felt that this multiplicity of low ratios is geologically significant, however, since other investigators have observed the "normal" value of 3 PPM for corals from Oahu.

After a careful consideration of all of the available information, the only explanation that would seem to justify these results would be indeterminate discrimination by the spectrometer system.

C. Examination of Age Data

A summary of the data associated with the age calculations is given in Table 5. Line 1 gives a theoretical test of the computer programs for calculating the ages. Thorium-230 has a half-life of about 80,000 years. Consequently, for an equilibrium system, the ThO/U8 ratio will be 0.500, at 80,000 years, and the U4/U8 ratio will be 1.1225. Activities of 10.0 dpm of thorium-230, 20.0 dpm of uranium-238 and 22.45 dpm of uranium-234 were substituted into the two age calculation programs to obtain the results given in line 1. For a non-equilibrium system with 15% excess uranium-234, the proper age of 68,000 years is obtained from each program.

_	AGES (10 ³ YRS)					DPM			Th230	Th230	<u>Th230</u>	Ru4/08	RU4/U8	
Samples	Üncorr	(т)	(0)	238	បរ+/ប8	238	234(0)	234(T)	230	<u>U234(0)</u> <u>U234(T)</u>	(0)	calc.	obs.	
Computer test	80	68	68	67	72,1	20,00	22.45	22.48	10.00	.445	.445	.500	1.148	1.1225
GER-V-orig. data	20.8	18.0	18.0	17.5	- 4	57.23	65.92	65.39	9.44	.143	.144	.165	1.16	1.152
GER-V-ID110	17.6	15.4	15.4	15.1	36.1	62.91	71.44	71.94	8.88	.124	.125	.141	1.141	1.136
GBR-V-100180	17.8	15.4	15.4	15.2	4.9	62.08	71,26	68.36	8.88	.125	.130	•143	1.154	1.148
GBR-H-ID110	33•3	28.6	28.6	28.8	16.1	60.73	69.42	69.14	15.23	.219	.220	.257	1.156	1.143
BF-1	227	172	172	175	163	36.31	39.75	39.67	31.21	.785	•789	.860	1.199	1.095
DH-1	140	116	116	117	162	55.80	61.11	61.83	39.24	.642	.635	.703	1.170	1.095
Eva-4	æ	8	æ	æ	400	26.93	28.25	0	47.68	1.69	0	0	0	1.049
NAS-A	520	256	256		181	45.73	49.86	49.88	45,23	.907	•907		1.18	1.09
Waimea	æ	æ	8	æ	172	23.15	25.29	0	33.43	1.32	0		0	1,093
FH-PH	8	8	æ	8	9.41	27.62	31.65	0	44.16	1.40	0		0	1.146
KH-1	8	8			351	48.01	50.69	o	53.76	1.06	0		0	1.056

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TABLE	5	

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SUMMARY OF AGE RESULTS

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Line 2 gives the values for Veeh's original data on the GBR-V sample, and lines 3 and 4 give the data obtained for this investigation of the same planchets on the ND 110 and ND 180 systems respectively. It will be noticed that the ages for our spectrometer systems are younger due to the smaller Th0/U4 ratio (column 15). Examination of the thorium-230 dpm (column 13) and the uranium-234 dpm (column 11) shows that there is too little thorium for the amount of uranium present for our data relative to Veeh's data, and that there is an excess of uranium in our data over that of Veeh's. This would imply that the uranium-232 dpm calibration factor is too large, and that the thorium alpha efficiency calibration factor is too small. The uranium data were all calculated with the larger of the two calibration factors cited previously. Use of the smaller calibration factor of 20.034 would give a value of 55.7 dpm of uranium-238 vs 57.23 obtained from Veeh's data. The proper calibration factor must obviously lie in between these as far as this particular sample is concerned. However, as cited previously in discussing the thorium-228 values derived from these calibration factors, there is not a consistent pattern associated with this.

It is difficult to believe that the thorium alpha efficiency is too low. First of all, to bring the thorium-230 dpm value in line with that observed from Veeh's data, the alpha efficiency would have to be increased from 23.75

to 39.5. This seems an unreasonable increase. Second, an independent calibration source was obtained from Dr. Teh Lung Ku at Scripps Oceanographic Institution and compared against the calibration source prepared in this laboratory. The Scripps source gave an alpha efficiency of 25.05 whereas the source prepared in this laboratory gave an efficiency of 26.98. The discrepancy between the two calibration sources was attributed at that time to an uncertainty in the history of the Scripps standard (77), since our standard had veen very carefully calibrated by the standard gravimetric thorium determination. Even so, the difference in the efficiencies is not sufficient, and in the wrong direction to contribute to the alpha efficiency problem being discussed here.

Each of the above thorium alpha efficiencies are dependent upon an accurate thorium-234 beta efficiency determination. If the beta counter was not working properly, this would be reflected in the alpha efficiencies and also in the thorium-230 dpm values based upon the thorium-234 beta efficiencies. However, due to the fact that the thorium-228 efficiencies are independent of the beta counting system and yet give values that lie very close to those obtained from the beta counting efficiencies, it was felt that the problem was not associated with the beta counting apparatus.

Subsequent closer examination of the thorium-228 efficiency values shows them not to be independent as initially felt. Thus, if the alpha efficiency be assumed constant, and the beta efficiency backcalculated from this, then the thorium-228 efficiencies of 2.04 and 2.22 as calculated for GBR-H sample represent beta efficiencies of 77.0 and 70.8 respectively, which represent thorium-230 dpm values of 13.8 and 12.8 respectively. These represent significant changes, but they do not go far enough in the right direction. To obtain a thorium value in line with that obtained from Veeh's data, the beta efficiency would have to be increased to 50.0% from the observable 11.34%. Of course, it is entirely possible and reasonable that both the alpha efficiency and the beta efficiency must be increased, each to a lesser extent than the extremes discussed here.

If the information obtained in the interlaboratory thorium efficiency studies is re-examined in light of what is now known concerning the apparent excess thorium-230, a new insight is gained in the problem. If it is assumed that the beta counter is not functioning properly, that the Scripps thorium standard is correct and that the spectrometer system is consistent (though it may be internally biasing against the different energies), then an alpha efficiency of 25.05 is correct. Similarly, if it is assumed that the thorium standard prepared in this laboratory is correct as to the micrograms of thorium-232 contained, then an efficiency of 66.0% is calculated, versus 61.2% observed.

This gives an alpha efficiency of 25.01, which is very comparable to the 25.05 obtained from the Scripps standard. All beta efficiency determinations we obtained by taking triplicate comparisons of the unknown, an evaporated standard, and a background in random order. The average of each of these was then taken to calculate the efficiency data. The use of an evaporated standard in the determination of each unknown efficiency had the purpose of eliminating fluctuations due to instrumental variations. To cross check this, an efficiency determination was made on a set of standards and a second thorium-232 standard prepared in this laboratory, and comparing this with the first thorium-232 standard alpha counted at the same time. The second thorium-232 standard had been independently calibrated using a proportional counter with an automatic sample changer. Eight alterations were taken using the two evaporated standards and the calibration standard to get an average of 26.6%. Six different alterations of the same samples on the G-M beta analyzer gave an average of 25.78. At the time this was felt to represent a good comparison.

In summary, the precautions which initially were taken to insure the correct operation and calibration of the beta analysis equipment seemed to indicate at that time that reliable data were being taken. Subsequent events have indicated that that was not the case, but no new beta efficiency data can be obtained on the samples discussed here due to the short half-life of 24 days for the thorium-234 beta tracer. Once the alpha spectrometry system becomes reliably operational, this data may be retrievable through the thorium-228 tracer inherent with, but dependent upon an accurate uranium-232 calibration.

If it assumed that there is a constant factor operational here, some discussion of the ages can be obtained. If the GBR-H uranium-238 data is normalized to that of GBR-V on the ND 110 system, then the thorium-230 value should be 9.17 for GBR-H rather than the observed 15.23. This means the observed value is 1.66 times too large. If this factor is used to adjust the thorium-230 dpm values of all other samples, the data listed in column 8 of Table 6 is obtained. Although these ages are interesting and quite possibly represent the relative ages of the samples, they certainly do not represent a very high degree of reliability, the principle reason being that it is not really felt that the constant factor applied to obtain them is in reality a constant. All evidence obtained to date indicate an unpredictable variability associated with these.

An interesting comparison may be made with these corrected ages and ages found by other investigators for analogous samples. Veeh and Veevers (85) reported the GBR-V sample as being 17,000 and 13,600 years old via the

		AGE (10 ³ YRS)			DP	Th230	Th230		
• Sampie	Uncorr	(т)	calc.	238	234(0)	230(0)	230 calc	U234 (0)	U234 cale.
GBR-V-ID110	17.6	15.4		62.91	71.44	8.88		.124	
GER-H-ID110	33•3	28.6	18	60.73	69.42	15.23	9.17	.219	.132
BP-1	227	172	68	36.31	39.75	31.20	18.8	•785	.473
DH-1	140	116	50	55.80	61.11	39.24	23.62	.642	.387
Eva-4	æ	œ	æ	26.93	28.25	47.68	28.70	1,69	1.02
KAS-A	520	256	85	45.73	49.86	45.23	27.25	.907	.546
Waimea	æ	æ	170	23.15	25.29	33.43	20,14	1.32	•79
FII-PII	æ		190	27.62	31.65	44.16	26.60	1.40	.84
KH~1	80	æ	110	48.01	50.69	53.76	32.38	1.06	.64

TABLE 6 SUMMARY OF CORRECTED AGES

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uranium-thorium and carbon-14 methods respectively. Buddemeier (86) has dated this by the carbon-14 method and obtained an age of 13,700 \pm 330 years. Thus, the age of the GBR-V sample seems well established, and the adjustment of GBR-H thorium-230 value to fit this age seems justified.

The corrected ages of the other samples may be considered in the light of two schools of thought. Ku (77) has dated some 15 coralline samples from the island of Oahu by the uranium-thorium method and found them all to be 120,000 years within the statistical error. Consequently, he feels that all of the horizons on Oahu that are datable by this method occurred within the timespan of the error level of these determinations, i.e., within $120,000 \pm 10,000$ years. Viewed in this perspective, the corrected ages obtained here would indeed support the factor discussed above as being approximately correct, since the average of the corrected ages is 112,000 years, and would also support the belief that the factor is not really a constant value. Other data published by Veeh (11) support this 120,000 year age for Oahu horizons falling within the limitations of the uranium-thorium method.

However, Stearns (87) holds to the school of thought that there are significantly younger horizons than the 120,000 year which seems to be the most commonly observed. In support of this he reports a thorium age on a sample collected at Diamond Head and analyzed by William Easton at

60,000 ± 20,000 years. This would correlate well with the 50,000 years corrected age obtained in this investigation for the Diamond Head sample supplied by Stearns. Subsequently, if this is shown to be real, this would be very significant to an understanding of the glacioeustatic fluctuations of the sea level. As it becomes possible to retrieve the data as discussed above, this problem may then be resolved.

D. Uranium-Helium Results

Only one of the samples discussed in this work was investigated on the mass spectrometer for it's helium values. This was the Koko Head sample and was chosen because of its unique history relative to the other samples investigated. As discussed under sample descriptions, this sample was obtained imbedded within a pillar of tuff near Koko Head. It was felt that possibly its contact with the hot lava while being erupted might have degassed the initial helium content and started the helium geochronometer over again. Because of the relatively unaltered condition of this sample, it was felt to be an ideal specimen for cross checking these two geochronometer systems. Based upon the standard cc of helium obtained and an estimated value of 3 PPM of uranium, an uncorrected age of 180,000 years was obtained. (Ages were determined by the graph in Fanale and Schaeffer (83).) Gramlich et al. (79) dated the Koko Head

event at about 40,000 years. The very preliminary age of 110,000 years as obtained by the thorium-uranium method of this investigation falls into the proper sequence, but may in actuality be much older if the U4/U8 ratio is any indicator, since this gives a U4/U8 age of 350,000 years. (Keeping in mind, of course, that these ratios have tended to be too low, an increase in this ratio of only 0.3. i.e., to 1.09 would lower the U4/U8 age to 180,000 years.)

On the basis of the preliminary data discussed above, it does not appear that substantial degassing of the initial helium content of the coral occurred by the baking process of being erupted. However, at the time these helium measurements were being made, this type of helium determinations were just being investigated and many problems had to be overcome just to obtain this preliminary information. Further refinements in the technique together with improved thorium-uranium data should prove very valuable in establishing these methods as reliable sources of important geological information at this institution.

E. Proposals for Further Work

1. Tracer Equilibration

One of the desired goals of this investigation which did not materialize due to apparent spectrometer difficulties, was a study of the requirements necessary to insure equilibration between the naturally occurring uranium, and the uranium-232 tracer added as a total uranium monitor. Although this problem can be completely eliminated by determining the total uranium content of the sample via other procedures such as fluorescence, x-ray fluorescence, etc., it is much more convenient to do this simultaneously with the separation and determination of the relative isotopic ratios, since this procedure must be done anyway. Consequently, it is important to know just how vigorous the conditions must be to insure this equilibration, and yet avoid the difficulties of redissolution described previously. Once an accurately functioning spectrometer system is obtained, the studies in this investigation would become more meaningful and further work could then be built upon these.

2. Spectrometer Calibration

It was suggested in the spectrometry discussion that a disturbing influence might be external to the spectrometer system. This could be further tested by removing the spectrometer system to an entirely different environment for a period of study of the same samples. If then the same results are obtained, the problem must lie either in the spectrometer itself, or in the planchets. The evidence, however, seems to negate the latter consideration. A final test of this would be to have the planchets analyzed in an independent laboratory for comparison with the data obtained here.

While investigating the problem of low U4/U8 ratios after the first accumulation of data, there was some evidence to support the belief that the solid state detector which had been used for most of the preliminary investigations and for accumulation of most of the uranium data had undergone a peculiar radiation damage which was influencing the discrimination of the higher energy peaks. In the testing and calibration procedures, this detector had been exposed to an estimated accumulated flux of a single isotope of approximately 10^6 to 10^8 events. As noted earlier in the discussion, single isotope planchets of uranium-234 and thorium-230 had been obtained through the courtesy of Dr. John Noakes of the Oak Ridge National Laboratory. These planchets have activities of 6800 and 5200 dpm respectively. Studies available (72) indicate that alpha particles lose over 50% of their total energy by the formation of ion pairs in the last one-tenth of their range through the absorbing medium. This means that the most extensive damage to a solid state detector occurs at the depletion depth corresponding to terminal range of the alphas under investigation. Since the energies of the uranium-234 and thorium-230 are 4.77 and 4.69 MEV respectively, this means that extensive exposure of a solid state detector to these particular isotopes would generate regions of relative insensitivity and thus nonlinearity at the depletion depth corresponding to these ranges. It is

conceivable then that selective radiation damage of this type could cause a solid state detector to become selectively discriminatory of energies passing through this depletion depth, effecting those most strongly which terminate in the damaged region, and others less strongly depending on the percentage of total energy being lost in the damaged region. This would explain the increase in the observed U4/U8 ratios after switching detectors on the ND 110 system. As an additional example of this, the detector which had been used on the ND 180 system and which also had acquired an extensive exposure to these two isotopes while designing and testing a biased amplifier system, was exhibiting a low U4/U8 ratio also. This detector had a rated bias voltage of 65 volts, but had been operated since its acquisition at a bias of 60 volts. The depletion depth of a solid state detector is a function of the resistivity of the detector material and the applied biasing voltage. Since these detectors are rated for a depletion depth for 15 MEV alphas, operation at lower than the rated voltages still gives adequate depletion depth and longer life to the detectors. When the biasing voltage for this detector was raised to 65 volts, much of the discrimination of the spectrometer disappeared. For example, the U4/U8 ratio for a recent sample on this system operated at 60 volts bias was 1.119, whereas that for operation at 65 volts was 1.149. A survey of the literature indicates that no studies have been made relative to this particular selective radiation damage and its effects upon the investigation of ratios of various energy alphas from the same spectrum. Further investigation of this would be a very valuable contribution to this field.

3. Additional Ion-Exchange Studies

It was suggested in the discussion on ion-exchange, that since ethers extract iron in hydrochloric acid systems, and alcohol favors the adsorption of uranium and thorium on anionic exchangers, that methyl or ethyl glycol-hydrochloric acid systems should be effective in accomplishing this desired separation. Preliminary investigations were carried out at that time, but due to problems of inadequate methodology, were judged at that time as not adequate. Τt is felt at this time, however, that the ethylene glycolhydrochloric acid system might indeed even be superior to the presently developed acetic acid-nitric acid system for the separation of large amounts of iron from uranium and Further investigation of this as to the thorium. distribution coefficients of uranium, thorium, iron, aluminum and calcium would have to be made, particularly to evaluate the relative values for thorium, aluminum and calcium for adequate resolution. After this work, further development could then be carried out on the separation conditions for uranium and thorium.

4. Uranium-Helium Studies

Only preliminary studies of this method have been carried out to date. One of the major difficulties encountered in this work was the inability to move the helium about in the system. Since the system was initially designed for argon, which can readily be moved from one section to another by adsorption on charcoal at liquid nitrogen temperature, the total volume of the system is large and thus the sensitivity for helium is decreased. A better means of handling the helium needs to be worked out, possibly by the addition of a Toepler pump. Improvements of this type would then facilitate investigation of further baked samples such as the Koko Head sample and comparison with non-baked samples to evaluate this as to the applicability of dating volcanic events in this manner.

IV. APPENDICES

APPENDIX A

Description and Circuit Schematics for Automatic Fraction Collector

The operation and circuitry of the automatic elution control system was discussed in the main body of this dissertation. Discussed here will be the operation and circuitry connected with the three fraction collection modes: constant time, constant volume, and preset number of drops.

