F. ULTRA-HIGH-SENSITIVITY MEASUREMENTS AND INVESTIGATION OF FUNDAMENTAL INTERACTIONS

The nucleus continues to be one of nature's classic laboratories for investigating both the strong and weak interactions. The equipment and techniques developed for investigating nuclei can be used to tackle many problems in nature. A range of ultra-sensitive investigations was pursued. Using ATLAS, the tradition of developing new and cutting edge Accelerator Mass Spectrometry (AMS) techniques continued with investigations of ^{39}Ar in sea water, ^{3}He in ^{4}He, and ^{244}Pu in the cosmos. Beyond these projects, synchrotron radiation from the Argonne Advanced Photon Source (APS) was used to determine the probability in enhancing the decay rate of the 31-year nuclear isomer in ^{178}Hf and refuting earlier claims of substantial enhancements. Investigations into the dynamics of confined plasmas also continued, focusing on the melting of confined cold plasmas. We continue to be interested in finding new avenues where our knowledge and equipment allow us to make significant contributions to important fundamental projects.

f.1. Developing an AMS Counting Technique for ^{39}Ar

(I. Ahmad, J. Caggiano, C. L. Jiang, A. Heinz, D. Henderson, R. C. Pardo, K. E. Rehm, R. H. Scott, R. Vondrasek, Ph. Collon,* M. Bichler,† W. S. Broecker,* L. DeWayne Cecil,‡ Y. El Masri,§ R. Golser,§ W. Kutschera,¶ B. E. Lehmann,|| P. Leleux,§ H. H. Loosli,|| M. Paul,** P. Schlosser,* and W. M. Smethie, Jr.*)

Scientific Justification

It is generally accepted that more geochemical and geophysical data is needed for proper modeling of the climate on Earth. Ocean currents play a particularly important role in this respect, because they transport large amounts of heat around the globe. Obviously, any advance in collecting data about the ocean system in this respect is welcome. A measurement of the cosmogenic radionuclide ^{39}Ar in ocean water was considered for some time to make an impact in oceanography due to a number of useful properties. The half-life of 268 years fits well to the time scale of oceanic currents and mixing (100 to 1500 years), the atmosphere is the only major pool of ^{39}Ar, and the inertness of argon makes it relatively easy to understand the distribution of ^{39}Ar on a global scale. An ^{39}Ar dating method for argon extracted from large water samples (~1000 liter) was developed some time ago using a low level decay counting technique.[1] Based on the results of Loosli's group at the University of Bern, a recent comparison of ^{39}Ar and ^{14}C ages for waters in the deep ocean emphasized the need for more ^{39}Ar measurements.[2]

The AMS method for measuring other radionuclides of interest (e.g. ^{14}C, ^{129}I) requires only ~1 liter of ocean water, making low level decay counting of ^{39}Ar virtually obsolete, hence, our effort to develop an AMS technique for ^{39}Ar. One liter of ocean water in equilibrium with the atmosphere contains about 9000 atoms of ^{39}Ar (about 6 cm^3 STP argon are dissolved in one liter of water). If this sample is detached from contact to the atmosphere for 1000 years, only about 700 atoms of ^{39}Ar will be left. To achieve the ultimate goal of ^{39}Ar/^{40}Ar ratio measurements with a 3% precision for 1000-year-old ocean water, one would have to collect 20 liter of ocean water, and to measure ^{39}Ar atoms from it with an overall detection efficiency of 7% (^{39}Ar atom detected per ^{39}Ar atom in the sample). Although this is currently still out of reach for our AMS technique at ATLAS, we believe that one can ultimately meet this goal.

The Technical Challenge

Measuring ^{39}Ar with AMS at natural levels is arguably the biggest technical challenge for the AMS method, and ATLAS is probably the only facility where it can currently be achieved. The difficulties can best be envisioned by comparing ^{39}Ar/^{40}Ar ratio measurements with those of ^{14}C/^{12}C. The latter is by far the most used radionuclide with AMS, partly because of the ease of performing the isotope ratio measurement. The natural (pre-bomb) ^{14}C/^{12}C ratio in atmospheric CO_2 is 1.2×10^{-12}, whereas the ^{39}Ar/^{40}Ar ratio in atmospheric argon

is only 8×10^{-16}. In addition, the stable isobaric background in ^{14}C measurements, ^{14}N, is virtually absent because nitrogen does not form negative ions. Therefore ^{14}C AMS measurements are performed exclusively with negative ions (mostly at tandem accelerators). In contrast to ^{14}C, ^{39}Ar measurements must be performed with positive ions because argon doesn't form stable negative ions. As a consequence, the stable isobar, ^{39}K, is also produced in the ECR ion source at ATLAS. Since potassium is a ubiquitous background at the trace element level in almost any material, one has to deal with a very strong isobaric interference.