1. Constant Time Collection Mode

The heart of the constant time control is a disc timer of basic construction shown in Figure Al. This arrangement is "on switched" in both the up and the down positions, but is "off" in the intermediate position. This allows repetitive cycles of the collection table rotation by the "up" switch, with the subvariations of another parameter by the "down" switch. Thus, for example, the turntable can be programmed to rotate every five minutes, while some other parameter may be set to be "on" two minutes of that five, and "off" the other three minutes. This was found to be particularly valuable when characterizing the effluents of various columns and separation schemes requiring large volumes of elution solutions by using a solenoid controlled diverting valve (see Fig. Al) and collecting only a portion

of the total effluent from the column. The block diagram schematic for the constant time control is shown in Figure A2 and should be self-explanatory.

2. Constant Volume Collection Mode

A block diagram for circuitry associated with this mode is given in Figure A3 and will be referenced to in the following discussion. The power supply circuitry is given in Figure A4 and will not be further discussed.

As discussed previously, this mode can operate in one of two ways. Either the effluent can be collected into a reservoir and dumped when a preset volume is obtained, or it can dispense directly into the collection tubes and cause rotation at a preset volume. To utilize this latter mode, the flow rate through the column must be five seconds per drop or less, as the turntable requires five seconds to complete rotation to the new position. If faster flow rates are required, then it is necessary to use the reservoir mode.

For the reservoir mode, the volume is determined by placement of a thermistor at a level within the reservoir that contains the desired volume (see Fig. 4, p. 31). A current is passed through this thermistor which causes a heating effect. As the liquid level rises to contact the thermistor, it is cooled, and thus increases its resistance. This increase in resistance causes a voltage drop which is

then amplified and activates a Schmidt trigger (see Fig. A5) causing rotating of the turntable through relay 1. Upon completion of the rotation, relay 2 is deactivated, applying a positive signal to the dump control circuit (see Fig. A6) which activates a timed Schmidt trigger, activating relay 3 for a preset time. Relay 3 controls the solenoid dump valve at the bottom of the collection reservoir. This timer may be set for any time up to 100 seconds.

In the direct collection mode, as the liquid level reaches the photocell sensing position, a positive going signal is generated by the photocell circuit (see Fig. A8). (This same circuit serves both for the constant volume level control and for the drop counting modes.) This signal is fed into the circuit through the 47 K resistor at position 5 and subsequently activates relay 1, causing rotation of the table. Additionally, the positive going signal from photocell circuit 2 (see Fig. 7, p. 33) associated with the changing of elution reservoirs is fed into the turntable rotation circuit at this same place through center tap C of a mini-plug to cause rotation of the turntable with a change of solution reservoirs.

3. Drop Counting Mode

The schematic for the counting circuit is shown in Figure A7. This circuit utilizes two 6 level 10 position relay stepper switches as the counters. Level 1 of each of

these stepper switches is wired one-for-one with a 10 position rotary switch for presetting the desired number of counts. As a drop passes the photocell, its associated circuitry generates a positive going signal which serves as the input to the counting circuit through the 10 K resistor at 4. This circuitry activates relay A which in turn steps RM 1 one step. When RM 1 reaches the 10th position, there is continuity through level 2 to activate relay B which then activates RM 2 one step. When the stepper positions are aligned with the rotary switch positions, there is continuity through to activate relay C, which generates a positive going signal to activate the turntable rotation circuitry, and simultaneously activates the "buzzer" system of level 4 to cause RM 1 and RM 2 to "home", i.e., to return to their unit positions. All contacts on level 3 and 4 are shorted together for the operation of this "homing" circuit. Level 3 is shorted so that relay C may become activated in all positions except the "home" position. Level 4 is shorted so that the "buzzer" may be activated by relay C in any position of the stepper switches except the "home" position. The cable interconnections between the Constant Volume Control unit, the counter unit, and the photocell units are diagrammed in Figure A9 and will not be further discussed.



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Fig. A-1 Diagram of constant time control and solenoid diverting value.



Fig. A-2 Constant time control schematic.



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FIG. A-7 COUNTING CIRCUIT



FIG.A-8 COUNTING PHOTO CELL CIRCUIT



FIG.A-9 CABLE CONNECTIONS FOR CVC, COUNTER & P.C. UNITS

APPENDIX B

Sample outputs for Programs 1, 2, and 3 arranged in the order listed in the program descriptions.

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	•.	•								
	·	• •	•••							
		•	• •							
hanananan tanan			+ 							
2 inches = 436										
P= 40	P=	69	P= 97							
H= 43	Н-	73	H= 101							
U238= 1566.0 <u>+</u>	39.6	U234= 1734.3 <u>+</u>	41.6 U232=	589.0 <u>+</u> 24.3						
R= 1,10752		T in min= 540	T in min= 540.708							
URANIUM DATA										
P= 39	P =	69	P= 97							
H= 42	Н=	72	H= 104							
U238= 1774.0 <u>+</u>	42.1	U234= 1936.4 <u>+</u>	44.0 U232=	681.0 <u>+</u> 26.1						
R= 1.09157		T in min= 613	.753							
URANIUM DATA										
:	•	•								
		•								
	•	•								
	•									
	•	• •								
	•	•	••							
	•••	• •	•							
hannan marana ka mara		vvvv1vvvvv	++++++++++++++++++++++++++++++++++++++	Corport						
2 inches = 598										
P= 40	P=	69	P= 98							
H= 43	H-	73	H= 103							
U238- 2001.0 <u>+</u>	44.7	U234= 2345.1 <u>+</u>	48.4 U232=	768.0 <u>+</u> 27.7						
R= 1.17199		T in min= 728	.257							

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URANIUM DATA Great Barrier Reef-Hammond, final. Cue 7.

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URANIUM U238= 11969.0 ± 109.4 U234= 13685.0 ± 116.9 U232= 4304.0 ± 65.6 T in min= 4329,864 R= 1.14337+ 1.4309 ex -2 THORIUM Th232- 98.0 ± 9.8 Th230- 3085.0 ± 55.5 Th228- 2616.0 ± 51.1 T in min= 7069.052 U EFF= 4.55% U238 PPM- .003 Th EFF= 2.69% Th230 PPM= 1.4136 ex -8 U-Th AGE= 30.20+1.2558 ex 1 K YRS U-U AGE= 16.08 K YRS UNCORR. AGE= 35.83 K YRS BACK CALC. U-U RATIO= 1.156 U238 dpm= 60.734 U234 dpm= 69.442 Th230 dpm= 16,203 Th230/U238= 2.6679 ex -1 TOTALED DATA FOR GBR-H, Uranium-234 correction equation. URANIUM U238= 11969.0 ± 109.4 U234= 13685.0 ± 116.9 U232= 4304.0 ± 65.6 R= 1.14337<u>+</u> 1.4309ex -2 T in min= 4329.864 THORIUM Th232= 98.0 ± 9.8 Th230= 3085.0 ± 55.5 Th228= 2616.0 ± 51.1 T in min= 7069.052

TOTALED DATA FOR GER-H, Uranium-238 correction equation.

U EFF= 4.55% U238 PPM= .003 Th EFF= 2.69% Th230 PPM= 1.4136ex -8

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 U-Th AGE(T)=
 30.66 K YRS
 U-Th AGE(C)=
 30.97 K YRS

 U-Th AGE(O)=
 30.66±
 1.2749ex
 1 K YRS
 UNCORR. AGE=
 35.83 K YRS

 U-U AGE=
 16.08 K YRS
 BACK CALC. U-U RATIO=
 1.15627

 U 238 dpm=
 60.734
 U234 dpm(O)=
 69.442
 U234 dpm(T)=
 69.092

 Th230 dpm=
 16.203
 Th230/U234(O)=
 2.3334ex
 1
 Th230/U234(T)=
 2.5309ex
 -1

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APPENDIX C

Sequential program listing for the Wang 720B computer programs developed for this investigation. Each program is accompanied by a program description page abstracting the function of the program and its operating procedure. PROGRAM DESCRIPTION: Program 1, data load and peak totals.

PROGRAM ABSTRACT: This program reads data from an 8-level axdii paper tape, loads 131 "words" of data into registers 6 through 136, determines 3 peak maxima and minima, the total counts under each peak, and formats this data on the model 702 with plotting capability.

PROGRAM DESCRIPTION: EXTERNAL MARKS USED: 409 (Uranium data analysis) 410 (Thorium data analysis) 411 (Plot data) 504 (Load data) 1401 (Record data) 1404 (Determine data type)

OPERATING PROCEDURE:

- 1. Insert tape: Press TAPE READY, RUN
- 2. Key: PRIME, LOAD PROGRAM
- 3. Key: SET P.C., 0872
- 4. Key: LEARN, STOP, END PROGRAM, RUN, PRIME
- 5. Key: 0, STORE DIRECT, 04
- 6. Insert tape 5 characters before first datum. (First datum must be preceded by a date of form xx/xx/xx.)
- 7. Key: PRIME, SEARCH, STORE INDIRECT (Program loads data, types data type and stops.)
- Press: MANUAL (Typewriter), type sample and cue number, AUTO (Typewriter)
- 9. For plot, key: PRIME, SEARCH, WRITE
- 10. For uranium data, key: PRIME, SEARCH, GROUP I

- 11. For thorium data, key: PRIME, SEARCH, GROUP II (System performs specified operations, writes, and stops.)
- 12. Key: 0, STORE DIRECT, 04, CUE #, GO
- Repeat steps 6 through 12 for each data block of sample.
- 14. After last data block of sample,
 - a. Key: 99, STORE DIRECT, 04, PRIME
 - b. Key: CUE #, SEARCH, 1401, GO
| | 0405 | -040S] | | |
|-------------------|--------------|--------------------|----|---|
| 1 | 1100 | $\frac{1100}{100}$ | | |
| ŝ | 1100 | 1100 | v | |
| 4 | 0700 | U | | |
| 5 | 0407 | SEARCH | | * |
| 7 | 0408 | HARE | ø | |
| 8 | 1101 | 1101 | • | |
| .9 | 0701 | 1 | | |
| 11 m | 10407 | SEARCH
P1 | | × |
| 12 0 | 0405 | TIARK | 4 | |
| 13 7 | 1102 | 1102 | | |
| 14 6 | 0702 | 2 | | |
| 16 P | 0609 | PI | | |
| 17 g | 3408 | HARK | Ø | |
| 18 0 | 1103 | 1103 | | |
| 19 5 | 0/03 | SEARCH | | * |
| 21 ÷ | 0609 | PI | | |
| 22 _ | 0408 | MARK | đ | |
| 23 2 | 1104 | <u>,1104</u> | | |
| 25 0 | 0407 | SFARCH | | * |
| 26 + | 10609 | PI | | |
| 27 X | 0408 | MARK | Ø | |
| 28 L | 1105 | 1105 | | |
| 10 O | 0407 | SFARCH | | * |
| 31 | 06.09 | PI | | |
| 32 8 | 0408 | MARK | ą, | |
| 33 1 | 07.06 | <u>0</u> | | |
| 35 | 0407 | SEARCH | | * |
| 36 5 | 0609 | PI | | |
| 37 = | 0406 | MARK | ŧ | |
| 10 10 | 0707 | 110/ | | |
| 40 5 | 0407 | SEARCH | | * |
| 41 o | 0609 | PI | | |
| 42 | 0405 | MARE | Ø | |
| 43 | 0708 | 8 100 | | |
| 45 | 0407 | SEARCH | | * |
| 46 | 0609 | PI | л | |
| 47 | 1109 | 11.09 | ¥ | |
| 49 | 0709 | 9 | | |
| 50 | 0407 | SEARCH | | * |
| 김아들 | 0609 | PI | , | |
| 53 = 0 | 0504 | ST INDIR | | |
| 54 2 | 0705 | 5 | | |
| 5528 | 0404 | ST DIR | | |
| 57 - | 104.03 | REG 2 | ß | |
| 582P | 1013 | 1013 | ¥ | |
| 59 0 0 | 0408 | MARK | Ü | |
| <u>60 N</u> 3 | <u>11015</u> | 1015 | | |
| 62 2 2 | 0604 | 0
1) P | | |
| 6325 | 0504 | ST INDIR | | |
| 64 ⁻ 1 | 0404 | ST DIR | | |
| 66 F - | 104.03 | EARE] | С | |
| 6722 | 12800 | 0800 | | |
| 684-6 | 0409 | GRULP 1 | | |
| 69 + + | 0301 | 1030 | | |
| 51ª Å | 6501 | 06.01 | | |
| 72 | 0405 | MARK | ø | |
| 73 | 0000 | | | |
| 74 | 0701 | | | |
| | | - | | |

76±±±	0700	0 V INDIR	
7800.	0701	1	
79 0 3	0400	+ DIR RFG 1	
814 C	0409	GROUP 1	
82 54	0501	0501 GEOUP 1	
84 84	0881	0801	
85 86	30408	MARK 1000	C
87 n.	0408	NARK	Ø
88 5		OSI3 MARK	5
90 E	0130	0810	•
91 0 -	0415	REY REG 2	
93 co	0701	1	
94 ~	0703	3	
96	0508	SKIP YsX	
97	0407	SEARCII 1500	1
99 0	0415	REY	
100+	0001	REG 1	
102 20	0507	SKIP Yg=X	
103 0 3	0407	SEARCH	,
105 0	0405	MARK	ø
1069	1502	1502	съ
108	0405	RE DIR	JK
	0000	REG O	
11107	0401	- DIR	
1123	0504	ST INDIR	
1145	1615	1015	
115	0408	NARK	₽
117	0701	1	
11800	0703	3	
120 Q	0503	SKIP YsX	
121 \$	0407	SEARCH	,
123	0415	REY	
124+0	0001	REG 1	
126 26	0507	SKIP Yg=X	
127 23	0407	SEARCH	,
129+m	0407	SEARCH	1
1300	1502	1502 NAREI	
132 0	1404	1404	•
13352	0415	REY PEC 136	
135+4	0701	1	
136 0	0509	SKIP Y=X	
136	1506	1506	
139	0412	WR A	
141	0214	U	
142 0	0113	R	
144 0	0206	2	
145 D	0104	I	
147 2 .	0115	M	
148	0002	SPACE	
147 S	10213	U	

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URANIUM-THORIUM AGE DATING PROGRAM 1, REVISED VERSION.

133

150 1551 1553 1554 1556 1558 1559 1661 1662 1665 1665	0112 0207 0112 0413 0515 0515 0515 0403 0300 0305 0300 0305 0703 0703 0703 07	A T A SIL DOWN END A STOP STOP NANK GROUP 1 0300 0305 3 2 3 KEY KFG 13	∉ SR(Find P & H) SR(Sum A's)
166 167 168 169 170 171 172 173 174 175 175 176 0	0602 0705 0707 0603 0712 0705 0603 0605 0605 0608 0415 0608	X S S S S S S S S S S S S S S S S S S S	
17790 DUE +35 562 JO	0000 0601 0414 0004 0415 0010 0415 0002 0306 (0415 0306 (0415 0701 0701 0701 0703 0703 0703 0708	KEG B STY REG 4 REY 10 5 STY REG 10 STY REG 1 REY REG 1 0 3 3	Sk(Sum A)
1930 194 195 196 197 198 199 200 201 202 203 204 205 206 206 207 207	0602 0605 0401 0514 0514 0514 0307 [0412 0103 0214 0102 0305 0314 0312	A DOWN - DIR REG 16 GO 0307 WR A SH UP U SH DOWN 2 3 8 -	SR(Wr. P & H)
2007+2210 2102+2214 2112 = x x x x x x x x x x x x x x x x x x	0413 0202 0412 0103 0214 0103 0214 0306 0314 0309 0413 0203 0413 0203 0412 0103	END A 0202 WR A SII UP U SH DOWN 2 3 4 END A 0203 WR A SH UP	SR(inc. reg & Wr. Ø) SR(Wr. Ø)
223 N 224 N 225 N	0214 0102 0306	U SH DOWN 2	

226	10314	3	
221	0300	2	
220	0613	END A	
230	0203	0203	SR(Wr C)
231	10415	REY	58(41. 2)
232	0106	REG 16	
233	0405	RE DIR	
234	0015	REG 15	
235	0603	+	
236 Z	0314	0314	SR(CR/LF)
23/ -	0412	WR A	
230	10103	SH UP	
240		SH DOUN	
241 0	0005	511 DOWN	
242 3	0413	END A	
243	0605	DOWN	
244	0411	WRITE	
245	0105	0105	
246	10411	WRITE	
247	U 51 5	1515	CD (1) (T)
240	0/07	USIU SEADON	SK(Wr. 1)
250	1401	1401	-
251	10203	1401	C
252	1506	1506	•
253	0412	WR A	
254	0103	SH UP	
255	02 07	Т	
256	0201	н	
257 ₽	0109	0	
258 2	0113	R	
259 0	0104	1	
261		U M	
262	0002	SPACE	
263 5	0213	D	
264 3	0112	Ă	
265	0207	Т	
266	0112	Λ	
267	0102	SH DOWN	
208	10413	END A	
209	0515	STOP	
271	6673		0
272	6410	GROUP 2	•
273	0300	0300	SR(Find F & H)
274	0305	0305	SR(Sum A's)
275	0307	0307	SR(Wr. P & H)
276	0412	WR A	
277	0103	SH UP	
278	0207	T DOWN	
279	0201	SH DOWN	
281 10.	10305	2	
2821~ ~	0314	3	
283	0306	2	
284	0006		
285-	0413	END A	
286	02.02	0202	SR(inc. reg.
287	0412	WR A	& Wr. 0)
200×	10103	SH UP	
2020	10207	SIL DOUS	
291-0	10201	h DONA	
262+ m	10306	2	
293 ℃ ~	10314	3	
2943	0301	0	
295	0006	-	
296	0413	END A	an (
297	0203	0203	5K (Wr. 2)
290	0103	WK A SU UP	
~ / /			

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300 301 302 303 203 304 305 306	0207 0102 0201 0306 0306 0312 0006	T SII DOWN h 2 2 8		375 376 377 378 379 380 381	07 05 04 12 09 06 04 13 03 04 97 01 07 03	5 WR A END A 0304 1 3	SR(inc. counter)
307 308 309 310 311 312	0203 0314 0310 0407 1401	6203 0314 0310 SEARCH 1401	SR(Wr. f) SR(CR/LF) SR(Wr. T)	382 383 384 385 386 387	0507 0407 1504 0405 0003	4 SKIP Yg=X SEARCH 1504 RE DIR REG 3 CH SICH	*
314 315 316 317 318 317 318	0411 0707 0404 0002 0604	NRITE 7 ST DIR REG 2 UP ST DIR	v	100 389 391 391 392 393 393 393 393	0604 0705 0601 0706 0703	UP 5 - 6 3	
320 E 321 322 323 324 325 \$	0001 0404 0003 0408 1503 0505	REG 1 ST DIR REG 3 NARK 1503 RE INDIR	0	395 + 01d 397 - 10 398 - 399 399 - 400	0711 0412 0907 0413 0700 0604	CH SIGN WR A I END A O UP	
326 P 327 E 328 L 329 Q 330 C 331 C	0415 0001 0507 0404 0001 0304	REY REG 1 SKIP Yg=X ST DIR REG 1 0304	SR(inc counter)	401 402 403 404 405 406	0504 0408 1505 0700 0604 0701	ST_INDIR MARK 1505 0 UP 1	0
332 333 334 335 336 337 337	0701 0703 0704 0507 0407 1503	1 3 4 SKIP Ye=X SEARCH 1503	*	407 3 85510 408 409 410 5510 411 2412	0700 0412 0800 0413 0701 0400	O WR A END A 1 + DIR	
339 340 E 341 E 342 C 343 C	0701 0700 0711 0604 0705	1 0 CH SIGN UP 5 WR A		414 415 416 416 417 418 419	0415 0000 0707 0700 0507 0407	REG O REY REG O 7 O SKIP Yg=X SFARCH	ŧ
345 0 346 0 347 348 349 ••0	0102 0108 1108 0413 0707	SH DOWN CR/LF 1108 END A 7 UP		420 421 422 U 423 423 424 425	1505 0700 0604 0701 0700	1505 0 UP 1 0	
351 E Q 352 353 354 E Q 355 E Q	0404 0002 0408 1504 0505 0604	ST DIR REG 2 HARE 1504 RE INDIR UP	Ø	426 427 428 429 430 431 +	0711 0412 0907 0907 0907 0907	CH SIGN WR A I I I	
357 P 358 359 CUR 360 0 361 362 C	0405 0001 0603 0702 0412 9702	RE DIR REG 1 2 WR A 2		432 0 433 0 434 435 436 437	0907 0907 0413 0314 0405 0001	I END A O314 REDIR REG 1	SR(CR/LF)
363 10 364 pc 365 x pc 366 x pc	06 02 04 05 00 03 06 01 07 12 07 05	X REDIR PEG 3 - 5		438 439 440 X 441 V 442 E 442 I	0412 0306 0002 0104 0206 0212	WR A 2 SPACE 1 n c	
369 E - 370 0+ 371 E 372 U 373 U 374 E	0000 0605 0608 0400 0003 0604	+ DOWN INT X + DIR REG 3 UP	X 100	4445 U Z U Z U Z U Z U Z U Z U Z U Z U Z U	0201 0205 0101 0002 0006 0413	h e SPACE END A	

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451 0400 0400 452 0314 0314 SR(CR/LF) 453 0515 STOP 454 454 12408 MARK 0 455 10300 0300 SR Find P & 456 10702 2 2 457 0604 UP 1 458 0604 UP 1 459 10404 ST DIR 6002 460 20002 REG 2 461 0707 7 1 463 0005 REG 5 464 12408 MARR # 463 0025 7 1 464 12408 11201 #	н
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	н
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	н
455	<u>_n</u>
456 0, 6702 2 457 2, 6604 UP 459 1, 0604 UP 459 2, 0604 ST DIR 460 2, 0002 REG 2 461 0707 7 462 0404 ST DIR 463 0005 REG 5 464 0408 HARR 8 465 0, 201 1201	
457 L 0700 0 458 . 0604 UP 459 ± 0404 ST DIR 460 ± 0002 REG 2 461 0707 7 462 0404 ST DIR 463 0005 REG 5 464 0408 MARR 8 465 0401 1201	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	
460 ⊆ 0002 REG 2 461 0707 7 462 0404 ST DIR 463 0005 REG 5 464 0408 MARK 0 465 0201 1201	
462 0404 ST DIR 463 0005 REC 5 464 0408 MARK 6 465 0201 1201	
463 0005 REC 5 464 0408 11ARK 6 465 1201 1201	
464 [0408 MARK] Ø 465 [020] 120]	
466 5 0703 3	
467 8 2 0701 1	
468 = 00000 + 0000 + 0000000 + 00000000000	
4705 E 0004 REG 4	
471 5 8 0415 REY	
4/2 & 20002 REG 2 2739 60301 0301 SP(find may	1
474 • C 0415 REY	• /
475 + 0002 REG 2	
$\frac{477}{478} + \frac{10701}{10701}$	
479 0507 SKIP Yg=X	
480 0407 SEARCH *	
482 [J405 HARK]	
483 1203 1203	
484 10415 REY 485 10007 REC 7	
486 0706 6	
487 0600 +	
488 10414 STY 489 10004 REG 4	
490 0702 2	
491 0705 5	
493 C414 STY	
494 0002 REG 2	
497 0 0001 REG 1	
498 5 0201 0201 SR(sum A)	
499 U 10405 RE DIR 500 10010 PEC 10	
501 \(\lappa\) 10010 REG 10	
502 0 0412 WR A + 10	
$503 \cdot 10401 - D1R$	
505 7 1307 REG 137	
506 U 0701 1	
507 10700 0 509 10404 ST DTR	
509 10005 REG 5	
510 0415 REY	
511 0007 REG 7 512 0303 0303 SR(find min	١.
513 (0415 REY	• /
514 .0003 REG 8	
515 10303 0303 SR(find min 516 10415 PFY	•)
517 0009 REG 9	
518 0303 0303 SR(find min	.)
520 10408 11XRK	
521 0301 0301 SR Find nax	
522 0700 0 523 0704 ST DTP	
524 10000 REG 0	

525	0405	HARKI	Ø
526	1508	1508	
527	10505	RE INDIR RYY	
529	0000	REG O	
530	0507	SKIP Yg=X	
531	10404	ST DIR RFC 0	
533	0507	SKIP Ye=X	
534	0302	0302	SR(st. reg. #)
535	10514	GO 0204	SP (1no
537	0405	RE DIR	counter)
538	0004	REG 4	
539	0508	SKIP YsX	50/00 000
540	0511	RETURN	reg ()
542	0407	SEARCH	*
543	1508	1508	- <u></u>
545	10302	0302	SR Store reg.
546	6405	REDIR	<u>BR BEBIE HERE</u>
547 '	0002	REG 2	
548	0404	ST DIR	
550	0511	RETURN	
551	0408	MARK	9
552	0303	0303	SR Search min.
554	0004	REG 4	
555	0414	STY	
556	0002	REG 2	
558	0700	ō	
559	0600	+	
560	0605	DOWN	
562	10004	REG 4	
563	0604	UP	
564	0701	1	
566	0703	2K A 3	
567	0404	ŠT DIR	
568	0000	REG 0	#
570	1204	1204	¥
571	0505	RE INDIR	
572 -	0415	REY	
576	105.08	SKTP Yex	
575	0200	0200	SR(st. min.
576	0511	RETURN	reg. #)
578	0415	REY REC D	
579	0508	SKIP YEX	
580	0404	ST DIR	
581	0000	REG 0	
583	0302	0302	SR(st. reg. #)
584	0514	CO	
585	0304	0364	SR(inc.
587	0004	REG 4	countery
588	05 08	SELP YSX	
589	0200	0200 PETURN	SR(st. min.
591	0407	SEARCH	t CS V)
592	1204	12 04	
593	0408	MARK	SR Find Die
595	10701	<u>1</u>	and A's
596	0705	5	
597 598	0404	ST DIR REG 5	
599	0415	REY	

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				1.			
600	0009	REG 9		75	0701	1	
601	0405	RĽ DIR		676	0400	+ DIR	
602	0008	REG 8		677	0002	REG 2	
603	0601	-		678	0415	REY	
604	0414	STY		679	0002	REG 2	
605	0000	REG O		680	0511	RETURN	
606	0604	UP		681	p408	MARK	g St. max,
607	04 05	RE DIR		682	<u>p200</u>	0200	SR min, or A
608	0007	REG 7		683	0415	REY	
609	0601	-		684	0005	REG 5	
610	0414	STY		685	0405	RE DIR	
611	0003	REG 3		086	0001	REG 1	
612	0405	RE DIR		687	0504	ST INDIR	
613	0010	REG 10		688	0701	1	
614	0404	ST DIR		689	0400	+ DIR	
615	0004	REG 4		690	0005	REG 5	
616	0606	EX		691	0511	RETURN	
617	0601	-		692	0408	MARK	
618	0701	1		693	0307	0307	SR WF. F & H
619	0702	2		694	0707	7	
620	0507	SKIP Yg=X		695	0404	ST DIR	
621	06 04	UP		696	0002	REG 2	
622	0514	GO		697	0604	UP	
623	0414	STY		698	0408	HARK	Ø
624	0002	REG 2		699	<u>p 5 0 9</u>	1509	
625	0306	0306	SR(set fop £A)	/00	0505	RE 1NDIR	- (E ah (⁶)
626	0405	RE DIR		/01	0309	0309	SRK-5 CH. FJ
627	0010	REC 10		702	0311	0311	SR(wr. P)
628	0404	ST DIR		/03	0312	0312	SR(wr. 0)
629	0002	REG 2		/04	0701	1	
630	0405	RE DIR		105	0700	0	
631	0011	REG 11		706	0508	SKIP YSX	
632	0404	ST DIR		/0/	0314	0314	SR(CR/LF)
633	0004	REG 4		708	0514	GO	
634	0306	0306	SR (set for EA)	209	0508	SKIP YSX	•
635	0405	REDIR		/10	0407	SEARCH	*
636	0012	REG 12		<u>/11</u>	1202	1202	
637	0404	ST DIR		412	0407	SEARCH	*
638	0004	REG 4		113	1509	1509	
639	0405	REDIR		<u>{</u> 14	0408	MARK	v
640	0011	REG II		415	1202	<u></u>	
641	0404	ST DIR		419	0505	KE INDIK	CD(5 -1 4)
042	0002	KEG Z		710	0309	0309	SK(-5 Ch. 4)
643	0306	0306	SK(set for 2.A)	/10	0313	0313	SR(Wr. n)
044	0405	KE DIR		719	0312	0312	SK(WT. V)
645	0003			720	0701	1	
640	0404	SI DIR		721	0703		
647	0013	KEG 13		722	0508	SKIP ISA	CD(CD(ID)
048	0405	RE DIR		725	0314	0314	SRUCRILI
649	0000			724	0514		
650	0404	SI DIR		725	0500	SKIP JSA DETUDN	
051	0014	KLG 14 DETUDN		727	0511	REIURN CO	
652	0511	MADE		729	0/07	CEADCU	4
653	0306	02.06	ED Con for St	720	1202	1202	
655	6700	0.00	JN JEL TUT CA	730	72.02		
656	0404	ST DIP		731	13.02	0308	SH Wr + 1/2
657	0001			7 3 2	- 1,5,5,5,	<u></u>	
658	0204	0204	SR(inc up lin)	7 3 3	0103	SH HP	
650	0204	0304	SR(inc. counter)	736	0006	-	
660	04.08	MARK	a	7 3 5	0003	BK SPACE	
661	6201	0201	SP Sum A	736	0000	DR DINOL	
662	0505	DE LUDID	SK SUU K	717	0102	ราย อุกษณ	
663	0/00			738	0/13	END A	
666	.0001	RFC 1		7 3 9	0612	SORX	
665	0304	0304	SR(inc counter)	740	0211	WRITE	
666	0405	REDIR	sa (inc. councer)	721	0301	0301	
667	0004	RFC 4		7 42	0511	RETURN	
668	0507	SETP YouY		743	0110	MARE	
669	0200	0200	SR(store sum)	744	63.69	(13(19)	SR - 5 ch. #
676	0511	RETURN	sulprove anmy	745	6666	UP	
671	0407	SEARCH	*	746	0705	5	
672	0201	0201	SR(sum A)	747	0601	-	
673	0403	THARK		748	0005	DOWN	
674	0304	0304	SR_Inc,_counter	749	0511	RETURN	

0408	HARK		825	1308	1308	
02.05		SR WT. 1	827	02.02	SI DIR RFG 22	
0000	REG 6		828	6404	STDIR	
0412	WR A		829	0000	REG O	
0403	: DIR		830	0405	RE DIR	
0404	ST DIR		831	1309	REG 139	
0006	REG 6		832	0404	ST DIR	
1201	RE DIK		833	0203	KEG 23	
1304			835	0001	EFC 1	
0006	REG 6		836	0700	0	
9412	WR A		837	0404	ST DIR	
0103	SH UP		838	1308	REG 138	
0207	т		8 3 9	0407	SEARCH	*
0102	SH DOWN		840	1406	1406	
0002	SPACE		841	0408		v
0206	1		841	04.05	DE DIP	
0002	SPACE		844	02 02	REG 22	
0115	n		845	0404	ST DIR	
0104	1		846	1308	REG 138	
0206	n		847	0468	MARK	C
0006	-		848	<u>n202</u>	0202	SRSet Ur. EA
0413	ERD A		849	0304	0304	SR(inc. count.)
0405	NE DIR		851	0104	<u> </u>	SK(INC. COUNT.)
0411	WEITE		852	6203	0203	SR Wr. SA
0503	0503		853	0505	RE INDIR	
0314	0314	SR(CR/LF)	854	0315	0315	SR(wr ∉€A)
0314	0314	SR(CR/LF)	855	0308	0308	SR (wr. <u>+</u> A)
0511	RETURN	····	856	0411	WRITE	
0406	6311	SP UP Pr	050	1505	1000	
0212-		3K WI. 10	859	64.08	MARY	7
0103	SHUP		860	6315	0315	SR WT. # EA
0005	P		861	0411	WRITE	
0102	SH DOWN		862	0501	0501	
0006	-		863	0304	0304	SR(inc. count.)
0413	END A		864	0511	RETURN	
04.05	MARE		866	0204	02.04	SE limit
0312	0312	SR Wr Ø	867	0701	1	
0411	WRITE		868	0400	+ DIR	
0300	0300		869	0004	REG 4	
0411	WRITE		870	0511	RETURN	
1313	1312	Skiine nount)	372	0000	0000	
0511	RETURN	Sa(fac. count)	873	0000	0000	
0408	HARK		874	0408	MARKI	¢
0313	0313	SR Wr. H=	875	2406	1406	
0412	WR A		876	0410	GROUP 2	
0103	SH UP		877	0715	CLEAR X	
0201	H SH DOUN		0/0 870	0407	SEAKCH SVTP V-V	*
0006	an boun		880	0509	END PROC	
0413	END A		550	0712	1.1.0 1 1.00	
0511	RETURN					
0405	LIAEK	<i>a</i>				
0314	0314	SF CR/LF				
0412	HK A					
0108	CR/LF					
0413	END A					
0511	RETURN					
0408	HARK]	0				
1401	1401					
6515	STOP					
0404	ST DIR					
0405	NEG D PEDTR					
13.06	REG 136					
0404	STDIR					
0108	REG 18					

PROGRAM DESCRIPTION: Program 2 and 3 data block collation and age calculation using U-238 age correction equation for program 2 and U-234 correction equation for program 3. Theoretical data based on an initial U4/U8 ratio of 1.150 is also calculated for program 3.

PROGRAM ABSTRACT: This program collates data from individual blocks of data previously stored on data tape cassettes and calculates the necessary age data.

PROGRAM DESCRIPTION: EXTERNAL MARKS USED: 404 (Load data from cassette.)

OPERATING PROCEDURE:

- 1. Insert tape: Press TAPE READY, RUN
- 2. Key: PRIME, LOAD PROGRAM
- 3. Key: 0, STORE DIRECT, 04
- 4. Key: CUE #, SEARCH, STORE DIRECT (Computer searches data tape for data set with proper cue #, collates data and stops.)
- 5. Key number of days between chemical separation and counting time, GO. (System calculates correction to U-232 peak for Th-228 daughter ingrowth, calculates a background correction (if any) and prints "TOTALED DATA FOR" then stops.)
- Press: MANUAL (Typewriter), type sample name, AUTO (Typewriter), GO. (System prints collated and corrected data, stops.)

- 7. Key: Sample weight, GO
- 8. Key: Thorium beta efficiency as a fraction, GO.
- Key: Thorium beta efficiency error as a fraction,
 GO.

(System makes all calculations, prints results, and stops.)

PROGRAM 2: URANIUM-THORIUM AGE, URANIUM-238 CORRECTION EQUATION.