In our last ATLAS run the $^{39}K^{8+}$ background ions arriving at the gas-filled spectrograph were 3 billion times more abundant in the beam than the $^{39}Ar^{8+}$ ions from a 1000-year-old water sample. Physical separation of ^{39}K from ^{39}Ar with the gas-filled spectrograph in the focal plane reduced ^{39}K by 4 orders of magnitude before the ions entered the focal plane detector. The remaining ^{39}K background was then separated from ^{39}Ar in the new large-acceptance focal plane ionization chamber (See Fig. I-60). This detector was developed by Michael Paul at the Racah Institute of Physics of the Hebrew University of Jerusalem, and was tested in an ATLAS run in July 2001.

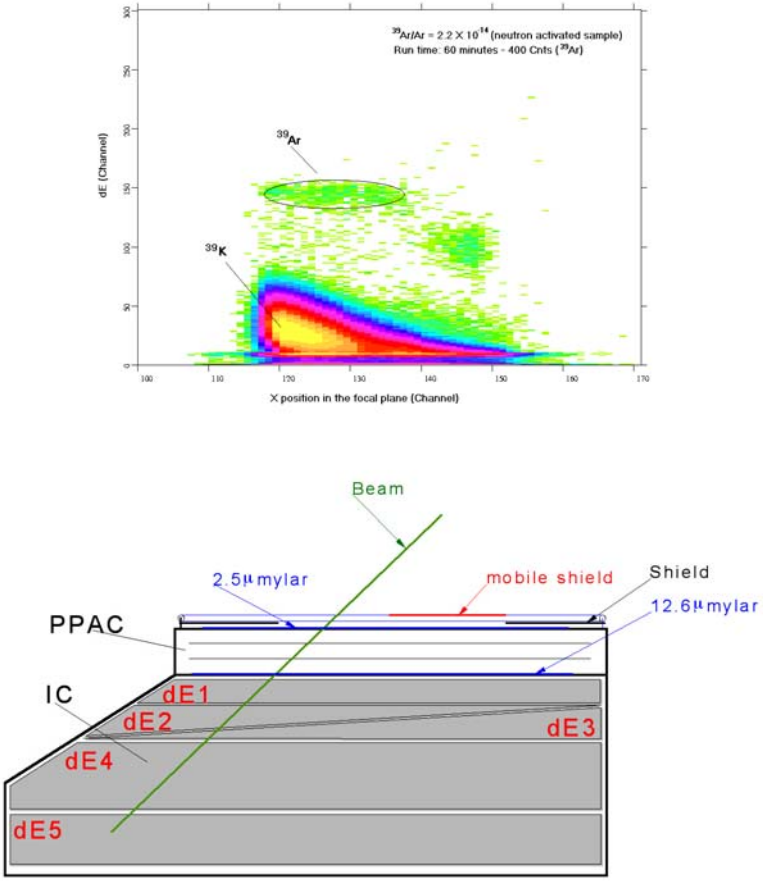

Fig. I-60. Typical focal plane position vs. ΔE signal obtained for a neutron activated argon sample using the ionization chamber (IC) coupled to the position sensitive PPAC detector. The clear separation of the ^{39}Ar from the ^{39}K background can clearly be seen.

Results from the Last ^{39}Ar Run

As compared to the run in February 2001, three major changes were implemented in order to reduce the ^{39}K background and to increase the overall detection efficiency, respectively:

1) A quartz liner was installed in the ECR II ion source. The $^{40}Ar^{8+}$ current was about the same as previously (45 - 50 eμA), but the ^{39}K background decreased by at least a factor of 10. During initial running with the quartz liner we noticed a defect of one bar of the permanent-magnet sextupole lens in ECR II, which resulted in burning a hole into the wall of the quartz cylinder. After replacing the faulty sextupole bar with a spare one, a second quartz liner was used, which was open ended on the front and the back, whereas the first liner had both ends of the cylinder closed by quartz plates. This latter configuration may have reduced the ^{39}K background further.

2) As mentioned above, we used the new focal plane detector from Israel, which accepts virtually all ^{39}Ar ions arriving at the split pole spectrograph. This resulted in a factor of about 2.5 in detection efficiency as compared to the standard focal plane detector.

3) A new gas-handling system for argon samples was developed during the past year and tested online for the first time during the august run. This system made it possible to measure up to 3 different samples/standards without having to gain access to the ECR source enclosure as all the pneumatic valves can be operated remotely. This new system coupled with the use of low neutron activated argon standards greatly improved our normalization procedures.