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	r 0303	0303	SR(set reg. 0-4	1 75 6	0400	+ DIR	
1	0515	STOP	=0)	49.2	0307	KEG 37	•
2.0	0404	STDIR		10 2	0512	LOAD PROC	-
10	10308			79 7	0408	MARY	
4 -	10405	REDIK REC 100		80 l	1400	1400	•
с н 6 н	10000	ST DIP		8146	0405	REDIR	
70	0202	RFG 22		820 1	0901	REG 91	
8	0405	REDIR		83.651	0404	ST DIR	
ĞΕ	1001	REG 101		8404	1001	REG 101	
10 ដី	0404	STDIR		85 ** *	0415	REY	(=) · · · · ·
11 00 <	0203	RE: 23		86 4	0307	REG 37	(Th time)
12 ដំ	0404	ST DIR		87.0	0408	MARK	•
13 ๛	0901	REG 91		88m H	0404	ST DIR	
14	0700	0		8958	0712	:	
15 0	0404	ST DIR		90 <u>é 8</u>	0700	0	
100	11001	REG IUI	•	3155J	0702	2	
1/	0407	SEAKCH	-	34 J. J	0705	2	
10		NADY	1	97 20	0602	ž	
20.	10500	STIP V=Y	•	65.84	0605	DOWN	
21 6	0415	REY		66	0401	- DIR	
22 2	0005	REG 5	(data cue)	97 l	0304	REG 34	(Th-230)
23	0405	RE DIR		98	0415	REY	
24 -	0308	REG 38		99	0306	REG 36	(U time)
25 2	0509	SKIP Y=X		100	0712	•	
26 e	0407	SEARCH	*	101	0700	0	
27	0513	LOAD PROG		102 8	0700	0	
28 <u>u</u>	0415	REY		103 N 🛒	0709	9	
29 - 29	0004	REG 4		10452	0/02	2	
30	0709	9		105	0602	X	
31 -	0709	y Cyto V-Y		102 - 5	0603	- DIP	
37 .	0/07	SKIP ISA SEARCH	*	108 24	0302	REC 32	(11-232)
3, 3	1400	1400	-	1000		STOP	(0-25-)
150	0415	REY		îĭó	0604	UP	
36×	0108	REG 18		īīi	0404	ST DIR	
37 2	0701	1		112	0001	REG 1	
38 .	0509	SKIP Y=X		113	0702	2	
39 0	0407	SEARCH	*	114	0706	N 6	
40	L 1506	1506		115	0704	m 4	
41	[0405	REDIR	(116	0710	∾ SET EXP	
42	0015	REG 15	(0-238)	11/	0/11	SCH SIGN	
43	10400	+ DIK		118	0700	~ 0	
44	0300	KEG 30		119	0/04	57 D T D	
43 8	0106	RE DIR	(11-234)	120	0002		
47 8	0400		(0-204)	122	0602	X	•
48	0301	REG 31		123	0605	DOWN	
49 -	0405	REDIR		124	0711	CH SIGN	
50 u	0107	REG 17	(U-232)	125	0614	e-X	
51 4	0400	+ DIR		126	0404	ST DIR	
52 🛋	0302	REG 32		ے 127	0000	REG 0	
53 7	0405	RE DIR	(IL time)	128 2	0604	UP	
54 ö	0006	REG 6	(U=CIMe)	129 6	0701	1	
22	0400	+ DIK		130 8	0700	0	
20	0305	KEG 30	•	111 6	0/00	CT DIB	
59	0513	TUAD PROC	-	111 -	0004	RFC 4	$(A^{\circ} U - 232)$
50	80203	MARK	•	134 8	0602	x	
60	1506	1506	-	135 N	0414	STY	
61	0405	REDIR		136 L	0005	REG 5	(A U-232)
62	0015	REG 15	(Th-232)	137 🛱	0415	REY	
63	0400	+ DIR		138	0001	REG 1	
64 🗒	0303	REG 33		139 5	0709	9	
65 🕫	0405	RE DIR	(=1, 220)	140 🛶	0709	60 9	
66 7	0106	REG 16	(IN-230)	141 ~	0704	N 4	
97 F	0400	+ DIR		142 m		SET EXP	
28	0304	KEG 34		143	0,11	F CR SIGN	
70	0107	RE DIK	(Th-228)	145	0701	~ ~	
71 9	10200	+ DIR	(22 0)	126 .4	0404	ST DIR	
72 I	0305	REG 35	•	147 L	0003	REG 3	
73 0	0405	REDIR		148 9	0602	X	
74 0	0006	REG 6	(Th time)	149	0605	DOWN	

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0711 CH SIGN		225	0006	-	
0614 e-X		226	0413	END A	
0401 - DIR 0000 BFG 0		228	0300	REG 30	(U-238)
5 REY	() == 0.08)	229	0411	WRITE	
3 REG 3	() Th-228)	230	0501	0501	SR/WE ± X
2 REG 2	(λ U-232)	232	0411	WRITE	
-		233	1503	1503	
S REDIK	(λ U-232)	234	0103	SH UP	
6 EX		236	0214	U Down	
3 + ' 5 DOWN		237	0102	2	
XDIR		239	0314	3	
REG 0		240	0309	4	
REG 4	(A [°] U-232)	242	0413	END A	
X DIR		243	0405	RE DIR	(11 - 234)
REG U		244	0411	WRITE	(0 20))
REG O	(A Th-228)	246	0501	0501	
REY		247	0306	0306 URITE	SR(wr ± X)
0 +		249	1503	1503	
6 EX		250	0412	WR A	
		251	0103		
2 REG 32	(U-232)	253	0102	SH DOWN #	
2 X		254	0306	2	
1 – DIR		256	0306	2	
2 REG 32	(corr. U-232)	257	0006	-	
8 NAKK 1 WRITE		258	0413	RE DIR	
2 WR A		260	0302	REG 32	(U-232)
SH UP		261	0411	WRITE 0501	
ò		263	0306	0306	SR(wr ± X)
/ T		264	0412	WR A	
L		266	0108	CR/LF	
E		267	0103	SHUP	
SPACE		268	0102	K SH DOWN	
3 D		270	0006	-	
		271	0413	END A	
		273	g 0301	REG 31	(U+234)
2 SPACE		274	0405	RE DIR	(11-238)
4 F 9 0		275	.10603	REG 30	(0-200)
3 R		277	9 06 05	DOWN	
Z SPACE Z SH DOWN		278	0308	ST DIR REG 38	(R)
3 END A		280	0411	WRITE	••
5 STOP		281	0105	0105 BEV	
3 SH UP		283	0301	REG 31	(U-234)
4 U		284	0605	DOWN	
LJ R 2 A		285	0612	EX	
16 N		287	0603	+	
04 I		288	F 0605	DOWN	
L4 U L5 M		290	F 0404	STDIR	
2 SH DOWN		291	0001	REG 1	
B CR/LF		292	20415	REG 30	(U-238)
3 SH UP		294	5 0605	DOWN	
4 U 2 CH DOUN		295	.]0612	SQRX	
$\frac{12}{6}$ Sn DOwn		297	2 0603	+	
14 3		298	00005	DOWN	
214 Q		233	0/15	SUK	

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300 301 302 303 304 305 306 307 309 310 312 313 312 313 315 316 317 318 319	04 00 0001 04 05 0001 06 12 04 15 03 08 06 05 03 00 04 11 15 15 03 04 04 05 04 05 03 00 04 11 15 15 03 06 04 05 04 05 00 06 05 00 06 05 00 05 000000000000	+ DIR REG 1 REG 1 SQRX REG 1 SQRX REG 38 X DOWN 0300 0304 WRITE 1515 0310 REG 16 REG 36 WRITE 0503 WR A CR/LF	(R) SR(wr. ±) SR(wr. exp numb SR(wr. T) (U time)	375 376 377 378 380 381 382 383 384 385 386 386 387 388 389 390 391 392 393 394 394 394 394 394 394 394 394 394	0413 0405 0305 0411 0306 0412 0108 04108 04108 04108 04108 0405 0310 0411 0503 0411 0503 0411 0503 0412 0108 0108 0108 0109 0413	END A RE DIR REG 35 WRITE 0306 WR A CR/LF END A 0310 RE DIR REG 37 WRITE 0503 WR A CR/LF CR/LF CR/LF END A	(Th-228) SR (wr ± X) SR (wr T) (Th time)
321 322 323 324	01 08 01 03 02 07 02 01	CR/LF SH UP T H		396 397 398 399	0404 0007 0515 0404	ST DIR REG 7 STOP ST DIR	(sample wt)
325 326 327 328	0109 0113 0104 0214	O R I U		400 401 402 403	0008 0515 0404 0009	REG 8 STOP ST DIR REG 9	(Th-234 eff) (Th-234 eff err)
329 330 331 332 333 334 335 336 336 338 338 339	0115 0102 0108 0108 0103 0207 0102 0201 0306 0314 0306	M SH DOWN CR/LF CR/LF SH UP T SH DOWN b 2 3 2		404 405 406 407 408 409 410 411 412 413 413	0415 0302 0302 0700 07002 07002 07002 07002 07002 07002 0000 0404 0404	REY REG 32 2 0 5 4 5 5 4 5 5 5 4 5 5 5 4 5 5 5 4 5	(U-232)
340 341 342 343 344	0006 0413 0405 0303 0411	END A RE DIR REG 33 WRITE	(Th-232)	415 416 417 418 419	0405 0306 0603 0414 0010	RE DIR REG 36 + STY REG 10	(U time)
345 346 347 348	0501 0306 0411 1503	0501 0306 WRITE 1503	SR (wr. ± X)	420 421 422 423	E 0301 0405 0302	REY REG 31 RE DIR REG 32	(U-234) (U-232)
349 350 351 352 353 354	0412 0103 0207 0102 0201 0306	WK A SH UP T SH DOWN h 2		424 425 426 427 428 429	0405 0001 0602 0414 0012	RE DIR REG 1 X STY REG 12	
355 356 357	0314 0301 0006	3 0		430 431 432 477	0415 0300 0405	REY REG 30 RE DIR	(U-238)
358 359 360 361 362 363	0405 0304 0411 0501 0306	RE DIR REC 34 WRITE 0501 0306	(Th-230) SR(wr. ± X)	4 3 4 4 3 5 4 3 6 4 3 7 4 3 8	06036 0709 0709 0712 0709 0712 0704 0704 0704 0704 0704 0704 0704 070	+ 2 4 9 • 4	(0-252)
364 365 366 367 368 369 370 371 371 372 374	0411 1503 0412 0103 0207 0102 0201 0306 0306 0312 0006	WRITE 1503 WR A SH UP T SH DOWN h 2 2 8		439 440 441 442 443 444 445 445 446 445 446 448 449	n 7077.7 - 0 7708 - 0 0405 0405 0405 0413 0413 0415 0405 0415 0405	A 7 B 8 RE DIR REG 7 + STY REG 13 RLY REG 30 RE DIR	(sample wt) (U-238)

(1) WATER STREET, ST STREET, ST STREET, STR

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450	E	0302	REG 32	(U-232)	525		0701	5	
451	÷	0603			527		0603	÷	
453	80	0001	REG 1	(U-232dpm/100))	528	6 1	0605	DOWN	
454	9	06 02	X	• •	529	8	0611	LN X	
455	5	0414	STY		530	୍ୟୁ	0711	CH SIGN	
456		L0011	REG 11		531	5	0604	012	
457		0415	REY	(Th 23/ aff)	232	5	0702	2	
458		0712	W REG 8	(11-254 611.)	534		0700	1 1	
460-		1 07 65	9 7 9 7		535		C710	N SET EXP	
461	3	07.06	86		536		0711	L CH SIGN	
462-		07.09	9 عـ		537		0700	- ₀	
4635	· _	07 08	₩ 8		538		0705	~ 5	
4640	E E	06 02	X		539	j	0404	STDIR	
405		0414	511		540		0603	REG J	
400	1	66415	REG 20 REV		542		0414	STY	
468	-	0304	REG 34	(Th-230)	543	i	0204	REG 24	
469	Ľ,	04 05	REDIR		544		0701	1	
470	P	0307	REG 37	(Th-time)	545		0700	0	
471	01	06 03	+		546		0404	ST DIR	
472	23	0405	REDIR	(overall Th off)	5/9		0005	NADV	,
4/3	1	0208	ALG 20	(overall in ell.)	549		1500	1500	F
475	1	0414	STY		550		0415	REY	
476	1	02 09	REG 29		551		0203	REG 23	(corr age)
477	1	04 05	RE DIR		552		0702	2	
478		0007	REG 7	(sample wt.)	553		0507	SKIP Yg=X	•
479	я	06 03			224		1503	5EARCH 1503	•
480	ă	0704	~ ~		556		0712	1000	
482	5	0707	E 7		557		0709	9	•
483	21	0700	φÖ		558		0709	è	
484	5	0700	0 _		559		0602	X	
485	÷	06 0 3	H +		560		0414	STY 22	
486	F	0414	STY DEC 21		201		0203	XEG 23	
407		0215	REY		563		0701	i	
489		02 09	REG 29	(Th-230 dpm)	564.		0705	5	
490		04 05	RE DIR		565		0415	REY	
491		0011	REG 11	(U-238 dpm)	566		0002	REG 2	(λ Th-230)
492	i	06 03	•		567		0602		
493		0/01	1		560	ě	0000	BEC 0	
495		0600	-		570	9	0415	REY	
496		0605	DOWN		571		0002	REG 2	(λ Th-230)
497	80	0412	WR A		572	H	0405	RE DIR	, · · · ·
498	~	0610	LOG X	SKIP	573	õ	0003	REG 3	(λ U-234)
499	1	0407	SEARCH		5/4	U	0601	PE DTD	
500	Ē	0611	1302		576	E	0300	RFG 30	(11-238)
502	ũ	0711	CH SIGN		577	- ŭ	0602	X	(,
503	-51	06 04	UP		578	44	0605	DOWN	
504	1	07 08	8		579	<u>_</u>	0403	+ DIR	
505		0706	86		52	1	0000	REG O	
505	LP LP	0700	NO FT FYP		587	r a	0003	REC 3	() H_234¥
508		0711	CH SIGN		583	-	0405	REDIR	(/ 0-104)
509	- 1	0700	H0		584	7	0203	REG 23	(corr age)
510		07 05	~ 5		585	÷	0602	Х	_
511		04 04	ST DIR		586		0605	DOWN	
512		0002	REG 2		587	0	0/11	CH SIGN	
516			STY		589	z	0404	ST DIR	
515		0202	REG 22		590		0004	REC 4	
516		0414	STY		591		0415	REY	
517	1	0203	REG 23		592		0002	REG 2	(λ Th-230)
518	(0408	MARK	a	593		0405	REDIR	(0077 077)
219		12201	1201		594	•	0203	KLG 23 Y	(corr age)
521		0308	REG 38	(Robs.)	596		0605	DOWN	
522		0701	1		597		0711	CH SIGN	
523		0601	-	·	598		0614	e – X	
F 0 /					r 0 0		10/01	D T D	

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10004	NHQ 4		675	10415	REY	
0604	UP		676	0208	REG 28	(overall Th eff)
10405	REDIR		677	0602	x	
0000	PFC A		678	10/17	STV.	
104.03			670	10206	DEC 26	
0402	A DIK		075	6200		
10000	REG U		680	10405	KE DIK	
10701	1		681	0208	REG 28	(overall Th eff)
0606	EX		682	0603	+	
0601	-		683	0605	DOWN	
06.05	DOWN		684	10713	SOX	
04.00	1 DTP		685	ได้งัดวี	ST DTP	
0000		(aple Th/U D)	696	10000		
0000	KLG U	(care. In/U K)	000			
10413	KET		00/	10405	REDIR	
02.09	REG 29	(Th-230 dpm)	688	0302	REG 32	(0-232)
04 05	RE DIR		689	10604	UP	
0011	REG 11	(U-238 dpm)	690	0612	SQRX	
0603	+		691	0606	EX	
0414	CTY		692	10603		
10001	NFC 1		603	06.05	DOWN	
			607	0000	2081	
0405	RE DIR		094	10/13	SUA .	
0000	REG O	(calc. Th/U R)	695	0404	ST DIR	
06 01	-		696	10001	REG I	
1 06 05	DOWN		697	0415	REY	
06.07	ABS X		698	0306	REG 36	(U time)
0415	PFY		690	106.05	DOWN	(<i>)</i>
0000		(provious diff)	200	10212	WD A	
		(previous diff.)	201	107.55		+ 100
0508	SKIP ISA		/01	0402	A DIR -	
04 04	ST DIR		702	0606	EX.	
0005	REG 5		703	10603	+	
05 08	SKIP YsX		704	0605	DOWN	
0407	SEARCH	*	705	0713	SOX	
11500	1500		706	0400	+ DTR	
101.08	WARY		707 8	10001	RFC 1	
11203	1502	•	700 8	10702	4	
1303	1303		100 -	10700	0	•
0415	REY		709 E.	0702	Z	
0203	REG 23	(corr age)	710 O	10705	5	
0405	RE DIR		711 🖬	0710	SET EXP	
0003	REG 3	() H=234)	712 5	10711	CH SIGY	
			, 12 0			
0602	x		713	0201	1	
0602			713	0701	1	
0602	X DOWN		713 L 714 L 715	0701		
0602 0605 0614	X DOWN e-X		713 L 714 L 715	0701 0701 0400	1 1 + DIR	
0602 0605 0614 0404	X DOWN e-X ST DIR		713 L 714 W 715 716	0701 0701 0400 0001	1 1 + DIR REG 1	
0602 0605 0614 0404 0000	X DOWN e-X ST DIR REG 0		713 714 715 716 717	0701 0701 0400 0001 0405	1 1 + DIR REG 1 RE DIR	
0602 0605 0614 0404 0000 0415	X DOWN e-X ST DIR REG O REY		713 714 715 716 717 718	0701 0701 0400 0001 0405 0001	1 1 + DIR REG 1 RE DIR REG 1	
0602 0605 0614 0404 0000 0415 0308	X DOWN e-X ST DIR REG 0 REY REG 38	(R obs)	713 714 715 716 717 718 719	0701 0701 0400 0001 0405 0001 0612	1 1 + DIR REG 1 REG 1 REG 1 SQRX	
0602 0605 0614 0404 0000 0415 0308 0701	X DOWN e-X ST DIR REG 0 REY REG 38 1	(R obs)	713 714 715 715 716 717 718 719 720	0701 0701 0400 0405 0001 0612 0604	1 1 + DIR REG 1 REG 1 SQRX UP	
0602 0605 0614 0404 0404 0415 0308 0701 0601	X DOWN e-X ST DIR REG 0 REY REG 38 1	(R obs)	713 714 715 716 717 718 719 720 721	0701 0701 0400 0001 0405 0001 0612 0604 0405	I I H DIR REG I REG I REG I SQRX UP RE DIR RE DIR	
0602 0605 0614 0404 0400 0415 0308 0701 0601 0605	X DOWN e-X ST DIR REG 0 REY REG 38 1 RE DIR	(R obs)	712 714 715 716 717 718 719 720 721 722	0701 0701 0400 0001 0405 0001 0612 0604 0405 0405	1 1 + DIR REG 1 REG 1 REG 1 SQRX UP RE DIR REC 10	(II aff)
0602 0605 0614 0404 0000 0415 0303 0701 0601 0405 0000	X DOWN e-X ST DIR REG 0 REY REG 38 1 RE DIR REC DIR	(R obs)	713 714 715 716 717 718 719 720 721 722 722	0701 0701 0400 0001 0405 0001 0612 0604 0405 0000	I I H DIR REG REG I SQRX UP REG IO H REG IO H I I I I I I I I I I I I I	(U eff)
0602 0605 0614 0404 0400 0415 0303 0701 0601 0405 0405	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0	(R obs) (calc Th/UR)	713 714 715 716 717 718 719 720 721 722 722 722	0701 0701 0400 0001 0405 0001 0612 0604 0405 0405 0405 0405	+ DIR + DIR REG 1 REC 1 SQRX UP REC 10 + DIR REC 10 + DIR	(U eff)
0602 0605 0614 0404 0405 0308 0701 0601 0405 0000 0602	X DOWN e-X ST DIR REG 0 REY REG 38 1 RE DIR REG 0 X	(R obs) (calc Th/UR)	713 714 715 715 717 718 717 718 719 720 722 723 723	0701 0701 0400 0400 0405 0001 0612 0604 0405 0010 0603 0603	I I H DIR REG I SQRX UP REG I C H DOWN C DOWN	(U eff)
0602 0605 0614 0404 0405 0308 0701 0601 0405 0000 0602 0701	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1	(R obs) (calc Th/UR)	713 714 715 716 717 717 718 719 721 721 722 722 722 722 722 722 722 722	0701 0700 0400 0001 0605 0604 0603 0603 0605 0713	I DIR + DIR REG 1 REC 1 SQRX UP REC 10 	(U eff)
0602 0605 0614 0404 0415 0303 0701 0601 0405 0405 0000 0602 0701 0600	X DOWN e-X ST DIR REG 0 REY REG 38 1 RE DIR REG 0 X 1 +	(R obs) (calc Th/UR)	713 714 715 717 717 717 717 717 717 717 722 722 722	0701 07001 0400 0001 0405 0001 0612 0604 0405 0010 0603 0603 0603 0605 00713 0400	I I H DIR REG I SQRX UP REG I DOWN SQX + DIR	(U eff)
0602 0605 0614 0404 0415 0308 0701 0601 0405 0601 0405 0602 0701 0600 0414	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X EG 0 X I + STY	(R obs) (calc Th/UR)	713 714 715 716 717 717 717 717 717 717 723 723 725 727 725 727 727 727	0701 0700 0400 0400 0601 0602 0604 0604 0603 0603 0605 0713 0400 0600	I DIR H DIR REG 1 REC 1 SQRX UP REG 10 H DOWN SQX H DIR REG 0	(U eff)
0602 0605 0614 0404 0415 0308 0701 0601 0405 0000 0602 0701 0600 0701 0600 0414 0205	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 - STY REG 25	(R obs) (calc Th/U R)	713 714 714 716 717 717 717 717 720 722 7223 7225 7225 7226 7228	0701 07001 04000 06001 06012 0604 0405 0603 0603 0603 0605 0605 0713 0400 0000 0405	I DIR REG 1 REG 1 REC 1 SQRX UP RE DIR REG 10 + DOWN SQX + DIR REG 0 FE DIR	(U eff)
0602 0605 0614 0404 0415 0308 0701 0601 0601 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY	(R obs) (calc Th/U R)	713 714 715 717 717 717 717 720 722 7223 7224 7226 7227 7226 7227 7228 9	0701 0701 0400 0001 0405 0001 0612 0405 0405 0405 0405 0710 0603 07400 0603 07400 0603 07400 0605 07400 0600 07400	I DIR H DIR REG 1 REC 1 SQRX UP REG 10 H DOWN SQX H DIR REG 0 FE DIR REG 0 FE DIR REG 0	(U eff)
0602 0605 0614 0415 0300 0701 0601 0405 0600 0602 0701 0600 0701 0600 0701 0600 0414 0205 0415 0405	X DOWN e-X ST DIR REG 0 REY REG 38 1 - REG 18 X REG 0 X 1 + STY REG 25 REY REG 9	(R obs) (calc Th/U R) (Th-234 eff. err.)	713 714 7716 7717 7717 7717 7722 7722 7722 7722	0701 0701 0400 0001 0405 0001 0604 0405 0604 0405 0603 0603 0603 0603 0605 0603 0405 0405 0602	I DIR REG I REG I REC I SQRX UP REG IO + DOWN SQX + DIR REG O FE DIR REG O SQRX	(Veff)
0602 0605 0614 0404 0415 0308 0701 0601 0601 0602 0701 0602 0701 0602 0701 0600 0415 0600 0415 0415 0415 0415	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X T STY REG 25 REY REG 9 PF DIR	(R obs) (calc Th/U R) (Th-234 eff. err.)	7113 7115 7115 7116 7118 7116 7118 7118 7118 7118 722 722 722 722 722 722 722 722 722 72	0701 0400 0400 0001 0605 0604 0604 0605 0010 0605 0713 0600 0405 0400 0405 0400 0405 0604	I I H DIR REG I SQRX UP REG I DOWN SQX H DIR REG O FE DIR REG O SQRX UP REG I SQR I DIR REG I SQRX UP SQRX I S SQRX I SQRX I SQRX I SQRX I SQRX I SQRX	(U eff)
0602 0605 0614 0415 0308 0701 0601 0405 0405 0701 0600 0701 0600 0414 0415 0405 0415 0415 0415	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 REG 9 REG 9 REG 1R	(R obs) (calc Th/U R) (Th-234 eff. err.)	77113 113 115 115 115 116 77116 77119 77212 77223 126 77229 012 77777 77229 77777777	0701 0701 0400 0001 0400 0001 0604 0405 0604 0405 0603 0603 0603 0603 0603 0603 0405 0603 0405 0603 0604 0604 0604	I DIR REG I REG I REC I SQRX UP REC IO + DOWN SQX + DIR REG O FE DIR REG O FE DIR REG O SQRX UP	(Veff)
0602 0605 0614 0414 0404 0415 0308 0701 0601 0405 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602 0705 0605 0415 0009 0405 0605	Z DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X I + STY REG 25 REY REG 9 RE DIR REG 8	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 L 714 L 715 716 717 718 719 720 721 722 724 725 727 728 727 728 729 730	0701 0701 0400 0001 0605 0601 0604 0605 0603 0605 0713 0605 0713 0605 0713 0605 0713 0605 0713 0605 0713 0605 0705 0400 0405	I I H DIR REG I SQRX UP REG I DOWN SQX H DIR REG O FE DIR REG O SQRX UP REG O SQRX UP REG DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I SQRX DIR REG I DIR REG I SQRX DIR REG I SQRX DIR REG I DIR REG DIR DIR REG DIR REG DIR REG DIR DIR DIR D	(U eff)
0602 0605 0614 0415 0300 0415 0701 0601 0405 0701 0600 0414 0701 0600 0414 0205 0415 0405 0415 0405 0405 0405 0405 04	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY P REG 9 REG 1R REG 8 + -	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 L B 714 L B 715 716 71718 7719 7721 7723 7724 7728 7729 7722 7728 7729 7731 2733	0701 0701 0400 0400 0400 0601 0604 0604 0605 0603 0605 0605 0605 0605 0605 0605	I DIR REG I REG I RED IR REC I SQRX UP REC IO TOWN SQX + DIR REG O FE DIR REG O SQRX UP REG 29	(U eff) (Th-230 dpm)
0602 0605 0614 0414 0404 0415 0308 0701 0601 0405 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0605 0415 0009 0415 0405 0405 0603 0605	X DOWN e-X ST DIR REC 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 RE DIR REG 9 RE 0 RE 9 RE 0 RE 1 - STY REG 25 REY REG 9 RE 0 RE 2 STY REG 8 + DUR	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 La 714 La 715 7716 7717 7718 7719 7721 7727 7224 7727 7227 7227 7228 7727 7229 7731 7732 7731 7333 7334	0701 0701 0400 0001 0405 0001 0604 0405 0010 0603 0603 0603 0605 0713 0600 0405 0405 0405 0405 0405 0405 0405	I I H DIR REG I SQRX UP RE DIR REG IO H DOWN SQX H DIR REG O SQRX UP REG O SQRX UP REG I DIR REG I SQRX UP REG I SQRX V SQX V SQRX V S V SQRX V S V S V S V S V S V V S V S V S V	(U eff) (Th-230 dpm)
0602 0605 0614 0414 0404 0415 0701 0601 0405 0701 0600 0404 0701 0600 0414 0205 0415 0405 0415 0405 0415 0405 0414 0009 0405 0405 0405 0405 0405 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 REG 1 REG 8 + DOWN SQX	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 L B 714 L B 715 7716 7717 7716 7717 7717 7717 7717 7	0701 0701 0400 0400 0400 0405 0604 0405 0604 0405 0603 0603 0605 0605 0605 0605 0605 06	I DIR REG I REG I RED IR REG I SQRX UP REG IO DOWN SQX + DIR REG O FE DIR REG O SQRX UP REG O SQRX UP REG DIR REG 29 X RE DIR	(U eff) (Th-230 dpm)
0602 0605 0614 0414 0404 0415 0308 0701 0601 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0605 0415 0009 0414 0205 0405 0603 0605 0713 0404	X DOWN e-X ST DIR REC 0 REY REG 38 1 RE DIR REG 0 X STY REG 25 REY REG 9 RE DIR REG 8 DOWN SQX ST DIR	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 La 714 La 715 7716 7717 716 7717 7718 7719 7721 7729 7721 7729 7727 7729 7731 7732 7733 7734 5735 7736	0701 0400 0400 0400 0405 0405 0405 0405 04	I DIR REG I REG I SQRX UP RE DIR REG 10 + DOWN SQX + DIR REG 0 SQX + DIR REG 0 SQRX UP RE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 11	(U eff) (Th-230 dpm) (U-238 dpm)
0602 0605 0614 0404 0405 0701 0601 0405 0602 0701 0600 0414 0205 0415 0405 0405 0415 0405 0414 0205 0414 0205 0414 0205 0415 0405 0415 0405 0415 0405 0415 0405 0415 0405 0415 0405 0415 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 8 + DOWN SQX ST DIR REG 0 C SQX ST DIR REG 0 C SQX C SQX C SQX C SQX C SCX C SCX C SCX C SQX C SCX SCX	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 L B 714 B 715 7716 7717 7718 7727 7718 7727 7727 7727 7728 7729 7729 7729 7729 7731 7733 7735 7737 7735 737	0701 0701 0400 0400 0400 0601 0604 0405 0604 0405 0603 0603 0603 0603 0603 0603 0603 06	I DIR REG 1 REG 1 SQRX UP REC 10 P DOWN SQX + DIR REG 0 FE DIR REG 0 FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 11 X	(U eff) (Th-230 dpm) (U-238 dpm)
0602 0605 0614 0415 0300 0701 0601 0405 0602 0701 0600 0415 0405 0405 0415 0405 0415 0405 0415 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X I STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 8 + DOWN SQX ST DIR REG 0 7	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 La 714 La 715 7716 7717 7716 7717 7719 7721 7727 7729 7721 7729 7721 7729 7731 7732 7734 7735 7737 733	0701 0400 0400 0400 0601 0604 0405 0604 0405 0603 0603 0605 0603 0605 0713 0400 0605 0713 0400 0605 0605 06012 0605 0605 0602 0602 0602 0602 0602 060	L DIR REG 1 REG 1 REC 1 SQRX UP RE DIR REG 10 + DOWN SQX + DIR REG 0 SQRX UP RE DIR REG 0 SQRX UP RE DIR REG 0 SQRX UP RE DIR REG 1 ST ST ST	(U eff) (Th-230 dpm) (U-238 dpm)
0602 0605 0614 0404 0405 0701 0405 0700 0405 0602 0701 0602 0701 0602 0414 0205 0405 0405 0405 0405 0405 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 9 RE DIR REG 8 + DOWN SQX ST DIR REG 0 7 7	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 113 114 115 7716 7718 7721 7721 7723 7723 7725 7728 7728 7728 7728 7733 7735 7735 7738 7738	0701 0701 0400 0400 0400 06012 0604 0604 0405 0604 0405 0603 0604 0209 0603 0603 0603 0604 0209 0603 0603 0603 0604 0209 0603 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0602 0603 0603 0603 0603 0603 0603 0604 0209 0603 0603 0602 070 070 0602 070 070 0602 070 070 070 0602 070	I DIR REG 1 REG 1 REC 1 SQRX UP REC 10 FE DIR REG 10 FE DIR REG 0 FE DIR REG 0 FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 1 X STY REC 27	(U eff) (Th-230 dpm) (U-238 dpm)
0602 0605 0614 0415 0308 0701 0601 0405 0405 0405 0405 0415 0405 0415 0405 0415 0405 0415 0405 0415 0409 0405 0405 0405 0405 0405 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - REG 38 1 - REG 38 1 - REG 0 X 1 + STY REG 25 REY REG 9 REG 25 REY REG 9 REG 0 X 1 + DIR REG 0 X 1 - REY REG 0 X 1 - REY REG 0 X 1 - REG 0 REY REG 9 REG 8 - DIR REG 0 X 1 - REG 0 REY REG 0 REY REG 0 REY REG 0 REY REG 0 REY REG 0 REY REG 0 REF 0 REG 0 REF 0 RE	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 714 715 715 716 717 721 722 722 722 722 722 722 722 722	0701 0701 0400 0400 0400 0401 0405 0401 0405 0405	I UIR REG I REG I REC I SQRX UP RE DIR REG IO + DOWN SQX + DIR REG O SQRX + DIR REG O SQRX UP RE DIR REG O SQRX UP RE DIR REG I SQRX UP RE DIR REG I SQR UP RE DIR REG I SQR C S C S S S S S S S S S S S S S	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0404 0415 0701 0405 0700 0405 0700 0602 0701 0600 0414 0205 0405 0405 0405 0405 0405 0415 0405 0415 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 9 RE DIR REG 0 7 5 7 7 5 7 7 7 7 7 7 7 7 7 7 7 7 7	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	7113 7117 7117 7116 7117 7118 7118 7117 7118	0701 0701 0400 0400 0400 06012 06012 0604 0603 0604 0603 06	I DIR REG 1 REG 1 SQRX UP RE DIR REG 10 DOWN SQX + DIR REG 0 FE DIR REG 0 FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 11 X STY REG 27 WR A	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0415 0308 0701 0601 0405 0701 0600 0602 0701 0600 0414 0205 0415 0405 0405 0405 0405 0405 0405 04	X DOWN e-X ST DIR REG 0 REY REG 38 1 - REG 38 1 - REG 0 X 1 + STY REG 25 REY REG 9 REG 9 REG 25 REY REG 9 REG 0 X 1 + DIR REG 0 X 1 - STY REG 25 REY STY REG 0 X 1 - STY REG 0 X 1 - STY REG 0 STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY REG 0 STY STY STY STY STY STY STY STY	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 714 715 717 777 777 777 777 777 777	0,701 0,701 0,400 0	I DIR REG 1 REG 1 SQRX UP RE DIR REG 10 + DOWN SQX + DIR REG 0 FE DIR REG 0 FE DIR REG 0 FE DIR REG 29 X REG 11 X STY REG 27 WR A SII UP	(U eff) (Th-230 dpm) (U-238 dpm) (≥ error)
0602 0605 0614 0404 0404 0405 0701 0405 0602 0701 0600 0415 0602 0701 0600 0414 0205 0415 0405 0415 0405 0415 0415 0405 0415 0405 0415 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 9 RE DIR REG 0 7 5 SET EXP CH SIGH	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	7113 7113 7117 7116 71716 71717 7189 7211 7223 7223 7223 7223 7225 72289 7231 7235 7235 7335 7335 7337 73389 72422 72389 7231 7233 7235 7237 7335 7337 73389 72422 72422 7242 7234 7233 7233 7233 7233 7235 7233 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7235 7237 7235 7237 7235 7237 7235 7237 7235 7237 7235 7237 7237 7235 7237 7247 7247 7247 7247 72577 7257 7257 72577 7	$\begin{array}{c} 0,701\\ 0,701\\ 0,400\\ 0,001\\ 0,400\\ 0,$	I DIR REG 1 REG 1 SQRX UP RE DIR REG 10 DOWN SQX + DIR REG 0 FE DIR REG 0 FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 11 X STY REG 11 X SIUP UP	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0415 0300 0415 0405 0405 0405 0405 0405 0405 04	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 - REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 9 RE DIR REG 8 + DOWN SQX ST DIR REG 0 7 7 5 SET EXP O 0 0 0 0 0 0 0 0 0 0 0 0 0	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 714 715 716 717 716 717 721 722 722 722 722 722 722	$\begin{array}{c} 0,701\\ 0,701\\ 0,400\\ 0,0001\\ 0,400\\ 0$	I UP TEC I REG I REG I SQRX UP REG I TOWN SQX + DIR REG I TEC I SQRX UP REG I SQRX UP STY REG I STY REG I STY STY REG I STY STY STY STY STY STY STY STY	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0404 0415 0308 0701 0405 0405 0602 0701 0602 0701 0602 0701 0600 0414 0205 0415 0405 0415 0405 0415 0405 0415 0405 0415 0405 040	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X I + STY REG 25 REY P REG 25 REY P REG 9 RE DIR REG 9 RE DIR REG 0 X T DIR REG 0 X STY REG 0 STY REG 0 SQX ST DIR REG 0 7 5 SET EXP CH SIGN 0 4	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	7113 7117 7117 7116 7117 7118 7118 7117 7118 7118 7118 7118 7117 7118	0701 0701 0400 0400 06012 06012 06012 0603 02002 0603 0603 0603 0603 0603 0603 0603 02002 0603	I DIR REG 1 REG 1 SQRX UP RE DIR REG 10 DOWN SQX + DIR REG 0 FE DIR REG 0 FE DIR REG 0 FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 10 SQRX UP X SI SQRX UP SPACE SPACE	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0415 0300 0415 0303 0405 0405 0405 0405 0405 0405 0414 0205 0414 0205 0414 0205 0414 0405 0409 0405 0403 0405 0405 0405 0405 0405 0405	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY P REG 9 RE DIR REG 9 RE DIR REG 8 + DOWN SQX ST DIR REG 0 7 7 5 SET EXP CH SIGN 0 4 + DIR	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	7113 7117 7115 7177 716 7777 721 7722 7722 7722 7722 7	0701 0701 0400 0001 0400 00012 0604 0604 0605 0605 0605 0605 0605 0605 0605 06005 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0602 0604 0200 0602 0604 0200 0602 0204 0202 0202 0202 0202 0202 0202 0202 0202 0202 0202 0202 0202 0202 0202 0200 0202 0200 0202 02	I UIR REG I REG I RED IR REC I SQRX UP REC IO T DOWN SQX + DIR REG O FE DIR REG O FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 11 X STY REG 27 WR A SII UP U SPACE SPACE E	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0404 0415 0308 0701 0405 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602 0713 0405 0415 0405 0415 0405 0713 0405 0713 0405 0713 0405 0713 0405 0713 0405 0713 0705 0710 0705 0710 0705 0710 0705 0711 0706 0705 0711 0706 0705 0711 0705 0711 0705 0711 0705 0705	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X T F STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 9 RE DIR REG 0 X T DOWN SQX ST DIR REG 0 7 5 SET EXP CH SIGN 0 4 + DIR C 0 0 0 0 0 0 0 0 0 0 0 0 0	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	7113 7113 7115 7716 7718 7721 77217 77223 77227 77228 9017233 77312 77316 77316 77317 77333 77335 77335 77337 77335 77337 77346 77442 77442 77445 6	0701 0701 0400 04001 04001 06012 06012 0605 0603	I DIR REG 1 REG 1 SQRX UP RE DIR REG 10 DOWN SQX + DIR REG 10 + DOWN SQX + DIR REG 0 FE DIR REG 0 FE DIR REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 1 X STY REG 11 X SPACE SPACE EF	(U eff) (Th-230 dpm) (U-238 dpm) (≥ error)
0602 0605 0614 0414 0404 0415 0701 0601 0405 0701 0600 0414 0205 0415 0600 0414 0205 0415 0405 0415 0405 0414 0205 0414 0205 0414 0205 0414 0205 0405 0405 0405 0707 0707 0707 0707 07	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X 1 + STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 9 RE DIR REG 0 7 7 5 SET EXP CH SIGN 0 4 + DIR REG 0 7 7 5 SET EXP CH SIGN 0 9 8 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 9 8 8 9 8 8 9 8 8 9 8 8 9 8 8 8 9 8 8 8 8 8 8 8 8	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 714 714 715 7716 77716 77721 77223 77223 77226 77229 77229 77229 77331 77333 7736 77389 774412 77445 77445 77445 77445 7777445	0701 0701 0400 04001 04001 06012 0604 0604 0605 0605 0605 0605 0605 0605 0605 0605 0605 0604 0713 0604 0200 0405 0604 0200 0405 0604 0200 0405 0604 0200 0405 0604 0200 0405 0604 0200 0405 0604 0200 0405 0604 0200 0405 0604 0200 0604 0200 0604 0200 0604 0200 0604 0200 0604 0207 0602 0602 0602 0602 0602 0602 0602 0207 02014 0001 0002 0001 0205 0205 02014	I DIR REG I REG I RED IR REG I SQRX UP REG IO DOWN SQX + DIR REG O FE DIR REG O SQRX UP REG IN REG 0 SQRX UP RE DIR REG 29 X RE DIR REG 11 X STY REG 27 WR A SII UP U SPACE SPACE F	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0404 0415 0308 0701 0405 0405 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0602 0701 0605 0713 0605 0713 0605 0713 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0710 0705 0705	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 0 X T F STY REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 0 7 5 SET EXP CH SIGN 0 4 + DIR REG 0 REG 0 7 5 SET EXP CH SIGN 0 REG 0 REG 0 7 5 SET EXP CH SIGN 0 REG 0 7 5 SET EXP CH SIGN 0 REG 0 7 5 SET EXP CH SIGN 0 REG 0 7 5 SET EXP CH SIGN 0 7 5 SET EXP CH SIGN 0 7 5 SET EXP CH SIGN 0 7 5 SET EXP CH SIGN 0 7 5 SET EXP CH SIGN 0 7 5 SET EXP CH SIGN 0 7 5 SET EXP CH SIGN 0 7 7 5 SET EXP CH SIGN 0 7 7 5 SET EXP 0 7 5 SET EXP 0 8 5 5 5 5 5 5 5 5 5 5 5 5 5	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	7113 7114 7115 77716 77718 77721 77722 77722 77722 77722 77722 77722 77312 7733 7733	0,701 0,701 0,400 0,4001 0,4001 0,4001 0,4001 0,4005 0,2014 0,2005 0,2005	I DIR REG 1 REG 1 SQX P REG 1 SQX P DOWN SQX DOWN SQX DOWN SQX P DOWN SQX P DOWN SQX P C SQX P C SQX C S SQX C S SQX C S S S S S S S S S S S S S	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
0602 0605 0614 0404 0404 0405 0701 0601 0405 0600 0405 0405 0405 0405 0405 0405	X DOWN e-X ST DIR REG 0 REY REG 38 1 - RE DIR REG 25 REY REG 9 RE DIR REG 9 RE DIR REG 0 7 7 5 SET EXP CH SIGN 0 4 + DIR REG 0 REG 0 7 7 5 SET EXP CH SIGN 0 4 + DIR REG 0 7 7 5 SET EXP CH SIGN 0 7 7 5 SET EXP CH SIGN 0 7 7 5 SET EXP CH SIGN 0 7 7 5 SET EXP CH SIGN 0 7 7 7 5 SET EXP CH SIGN 0 7 7 7 7 7 7 7 7 7 7 7 7 7	(R obs) (calc Th/U R) (Th-234 eff. err.) (Th-234 eff.)	713 113	0701 0701 0400 04001 04001 06012 0604 0604 0605 0605 0605 0605 0605 0605 0605 0605 0605 06005 00205 00214 00005 00014 00005 00014 00005 00014 00005 00014 00005 00014 00005 00014 00005 00014 00005 00014 00005 00014 00005 00005 00014 00005 00005 00014 00005 00005 00014 00005 00005 00014 00005 00005 00014 00005 00005 00014 00005 00005 00014 00005 00005 00005 00014 00005 00005 00005 00014 00005	I DIR REG I REG I REG I SQRX UP REG IO TOWN SQX + DIR REG O FE DIR REG O FE DIR REG O SQRX UP REG Z9 X REG II X STY REG 27 WR A SII UP U SPACE SPACE FF SH DOWN	(U eff) (Th-230 dpm) (U-238 dpm) (age error)
	0004 0402 0000 0701 0606 0400 0400 0400 0405 0209 0415 0209 0414 0001 0603 0404 0401 0404 0405 0605 0508 0404 0405 0508 0405 0508 0404 0405 0508 0405 0408 1503 0405 0405 0405 0405 0405 0405 0405 0	0004 REG 4 0402 X DIR 0 0000 REG 0 0701 1 0 0605 D0WN 0 0601 - 0 0605 D0WN 0 0400 + DIR 0 0400 REG 0 0415 REY 0 0411 REG 1 0603 + 0 0414 STY 0 0601 - 0 0603 + 0 0404 STG 1 0605 DOWN 0 06607 ABS X 0 06607 ABS X 0 06607 ABS X 0 0405 REY 0 00005 REG 5 0508 SKIP YsX 0 0407 SEARCH 1503 1503 1503 1503 0415 REY 0 0203 REG 23 </td <td>0004 REG 4 0402 X DIR 0000 REG 0 0701 1 0605 D0WN 0400 + DIR 0700 REG 0 0601 - 0605 D0WN 0440 + DIR 0700 REG 0 07415 REY 0700 REG 1 07415 REY 1 0701 REG 1 07415 REY 1 07415 REG 1 07415 REG 1 0701 REG 1 0701 REG 1 0703 + 1 0701 REG 1<td>0007 REG 4 678 0402 X DIR 679 0402 X DIR 679 0000 REG 0 680 0701 1 681 0605 D0WN 682 0606 EX 682 0605 D0WN 683 0606 EX 683 0607 + DIR 685 0700 REG 0 (calc. Th/U R) 686 0415 REY 687 690 0601 REG 11 (U-238 dpm) 690 0613 + 692 693 694 0401 REG 1 694 693 0401 REG 1 695 696 0603 + 697 696 695 0601 - 693 694 695 0601 - 696 695 696 0605 DOWN 696 696 696 0605 DOWN 697 696 697</td><td>0004 REC 4 676 0412 0402 X DIR 679 0206 0402 X DIR 679 0206 0701 1 681 0208 0606 EX 682 0603 0601 683 0605 0000 0605 D0WN 682 0405 0400 + DIR 683 0405 0400 + DIR 685 0404 0700 REG 0 (calc. Th/U R) 686 0000 0415 REY 687 0405 0604 0601 0209 REG 1 (U-238 dpm) 690 0612 0603 + 692 0603 0605 0404 0601 - 693 0605 0404 0601 - 693 0605 0404 0605 D0HN 696 0001 0405 0605 D0HN 696 0206 0405 0601 - 698 0306 0405</td><td>0004 REG 4 676 0414 STY 0402 X DIR 679 0206 REG 26 0000 REG 0 680 0405 REG 28 0701 1 681 0206 REG 28 0606 EX 682 0603 + 0601 - 683 0605 D0WN 0605 D0WN 684 0713 SQX 0400 + DIR 685 0404 ST DIR 0000 REG 0 (calc. Th/U R) 686 0302 REG 02 0415 REY 689 0604 UP 0601 REG 02 0603 + 0401 REG 11 (U-238 dpm) 690 0612 SQRX 0603 + 0601 REG 12 SQRX 0605 D0WN 0605 D0WN</td></td>	0004 REG 4 0402 X DIR 0000 REG 0 0701 1 0605 D0WN 0400 + DIR 0700 REG 0 0601 - 0605 D0WN 0440 + DIR 0700 REG 0 07415 REY 0700 REG 1 07415 REY 1 0701 REG 1 07415 REY 1 07415 REG 1 07415 REG 1 0701 REG 1 0701 REG 1 0703 + 1 0701 REG 1 <td>0007 REG 4 678 0402 X DIR 679 0402 X DIR 679 0000 REG 0 680 0701 1 681 0605 D0WN 682 0606 EX 682 0605 D0WN 683 0606 EX 683 0607 + DIR 685 0700 REG 0 (calc. Th/U R) 686 0415 REY 687 690 0601 REG 11 (U-238 dpm) 690 0613 + 692 693 694 0401 REG 1 694 693 0401 REG 1 695 696 0603 + 697 696 695 0601 - 693 694 695 0601 - 696 695 696 0605 DOWN 696 696 696 0605 DOWN 697 696 697</td> <td>0004 REC 4 676 0412 0402 X DIR 679 0206 0402 X DIR 679 0206 0701 1 681 0208 0606 EX 682 0603 0601 683 0605 0000 0605 D0WN 682 0405 0400 + DIR 683 0405 0400 + DIR 685 0404 0700 REG 0 (calc. Th/U R) 686 0000 0415 REY 687 0405 0604 0601 0209 REG 1 (U-238 dpm) 690 0612 0603 + 692 0603 0605 0404 0601 - 693 0605 0404 0601 - 693 0605 0404 0605 D0HN 696 0001 0405 0605 D0HN 696 0206 0405 0601 - 698 0306 0405</td> <td>0004 REG 4 676 0414 STY 0402 X DIR 679 0206 REG 26 0000 REG 0 680 0405 REG 28 0701 1 681 0206 REG 28 0606 EX 682 0603 + 0601 - 683 0605 D0WN 0605 D0WN 684 0713 SQX 0400 + DIR 685 0404 ST DIR 0000 REG 0 (calc. Th/U R) 686 0302 REG 02 0415 REY 689 0604 UP 0601 REG 02 0603 + 0401 REG 11 (U-238 dpm) 690 0612 SQRX 0603 + 0601 REG 12 SQRX 0605 D0WN 0605 D0WN</td>	0007 REG 4 678 0402 X DIR 679 0402 X DIR 679 0000 REG 0 680 0701 1 681 0605 D0WN 682 0606 EX 682 0605 D0WN 683 0606 EX 683 0607 + DIR 685 0700 REG 0 (calc. Th/U R) 686 0415 REY 687 690 0601 REG 11 (U-238 dpm) 690 0613 + 692 693 694 0401 REG 1 694 693 0401 REG 1 695 696 0603 + 697 696 695 0601 - 693 694 695 0601 - 696 695 696 0605 DOWN 696 696 696 0605 DOWN 697 696 697	0004 REC 4 676 0412 0402 X DIR 679 0206 0402 X DIR 679 0206 0701 1 681 0208 0606 EX 682 0603 0601 683 0605 0000 0605 D0WN 682 0405 0400 + DIR 683 0405 0400 + DIR 685 0404 0700 REG 0 (calc. Th/U R) 686 0000 0415 REY 687 0405 0604 0601 0209 REG 1 (U-238 dpm) 690 0612 0603 + 692 0603 0605 0404 0601 - 693 0605 0404 0601 - 693 0605 0404 0605 D0HN 696 0001 0405 0605 D0HN 696 0206 0405 0601 - 698 0306 0405	0004 REG 4 676 0414 STY 0402 X DIR 679 0206 REG 26 0000 REG 0 680 0405 REG 28 0701 1 681 0206 REG 28 0606 EX 682 0603 + 0601 - 683 0605 D0WN 0605 D0WN 684 0713 SQX 0400 + DIR 685 0404 ST DIR 0000 REG 0 (calc. Th/U R) 686 0302 REG 02 0415 REY 689 0604 UP 0601 REG 02 0603 + 0401 REG 11 (U-238 dpm) 690 0612 SQRX 0603 + 0601 REG 12 SQRX 0605 D0WN 0605 D0WN