Together with a reduction of sample consumption due to a reduced pumping in the ECR II source (because the cylinder of the quartz liner did not allow pumping through the side port), and due to an improvement of ion optical transmission from ECR II to the split pole spectrograph, the overall efficiency was about 2×10^{-3}. This is about a factor of 5 higher than the overall efficiency of the February 2001 run. Normalization of the samples was achieved by using neutron-activated samples with known $^{39}Ar/^{40}Ar$ ratios of 2×10^{-14}. We measured several samples of known $^{39}Ar/^{40}Ar$ ratio in the range from atmospheric ($^{39}Ar/Ar = 8.1 \times 10^{-16}$) to 10% atmospheric ($^{39}Ar/Ar = 9.7 \times 10^{-17}$) values.

Future Plans

Recent results encourage us to pursue this technique. We will concentrate our efforts on the ECR source in order to try and reduce the ^{39}K background by several orders of magnitude so that we may be able run with higher intensity Argon beams (in the present state, running with higher intensity beams would swamp the detector with ^{39}K ions). For this we must identify the sources of ^{39}K and start a systematic analysis of the factors influencing its intensity in the beam. This information will then be used in the next phase of this project: the development of a small ECR source dedicated to noble gas AMS.

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[1]H. H. Loosli, Earth Planet. Sci. Lett. **63**, 51-62 (1983).
[2]W. S. Broecker and T.-H. Peng, Nucl. Instrum. Methods **B172**, 473-478 (2000).

f.2. Measurement of the ^{3}He Component in Isotopically Purified ^{4}He by AMS

(R. C. Pardo, A. Heinz, R. V. F. Janssens, C. L. Jiang, K. E. Rehm, J. P. Schiffer, R. H. Scott, R. C. Vondrasek, J. M. Doyle,* P. Collon,† P. R. Huffman,‡ and D. McKenzie*)

An experiment to determine the fractional concentration of ^{3}He remaining in isotopically purified ^{4}He was initiated. This measurement is in support of a program to improve the accuracy of the neutron beta decay lifetime.[4] The lifetime measurement is achieved by trapping free neutrons in a superfluid helium bath and observing their subsequent decay. Any capture of free neutrons by ^{3}He in the bath will reduce the apparent lifetime in this measurement. To achieve the desired neutron lifetime accuracy, the liquid helium trap material must be free of ^{3}He to a level of 1 part in 10^{14}.

The dominating problem in such a highly sensitive measurement of the $^{3}He/^{4}He$ ratio is the background ^{3}He present from past usage of natural helium (~2-10 × 10^{-8} $^{3}He/^{4}He$). By operating the source at extremely high pressures, we hoped to "overpower" the background with the material of interest. In an initial

run, the standard ECR-I source was used except that a 1-mm diameter extraction aperture replaced the standard 8-mm diameter aperture. Measurements were made with and without the standard pumping available to the source. The results are shown in Fig. I-61 and show the generally expected trend, but indicate that the actual ^{3}He background in this source is higher than anticipated.

Therefore a "new" source was constructed consisting of a new extractor electrode with a quartz tube directly attached forming a small isolated volume for creating the helium plasma. Off-line tests confirmed its ability to deliver sufficient beam with over 100 microamps of ^{4}He extracted. A two-day test in September determined that the background helium in this new "source" is at least two orders of magnitude lower than the original ECR-I source.

Our goal is to achieve a sensitivity of the order of 10^{-15} in the ^{3}He/^{4}He ratio.

*Harvard University, †Lamont-Doherty Earth Observatory of Columbia University, ‡National Institute of Standards and Technology