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900	0106	•		975 03	09	4	
901 u	0002	SPACE		976	0002	SPACE	
02 🗠	0112	A		977 🛃	0213	đ	
203 22	0015	G		978 🖓	0005	р	
)04 · 🛱	10205	E		979	0115		
05	10102	SH DOWN		980 ⊃	0006	-	
065	0006	•		981 a	0413	END A	
070	10413	END A		982 -	0405	RE DIR	
0852	10405	REDIR		983 7	0012	REG 12	(U-234 dpm)
	0202	RFC 22	(uncorr. age)	984 5	0411	WRITE	(*********
ນັ້ນ ຢູ່	10/12		(0.95	0202	0202	
10.0	10212	• 6 A	÷ 1000	903	0203 0212	UD 4	
111	0403	+ DIR		900	0412		
145	10411	WRITE		987	0108	CK/LF	
113-	0302	0302	(988	0108	CR/LF	
14	10302	0302	SR (Wr. K YKS)	989	0103	SHUP	
915	0412	WR A		990 z	0207	T	
916	0108	CR/LF		991	0102	SH DOWN	
917	0108	CR/LF		992 *	0201	h	
918	0103	SH UP		993 =	0306	2	
919	10200	В		994 ä.	0314	3	
20	0112	Å		995 "	0301	0	
121	10212	č		996	0002	SPACE	
177	10202	x		667 m	0213	d	
523	10002	SPACE		663 N	0005		
51 Z	10215	C STACE		666 L	0115	P	
724 176 B	0112			1000 H		-	
22	10112	Ŷ.		1000			•
20 0	0209	L		1001 0	0413	LNDA	
27 1	0212	.		1002 -	0405	RE DIR	
28	10106	•		1003 🖫	0209	REG 29	(Th-230 dpm)
929 H	10002	SPACE		1004 3	0411	WRITE	
930	0214	ប		1005	0203	0203	
31	20102	SH DOWN		1006	0411	WRITE	
32 -	10000	-		1007	1505	1505	
33 5	0103	SH UP		1008	0412	WR A	
34 2	0214	U U		1009	0103	SHUP	
115 0	10002	SPACE		1010	0202	T	
576 2	0112	P		1011	0102		
		л 4		1011	0102	Sh DOWA	
, , , , , , , , , , , , , , , , , , ,	10111	Ŷ		1012	0201	3	
120 1	020/	ţ		1013	0300	2	
33 -	10104	1		1014	0314	3	
40 -	101.03	0		1015	0301	ý	
941 -	0102	SH DOWN		1016	0009	/	
942	10006	•		1017 🏼	0103	SH UP	
943	0413	END A		1018 ,	0214	Ŭ	
944	0405	RE DIR		1019 -	0102	SH DOWN	
945	0205	REG 25	(backcalc. R)	1020 🛱	0306	2	
346	0411	WRITE		1021	0314	3	
47	0103	0103		1022	0312	8	
4.8	10412	WR A		1023 21	0006		
1.0	0108			1026 0	0413	END A	
50	10108			1025 0	0215	REV	
55	10102			1026 N	0700	PEC 20	(Th-230 dom)
	10217	311 01		1027	0203		(110250 494)
52	10113	CU DOUN		1056 8			(11.228.45-)
(<u>)</u> .	0102	SE DOMU		1020		KEG II	(U-238 dpm)
24	0306	4		1029 8	0603	+	
55 E	0314	3		1030 🚍	0605	DOWN	/
756 m	0312	8		1031 H	0304	0304	SK (wr exp numb)
957 <u> </u>	0002	SPACE		1032 🛥	0412	WR A	
958 m	0213	d		1033	0108	CR/LF	
)59 ∾'	10005	D		1034	0108	CR/LF	
960 L	10115	in in the second		1035	0108	CR/LF	
961 -	0006			1036	0108	CR/LF	
967 e	10413	END A		1037	0413	END A	
163 H	10405	REDIR		1038	0515	STOP	
	0011	REC 11	(H-238 dpm)	1030	62.08	MARY	
66 3	10/11	UDITE	(1040	6306	0306	SR WT + X
144	10203	0203		1040	82.15		
000	10203			1041	0002	NT A	
	10411	WKITE		1042	0002	STALL FU UD	
808	12202	1202		1043	0103	SHUP	
204 -	10412	WK A		1044	0006	+	
10 ~	10103	SHUP		1045	0003	BK SPACE	
//1 🔳	0214	U		1046	0000	*	
72 _	0102	SH DOWN		1047	0102	SH DOWN	
973 🗄	0306	2		1048	0413	END A	
74 5	10314	3		1049	0612	SORX	

2							
750	10413 10405	END A RE DIR		825 826	0405	RE DIR REG 21	(Th-230 PPM)
752 ũ 753 Ψ	0010	REG 10 WRA	(V ett.) + 100	828	0514	GO GO	SK (wr exp numb)
254 p	0702	2	1 100	829 830	0412	WR A CR/LF	
756 8	0202	0202		831	0108	CR/LF	
757 원	0412	WR A		832	0103	CR/LF CR/LF	
759 2	0305	ž		834	0103	SHUP	
760	0413	END A		835	0214	U SH DOWN	
762	L1508	1508		837	0000	-	
763	0412	WR A		838	0207	T	
765 z	0102	SH DOWN		840	0102	SH DOWN	
767	0306	2 3		842	0002	SPACE	
768 2	0312	8		843	0103	SH UP	
770	0002	SPACE		845 v	0015	Ĝ	
77 <u>1</u> 8	0103	SH UP		846 5	0205	E SH DOWN	
773 2	10005	P		848 × ·	0006		
774	0115	M SH DOWN		849	0413	END A RE DIR	*
776 -	0006			851 +	0203	REG 23	(corr age)
777 ii 778 is	0413	END A RE DIR		852 ×	0403	WK A + DIR	+ 1000
779	0013	REG 13	ZU-238 PPM)	854	0411	WRITE	
780	0103	0103		856 8	0300	0302	SR (wr K YRS)
782	0412	WR A		857 🛱	0604		
784	0108	CR/LF		859 문	0207	REG 27	(age error)
785	0103	SH UP T		860	0602	X DOWN	
787	0102	SH DOWN		862 u	0412	WRA	: 1000
788 № 789	0201	h SPACE		863 4	0403	: DIR 0304	SR (wr exp numb)
790 2	0103	SH UP		865 5	0514	GO	
791	0205	F		867	0411	WRITE	SR (WE K 1KS)
793	0014	F		868	1504	1504	
795	10006	SH DOWN		870 vi	0103	SH UP	·
796 등	0413	END A		871	0214	U SH DOWN	
798 .	02 08	REG 28	(overall Th eff.)	873 ×	0000	-	
799 H	0412	WR A 2		874 z 875 z	0103	SH UP U	
801 🛥	0411	WRITE		876	0002	SPACE	•
802	0202	WR A		878 0	0015	Ĝ	
804	0103	SH UP		879 .	0205	E SH DOWN	
806	0413	ÊND A		881 5	0006	=	
807	0411	WRITE		882 - 883 w	0413	END A RF DIR	
809	0412	WR A		884	0204	REG 24	(U-U age)
810	0103	SH UP T		885 H 886 H	0412	WR A + DIR	<u>→</u> 1000
812 z	0102	SH DOWN		887	0411	WRITE	
813 814	0201	h 2		888 889	0302	0302	SR (wr K YRS)
815 2	0314	3		890	0412	WR A	
817	0002	SPACE		892	0108	CR/LF	
818 5	20103	SH UP		893 894	0103	SH UP	
820 .	0005	P		895	0206	Ň	
821	0115	M SH DOWN		896 897	0212	C O	
823 3	0006	-		898	0113	R	
831	10/13			899	10113	ĸ	

PROGRAM 3: URANIUM-THORIUM AGE, URANIUM-234 CORRECTION EQUATION.

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123456789011234567891112345678	SetH Program for load 0303 0512 0512 05050 0500 0000 00000 000000	0303 STOP ST DIR REG 38 RE DIR REG 72 ST DIR REG 22 RE DIR REG 73 ST DIR REG 51 0 ST DIR REG 73 SEARCH LOAD PROG	SR (set reg. 0-41 =0 (cue number)	5889 59912 59935 5995 5995 5995 5997 5998 6002 6002 6004 6003 6005 6006 6006 6006	1500 0405 0404 0309 0301 0408 1504 0307 0308 0504 0701 0705 0600 0701 0705 0600 0701 0705 0600 0701 0705 0600 0701 02001	1500 RE DIR REG 23 ST DIR REG 39 0301 MARK 1504 0307 0308 UP 1 5 X 1 + + STY REG 20	(corr age SR (set T) SR (1 01 X T) SR (exp-λU·234T) (A U·232 (C))
	D	2 10	80	608 609	[∞] 0606 [∞] 0309 [∞]	EX 0309	SRq(det R calc)
566	rrogram	2, steps 19 -	80	611	L 0200 S 0311	REG 20 0311	(A U 232 (G)) SR (sk p-d ff)
81 82	0405 0501	RE DIR REG 51		613 614	0508	SKIP YSX SEARCH	*
83 84	0404 0703	ST DIR REG 73		615 616	1504	1504 RE DIR	
5.0.0	Program	2 etene 85 -	543	618	0404	ST DIR	(corr æge) (ave (C))
JEE	riogram	1, 200 , 05 -	545	620 621	0301	0301 MARK	SR (
544	0415	REY		622 623	1505 0307	1505 0307	SR (1 01 X T)
545	0203	REG 23 2	(corr. age)	624	0415	REY REG 11	(U-238 dpm)
547	0507	SEARCH	*	626	$ \begin{array}{c} 0405 \\ 0012 \\ 0309 \end{array} $	REG 12	(U-234 dpm)
550 551	0415	REY REG 29	(Th-230 dpm)	629	0405	RE DIR REG 11	(U 238 dpm)
552 553	0405	RE DIR REG 12	(U-234 dpm)	631 632	°°°10602 °°0405	X RE DIR	
554 555	2 0603	STY		633 634	· 0012 2 0311	REG 12 0311	(U 234 dipm) SR(sk p-d ff)
556	~ 10001 5 10415	REG 1 REY PEC 11	(11-238 dpm)	635	e 0508 0407	SKIP YSX SEARCH	*
559	o 0701 ≺ 0712	1	(0-100 црш)	638	0405	RE DIR REG 23	
561 562	. 0701	i 5		640 641	0404	ST DIR REG 41	(age (0))
563 564	0602 0414	X STY		_			
565	0006	REG 6 0301	SR (set T)	See	Program 2,	steps 632	- 827 (SR 312 replaces CR'LF)
568	1500	1500	г SR (1 01 X T)	838	0312	0312	SR (CR/LF)
57Ó 571	0308	0308 REY	SR (exp-λ0-234T)	840 841	2 0412 (0103	WR A SH UP	
572 573	0006	REG 6 X	(A ^U U-232)	842 843	E 0300 0207	(T	
574	0605	DOWN ST DIR	/····	844	0301 0102) Sh down	
577 578	0415	REG 19 REY REC 11	(H = 238 dpm)	840	- 0413	END A	
579 580	₩ 0309 10405	0309 RE DIR	SR	849	0400	REG 40 WR A	(age (T))
581 582	0011	REG 11 X	(U-238 dpm)	851 852	e 0403 1 0411	+ DIR WRITE	+ 1000 .
583 584 585	ບັບ405 0109 0311	RE DIR REG 19 0311	(A U-234 ()) SR	853 854 855	T 0302 ≥ 0302 0411	0302 0302 WRITE	SR (wr K YRS)
586 587	0508	SKIP YBX SEARCH	*	856 857	1504 10313	1504 0313	SR (wr U Th age)

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12345678901123456789001123456789001123456789001123456789001123456789001123456789000000000000000000000000000000000000	Sett program for load Sett program for load Sett program for load Sett program Sett program Set	0303 STOP ST DIR REG 38 REG DIR REG 72 ST DIR REG 23 ST DIR REG 23 ST DIR REG 51 O ST DIR REG 73 SEARCH LOAD PROG	SR (set reg. 0-41 =0 (cue number)	\$889 \$991 \$992 \$992 \$995 \$995 \$996 \$996 \$990 \$990 \$001 \$001 \$001 \$001 \$001 \$001	1500 0203 0404 0301 0404 0301 0307 0307 0307 0307 0307 0307 0307	1500 RE DIR REG 23 ST DIR REG 39 0301 MARK 1504 0307 0308 UP 1 5 X X 1 + STY REG 20	(corr age SR (set T) SR (1 01 X T) SR (exp-λU·234T) (A U·232 (C))
	-			607 608 609	© 0701 © 0606 0309	1 EX 0309	SRq(det R calc)
See	Program	2, steps 19 -	- 80	610	10405 20200	RE DIR REG 20	$(A \cup 232 (C))$
81 82	0405	RE DIR REG 51		613	0508	SKIP YEX SEARCH	*
83 84	0404 0703	ST DIR REG 73		615 616	1504	1504 RE DIR	
				617 618	0203	REG 23 ST DIR	(corr age)
See	Program	2, steps 85 -	- 543	620	0301	0301	(age (C)) SR (
544	0415	DFY		622	1505	1505	SR (1 01 X T)
545 546	0203	REG 23 2	(corr. age)	624 625	0415 0011	REY REG 11	(U-238 dpm)
547 548	0507 0407	SKIP Yg=X SEARCH	*	626 627	0405	RE DIR REG 12	(U.234 dpm)
549	1503	1503 REY	(Th-230 dom)	628	0 0 3 0 9	RE DIR	SR (det R calc)
552	0405	REDIR REDIR RFC 12	(II-234 dpm)	631	©10602 □0405		(0 290 000)
554 555	0603	T STY		633 634	0012 2 0311	REG 12 0311	(U 234 dpm) SR(sk p-d ff)
556 557	0001	REG 1 REY		635 636	80508 0407	SKIP YSX Search	*
558 559 c	0701	REG 11 1	(U-238 dpm)	637 638	1505	1505 RE DIR	
560	0701	i		640	0404	ST DIR	
563 564	T 0602	Z X VTV		041	.0401	KL0 41	
565	0006	REG 6 0301	SR (set T)	See	Program 2	, steps 632	- 827 (SR 312 replaces CR'LF)
567 568	0408	MARK 1500	•	837 838	0312 0312	0312 0312	SR (CR'LF) SR (CR'LF)
569	0307	0307 0308	SR (1.01 X T) SR (exp-λU-234T)	839	Z 0412	WR A	SK (wr U Thage)
572	0006	REG 6	(A [°] U-232)	842	E 0300		
574	0605	DOWN ST DIR		844) Sh down	
576 577	0109	REG 19 REY	(A U-234 ())	846 847	0006	END A	
578 579	20011 20309	REG 11 0309	(U-238 dpm) SR	848 849	L 0405 0400	REDIR REG 40	(age (T))
580 581	- 0405 - 0011	RE DIR REG 11	(U-238 dpm)	850 851	• 0412 • 0403	WR A + DIR	+ 1000
582 583	S 0405	RE DIR REC 19	(A = 1-234 (1))	853 854	10302	0302	SR (Wr. K. YRS)
585 586	0311	0311 SKIP V=¥	SR	855	0411	WRITE 1504	5. (** * 183)
587	10407	SEARCH	•	857	6313	0313	SR (wr U Th age)

PROGRAM 3: URANIUM-THORIUM AGE, URANIUM-234 CORRECTION EQUATION.

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858	z	0412	WR A		936		0302	0302	SR (wr K YRS)
859	Ĩ	0103	C SH UP		937		1505	WRITE 1505	
861	ຶ	0212	Ċ		939		0412	WR A	
863	286	0102	SH DOWN		941		0200	B	
864	<u> </u>	10006 10413	TND A		942		0112	A C	
866	L L	0405	REDIR		944		0204	ĸ	
867	ŝ	0309	REG 39 WRA	(age (C))	945		0212	SPACE C	
869	a	0403	+ DIR	+ 1000	947	z	0112	Ă	
871	H	0302	0302		948		0212	Č	
872	Ä	0302	0302	SR (wr K YRS) SR (CD/LE)	950	0	0106	SPACE	
874	z	0313	0313	SR (wr U/Th age)	952	9 C 1	0214	U	
875 876	-	0412	WR A SH UP		953	- 14	0102	SH DOWN	
877	S	0300	(955	1	0103	SH UP	
878	88	0301	2		956		0002	SPACE	
880		0102	SH DOWN		958	្ព	0113	R	
882	11	0413	END A		959	80	0207	Î,	
883 884	c o	0405	RE DIR RFC 41	(828 (0))	961.	Å,	0104	I	
885	e	0412	WRA	+ 1000	963	þ,	0102	SH DOWN	
886 887	H	10403	+ DIR WRITE	• - · · ·	964	0	0006	END A	
888	ŝ	0302	0302		966	r i t	0405	RE DIR	
890		0411	WRITE	SR (WI K IRS)	967	и	0205	WRITE	(mack calc K)
891		1504	1504		969	(0103	0103	CD (CD /I D)
893		0103	SH UP		971		0412	WR A	SK (CK/LF)
894		0214	UN		972		0103	SH UP	
896	N	0212	č		974	E	0102	SH DOWN	
897 898		0109	O R		975	p	0306	2	
899	8	0113	R		977	38	0312	8	
901	8	0002	SPACE		978	1.2	{0213	d SPACE	
902	Ц	0112	A C		980		0005	P	•
904	00	0205	E		982	Ţ,	0006	-	
905	un	0102	SH DOWN		983	μr	0413	END A RF DTR	
907.	e	0413	END A		985		0011	REG 11	(U-238 dpm)
908	Ĩ	0202	REG 22	(uncorr age)	986 987		10411	WRITE 0203	
910	5	0412	WRA	+ 1000	988		0411	WRITE	
912		0411	WRITE		989		0412	WR A	
913		0302	0302	SP (Wr K YRS)	991		0103	SH UP	
915		0302	0302	SR (CR/LF)	993		0102	SH DOWN	
916 917		0412	WR A SH UP		994 995		0306	2	
918		0214	U DOUN		996	Ē	0309	4	
920	_	0000	SH DOWN		997	P	0213	d	
921	z	0103	SH UP		999	<u></u>	0005	P	
923	# 61	0002	SPACE		1001		10103	SH UP	
924	88	0112	A G		1002	23/	10300	(0	
926	5	0205	Ē		1004	7	0301))	
928	5	0006	SH DOWN		1005	· a	0006	SH DOWN	
929	e	0413	END A		1007	ri C	0413	END A	
931	Ľ.	0204	REG 24	(U-U age)	1009	5	0012	REG 12	(U-234 dpm)
932 933	Э	0412	WR A → DIR	+ 1000	1010		0411	WRITE 0203	
934		0411	WRITE		1012		0411	WRITE	
935		10302	0302		т013		U202	1202	

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1014 1015 1016 1017 1017 10221 10221 10222 10225 10226 10228 10228 10228 10229 10312 10333 10345 10345 10346 10338 10345 10336 10339 10442 10442	0412 0214 0306 0314 0002 0213 0002 0213 0005 0103 0105 0103 0202 0413 0405 0413 0405 0413 0413 0412 0413 0412 0413 0412 0413 0412 0413 0412 0413 0412 0413 0412 0413 0416 04 04 04 04 04 04 04 04 04 04 04 04 04	WR A SH UP U SH DOWN 2 3 SPACE d SPACE d SPACE d SP SH UP (C C SH DOWN SH DOWN END A REG 19 WRITE 0312 WR A SH UP T SH DOWN 2	SR (CR/LF)	1092 1094 1095 1096 1097 1097 1097 1009 1101 1102 1103 1104 1103 1104 1105 1106 1107 1108 1109 1110 1111 1112 1112 1114 1115 1116 1117	Write Th-230/U-234 (C) ratio 000000000000000000000000000000000000	h 2 3 5 4 5 5 5 7 5 7 7 7 7 7 7 7 7 7 7 7 7 7	(Th-230 dpm) (U 234 (C)) SR (Wr exp numb) SR (CR/LF) SR(CR/LF)
1043 Å	0314	3		Subrou	tines in	addition to	those of Program 2
1046 1046 1046 1047 1047 1051 1051 1055 1055 1055 1055 1055 105	0002 0213 0005 0115 0006 0413 0405 0209 0411 0203	SPACE d P END A RE DIR REG 29 WRITE 0203	(Th-230 dpm)	1138 1139 1140 1141 1142 1143 1144 1145 1146	0408 0301 0415 0202 0703 0603 0414 0203 0701	MARK 0301 REY REG 22 3 : STY REG 23	SR Set T
1055 1056 1057 1058 1059	0411 1505 0412 0103 0207	WRITE 1505 WR A SH UP T SH DOWN		1147 1148 1149 1150	0404 0005 0511	ST DIR REG 5 RETURN	
1061 1062 10663 10665 10665 10668 10668 10668 10670 1071 1067 10771 1067	0201 0306 0314 0301 0009 0103 0214 0102 0306 0314 0309	A B B B B B B B D C W B B D C W B C C W D C C C C C C C C C C C C C C C C		1231 1232 1233 1234 1235 1236 1236 1237 1238 1239 1240 1241	0408 0307 0415 0203 0701 0712 0700 0701 0602 0414 0203	MARK 0307 REY REG 23 1 0 1 x STY REG 23 STY REG 23	SR 1 01 X T
1073 1073 1073 1075	0300 0109 0301 0102 0006 0413 0415 0209 0405 0405 0012	SH DP () SH DOWN END A REY REG 29 RE DIR REG 12	(Th-230 dpm) (U-234 (0)dpm)	1242 1243 1244 1245 1246 1246 1247 1248 1249 1250 1251	0408 0308 0405 0711 0602 0605 0614 0511	HARK O308 RE DIR REG 3 CH SIGN X DOWN e-X RETURN	SR Exp-λU 234T
1083 H 1084 A 1085 1085 1087 1088 1089 1090 1091	0603 0605 0304 0411 1505 0412 0103 0207 0102	+ DOWN 0304 WRITE 1505 WR A SH UP T SH UP T	SR(wr exp numb)	1252 1253 1254 1255 1256 1257 1258 1258 1259	0408 0309 0603 0701 0606 0601 0414 0000	MARK 0309 + 1 EX - STY REG 0	∮ SR Det R selc

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1260 1261 1262 1263 1266 1266 1266 1266 1266	0415 0402 0405 0601 0404 0404 0404 0404 0404 0605 0605 04004 0711 0415 0605 0605 0605 0614 0701 0701	REY REG 2 RE DIR REG 3 - STY REC 4 RE DIR REG 2 EX DOWN X DIR REG 0 REG 4 CH SIGN REG 23 X DOWN E-X UP 1		1347 1348 1350 1351 1353 1355 1355 1355 1355 1355 1355 1355 1356 1360 13662	0103 0214 0102 0000 0103 0201 0201 0002 0103 0103	SH UP USH DOWN SH DOWN SH DOWN h SPACE SH UP A G E ND A RETURN 0000 0000 0000 0000 0000 0000 0000 0
1284 1285	0606	EX		Contin	ue 0000	codes to
1 2867 1 2887 1 2889 1 2990 1 2991 1 2993 1 2993 1 2995 1 2996 1 2997 1 2998 1 2999 1 3000 1 301	0602 0000 0415 0203 0203 0605 0711 0604 0701 0604 0701 0604 0701 0604 0701 0604 0701	DOWN X DIR REG O REY REC 2 RE DIR REG 23 X DOWN CH SIGN e-X UP 1 EX RETURN		1403 1404 1405 1406 1407 1408 1409	0408 0513 0513 0407 0509 0515 0512	MARK LOAD PROG SEARCH SKIP Y=X STOP END PROG
1 318 1 319 1 320 1 322 1 322 1 323 1 324 1 325 1 326 1 327 1 328 1 327 1 328 1 327 1 328 1 330 1 331 1 333 1 334 1 335 1 336	0408 0311 0603 0400 0000 0415 0001 0405 0601 0605 0607 0415 0605 0605 0508 0405 0508 0405 0508	MARK 0311 : DOWN + DIR REG O REY REG 1 REG 1 REG 0 - DOWN ABS X REY REG 5 - SKIP Y SX ST DIR REG 5 - SKIP Y SX ST DIR REG 5 - SKIP Y SX	SR Skip-d'ff			
1337 1338 1339 1340 1341 1342 1343	0408 0312 0412 0108 0108 0413 0512	MARK 0312 WR A CR/LF CR/LF END A END PROG	SR CR/LF			
1344 1345 1346	0408 0313 0412	MARK 0313 Wr A	Ø SR Wr U∕Th age			

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PROGRAM DESCRIPTION: Cumulative error for multiple productquotient combinations.

PROGRAM ABSTRACT: This program determines the product or quotient, along with its accompanying statistical error, for a series of product-quotient combinations of any length.

EXTERNAL MARKS USED: 409 (GROUP 1), 410 (GROUP 2)

OPERATING PROCEDURE:

- 1. Insert tape: Press TAPE READY, RUN
- 2. Key: PRIME, LOAD PROGRAM
- 3. Key: First number, GO (System types out columnar headings of NUMBER, ERROR, ANSWER, CUM. ERR. (cumulative error))
- 4. Key: Error of first number, SEARCH, GROUP 2
- 5. Key: X (System multiplies first number by 1.0 ..., prints out information under proper columnar headings.)
- 6. Key: Next number, SEARCH, GROUP 1
- 7. Key: Next number error, SEARCH, GROUP 2
- 8. Key: X or : (System makes specified calculations, writes calculated information under the proper columnar headings.)
- Repeat steps 6 to 8 for all subsequent factors or divisors.

CUNHULATIVE ERROR FOR DIFFERENCE-QUOTIENT COMBINATIONS.

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36 0014 REG 14 111 0002 SPACE 37 0602 SQRX 112 0205 E 38 0604 UP 113 0113 R 39 0405 REDIR 114 0113 R 40 06015 REG 15 0109 0 41 0600 + 116 0113 R 42 0600 + 116 0113 R 44 0106 REDIR 118 0108 CR/L 44 0106 REDIR 118 0108 CR/L 44 0106 REDIR 118 0100 REG 45 0605 DOWN 121 0010 REG 46 0702 2 123 0600 0600 47 0404 ST DIR 124 50 0411 WRITE 50 0107 REG 17 125 1504 1504 51 $(2455 REP JIR 126 $	123456789012345678901234567890123456789012345	err. subtr and calc. err.	(0404 0604 0515 0404 0601 0404 0601 0612 0602 0612 0603 0612 0603 0612 0603 0612 0603 0612 0603 0612 0603 0612 0603 0612 0604 0604 0604 0604 0604 0604 0604 060	ST DIR (index REG 10 UP STOP (index ST DIR REG 11 - STY REG 12 RE DIR REG 10 SQRX UP - RE DIR REG 11 SQRX RE DIR REG 12 + DOWN WR A 2 ST DIR REG 13 STOP (index ST DIR REG 14 UP ST DIR REG 15 - STY REG 16 RE DIR	sample counts) bgd, counts) std, counts) bgd, counts)	75 776 777 881 882 883 884 885 886 888 886 991 993 995 996 995 996 995 996 995 996 1001 1003 1006 1006 1006 1006 1006 100	0605 0412 0402 0404 0109 0411 1503 0114 0103 0115 0104 0206 0104 0411 1505 0200 0413 02114 0200 0413 02114 02016 02016 02101 02113 02113 02114 02016 0213 02113 02114 02016 0213 02113 02114 02016 0213 02113 02114 02016 02113 02114 02016 02113 02114 02016 02113 02114 02016 02113 02114 02016 02115 02116 02115 02116 02115 02116 02115 02116 02116 02115 02116 02116 02115 02116 02115 02116 02115 02116 02115 02116 02115 02115 02116 02115 02116 02115 0215 0000000000	DOWN WR A X DIF ST DJ REG WRITI 1503 WR A SHUE M SHUE SO WR A S U B T SO WR A S U U B T SO S WR A S U U B T SO S WR A S U U S C S U U S C S C S C S C S C S C
$52 \le 0.0012$ REC 12 $127 \ge 0.0011$ REC $53 \le 0.0455$ RE DIR $128 = 0.0411$ WR IN $54 \le 0.0106$ REC 16 $129 = 0.0600$ 0600 $55 \le 0.0603$ $130 = 0.0411$ WR IN $56 = 0.0603$ $130 = 0.0411$ WR IN $57 = 0.0412$ WR A $132 = 0.0405$ RE DIR $58 = 0.0102$ $133 = 0.012$ WR A $132 = 0.0405$ RE DI $59 = 0.0404$ ST DIR $133 = 0.012$ WR A $132 = 0.0405$ RE DI $59 = 0.0404$ ST DIR $133 = 0.012$ WR MITF $0600 = 0.0600$ 0600 $59 = 0.0404$ ST DIR $136 = 0.0411$ WR INTF $060 = 0.0600$ 0600 $61 = 0.0405$ RE DIR $136 = 0.0405$ RE DI $060 = 0.0605$ 0.0013 REG $62 = 0.013$ REC 17 $140 = 0.0405$ RE DI 0.013 REG $64 = 0.0604$ UP $139 = 0.013$ REG 0.013 REG $65 \le 0.0405$ RE DIR $140 = 0.0413$ WR	333344444444444455	ff. subtr. and calc.	0014 0612 0604 0605 0615 0612 0600 0600 0106 0005 0603 0603 0603 0603 0605 0603 0605 0603 0605 0605	REG 14 SQRX UP RE DIR REG 15 SQRX + RE DIR REG 16 + DOWN WR A 2 ST DIR REG 17 REG 17 REG 17		111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 2125 22 125 22 125 22 22 22 22 22 22 22 22 22 22 22 22 2	0002 0205 0113 0109 0113 0109 0108 0413 0405 0010 0411 0600 0411 1504 0405	- SPACH R R O R SH DC CR/LH END A RE DI REG WRITE 0600 WRITE 1504 RE DI
	35555555566666666666666666666666666666	tum.err. calc.%e	04 05 06 03 06 03 06 03 04 12 06 03 04 12 04 02 04 02 04 02 04 02 04 05 04 05 04 05 04 05 07 13 06 05 07 13 07 13 06 05 07 13 07 13 00 05 00 05 000 05 0000000000000000000	RED IR REG 16 		12890 2 GARES 2 4 LJ 3 13312 3 45 2 4 LJ 3 133345 2 4 LJ 3 13367 1 13367 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	0411 0600 1504 0405 0411 0600 0411 1504 0405 0411 1504 0405 0411 0103 0412 0103 0412 0103 0413	WEITE 0600 WEITE 1504 RE DI RE DI WEITE 1504 RE DI WEITE 0600 WEITE 0103 WE A END A END A END A

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CUMMULATIVE ERROR FOR DIFFERENCE-QUOTIENT COMBINATIONS (CONTINUED)

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1512534556789012234 1556789012166666789012234 1156666789012234 1166666789012234	write std. columns	1504 00015 004001 15005 0001 15005 0001 10000 10000 10000 10000 10000 10000 10000 10000 1000000	1504 RE DIR REG 15 WRITE 0600 WRITE 1504 RE DIR REG 16 WRITE 0600 WRITE 1504 RE DIR REG 17 WRITE 0103 WR A CR/LF SH UP Z SPACE E
174 175 177 178 180 181 182 183 184 185 186 187 190 192 193 195 195 197 198 199 200 201	write % eff. ± err.	0014 0106 0106 0106 0106 0113 00405 01413 004013 004013 004013 004013 004013 00000 004013 00000 004013 00000 004013 00000 004013 00000 00413 00106 004013 00000 00413 00000 00413 00000 00413 00000 00413 00000 004013 000000 004013 000000 004013 000000 004013 000000 004013 000000 004003 000000 004003 000000 004013 000000 004013 000000 004013 000000 004013 000000 004013 000000 004013 000000 004013 000000 004013 000000 004013 000000 00000 004013 000000 004013 000000 004013 000000 004013 000000 000000 00413 000000 0000000000	F F F F END A REG 18 WRITE 0203 WR A SPACE SH UP + K SPACE SH UP + K SPACE SH DOWN END A RE DIR REG 19 WRITE 0203 WR A CR/LF CR/LF END A STOP END PROG

PROGRAM DESCRIPTION: Cumulative error for differencequotient combinations.

PROGRAM ABSTRACT: This program determines the percent efficiency and the efficiency error for the thorium-234 beta tracer. It obtains two differences, takes the quotient of these two differences, and then calculates the error on this quotient in terms of square root counting statistics.

OPERATING PROCEDURE:

- 1. Insert tape: Press TAPE READY, RUN
- 2. Key: PRIME, LOAD PROGRAM
- 3. Key: Sample counts, GO
- 4. Key: Background counts, GO
- 5. Key: Standard counts, GO
- 6. Key: Background counts, GO

(System writes column headings of MIN. (minuend), SUBT. (subtahend), DIFF. (difference), and % ERROR, calculates desired information, enters the information under the proper column headings, writes % EFF. (efficiency) =, and writes the quotient along with its ± statistical error.)

1	20	0404	ST DIR REG 10		94 95	0411 1503	WRITE 1503	
2	Ē	0700	O ST DIR		96 97	0405	RE DIR REG	8
4 5	Ē,	0008	REG 8 1		98 99	0612	REY	_
6 7	Ξ	0404	ST DIR REG 7		100	0007	REG X	7
8 9		0411	WRITE 1505		102	0605	DOWN 0300	
10 11		0412 0103	WR A Sh UP		104 105	0412 0103	WR A CR/LF	
12 13		0205	N U		106 107	0108 0413	CR/LF END A	
14 15		0115	н. в		108 109	0515	STOP MARK	
16 17		0205	E R		110 111 o	0300 0604	0300 UP	
18 19		0413	END A WRITE		$\frac{112}{113}$ v	0610 0412	LOG X WR A	
20		1513	1513 WR A		114 L 115 O	0610 0407	LOG X SEARCH	
22	s E	0205	E		116 ^	1404 0414	1404 STY	
24	č	0113	R		118 E	0001	REG INT X	1
26	ס	0113	R END A		120 č	0604	UP SEARCH	
28	ě	0411	WRITE		122	1405	1405 MARK 1	
30	۔ د	0412	WR A		124	1404	1404	
32	Ξ,	0206	N c		126. 127E -	0414	STY	,
34	ž	0100	S W F		1282	0604	UP	-
36	ŭ	0113	R FND A		130 L Č	0509	SKIP Y	- X
38	+	0411	WRITE		132]	1405	1405	
40	s	0412	WR A			0701	i	
42		0214	U U		136 2 3	0001	REG	1
43		0106	m in			0701	1	
45		0205	E		140 0	0404	ST DIR	х •
48		0113	R		1410	0407	SEARCH	U
50		0102	SH DOWN		143	0408	MARK	
52		0108	CR/LF CR/LF		145 146 E +	0605	DOWN	
53		0413	<u>stop</u> (index	number)	14822	0001	REG	1
55		0408	GROUP 1	v	150 <u>-</u> - {	0412	LOGX	
57	•	0404	REG 10		151 m ú 152+	0301	0301 G0	
60 60		0408	HARK HARK	¢	1540 -	0000	REG	0
62		0410	ST DIR		155	0613 0603	10=X	
63		0604	REG II UP		157 E	1408	1406	
66	Ľ	0010	REDIR REG 10		160	0411	WRITE	
67	ۍ . ۱	0603	DOWN		161 <u>0</u> 162 X	0104	WR A	
69 70	•	0400	+ DIR		163 N	0205	SPACE e	
71 72	0	0008	REG 8 REY		165 - 166	0215	X SPACE	
73 74		0007	REDIR		167 2	0413 0405	END A RY DIR	
75 76		0010	REG 10 STOP (press	x or ÷)	169 170 L	0000	REG WRITE	0
77 78		0414	STY REG 7	,	171 3 172	0200 0511	0200 RETURN	
79 80		0411 1500	WRITE 1500		173 174	0408 0301	MARK 0301	
81 82		0405	RE DIR REG 10		175 17620	0414 0001	STY REG	1
83 84	Suc	0300	0300 WRITE	SR	177 1780.V	0604 0701	U P 1	
85 86	2	1505 0405	1305 RE DIR		179×.{ 180≌E	0601 0605	DOWN	
87 88	õ	0011	REG 11 0300	SR	181 + 2 182 + 2	0415 0001	REY REG	1
89 90	ŝ	0411 1503	WRITE 1503		1835 184	0511 0515	RETURN STOP	
91 92	Ē	0405	REDIR REG 7		185 L	0512	END PRI	26
93	3,	0300	0300	SR				

CUMMULATIVE ERROR FOR MULTIPLE PRODUCT-QUOTIENT COMBINATIONS

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