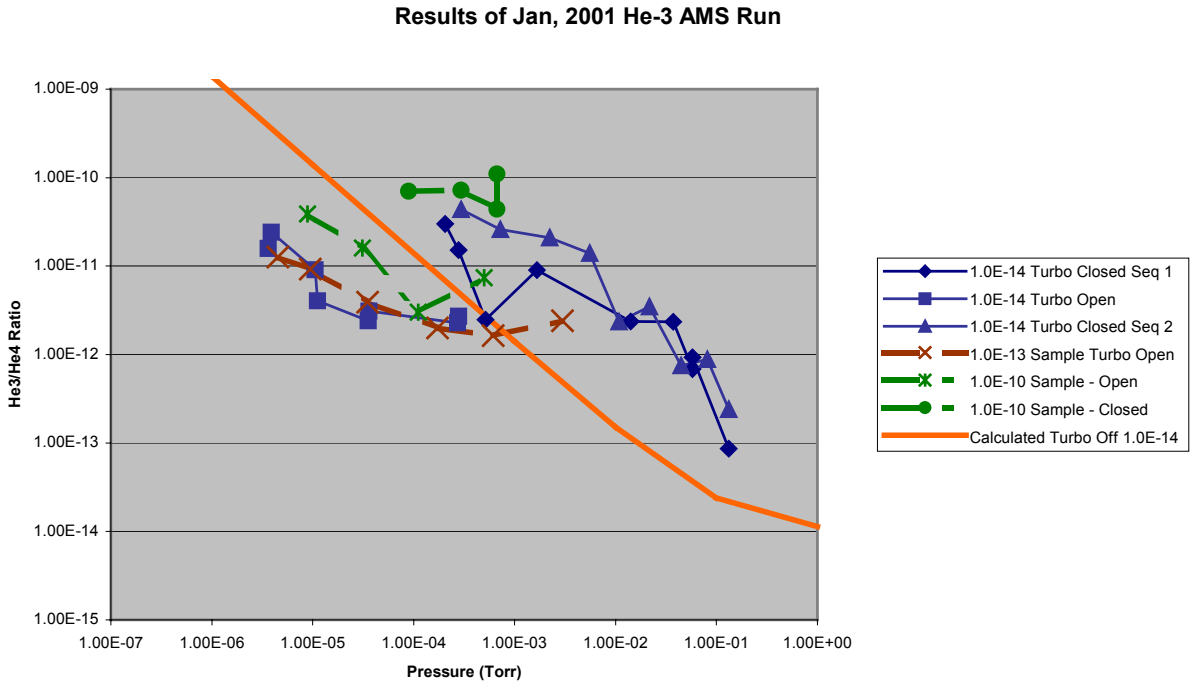

Fig. I-61. Summary of ^{3}He AMS Data from January 2001 run.

f.3. Experimental Limit of Interstellar ^{244}Pu Abundance (I. Ahmad, C. Feldstein,* A. Valenta,* S. Ghelberg,* S. Jiang,* Y. Bendov,† D. Berkovits,† C. Bordeanu,‡ Y. Hashimoto,§ T. Nakanishi,§ and K. Sakamoto§)

Recent data of the Ulysses and Galileo space missions and of the AMOR ground-based radar array point to the penetration of a population of interstellar medium (ISM) grains into the inner Solar System.[1] A steady-state deposition of such grains onto Earth would result in their accumulation in earth reservoirs such as deep-sea sediments and ferromanganese nodules. These two reservoirs are characterized by extremely low sedimentation rates (respectively of the order of 1 mm/kyr and 1 mm/Myr), resulting in a favorable ratio between extraterrestrial and terrestrial matter.

Several short-lived nuclides ($T_{1/2} \leq 100$ Myr) are known to have been alive in Early-Solar material. These radioactivities, now extinct in the Solar System, are expected to be present in the ISM where it is estimated that nuclides with lifetimes ≥ 5- 10 Myr attain approximate steady-state abundances.[2] An unmistakable signature of fresh ISM material deposited on Earth would be the presence of such short-lived

species. Among those, transuranium elements are favored since their natural production by other means, e.g. cosmic-ray interaction with matter, is unlikely.

We determined the ^{244}Pu content of the Pu fraction separated from 1 kg of North-Pacific deep-sea sediment.[3] The chemical separation and alpha-counting of the Pu-fraction were performed at Kanazawa University. The accelerator-mass-spectrometry (AMS) analysis of the Pu isotopes shows a distribution expected for nuclear fallout (Fig. I-62) and sets a limit of < 0.2 ^{244}Pu atoms cm^{-2} yr^{-1} (90% confidence level) for extraterrestrial deposition. Using existing experimental data on the rate of accretion of ISM grains onto Earth and further assuming that the ISM has an Early-Solar uranium abundance, we derive a limit of $(^{244}\mathrm{Pu/U})_{\mathrm{ISM}} < 1 \times 10^{-3}$.

These results are compared with the recent measurements[4,5] of the Munich group on ^{60}Fe and ^{244}Pu in deep-sea ferromanganese crusts. We are also pursuing our measurements with the separation of Pu, Cm and Hf from a deep-sea piston core (sediment depth from 3 cm to 230 cm), clean of material of fallout origin.

*Hebrew University, Jerusalem, Israel, †Soreq NRC, Yavne, Israel, ‡Weizmann Institute, Rehovot, Israel, §Kanazawa University, Japan

[1]E. B. Grün *et al*., Nature **362**, 428 (1993); M. Baguhl *et al*., Science **268**, 1016 (1995); J. W. Baggaley, JGR **105**, 10353 (2000).
[2]B. S. Meyer and D. D. Clayton, Space Sci. Rev. **92**, 133 (2000).
[3]M. Paul, A. Valenta, I. Ahmad, D. Berkovits, C. Bordeanu, S. Ghelberg, Y. Hashimoto, A. Hershkowitz, S. Jiang, T. Nakanishi and K. Sakamoto Ap. J. **558**, L133 (2001).
[4]K. Knie, G. Korschinek, T. Faestermann, C. Wallner, J. Scholten, W. Hillebrandt, Phys. Rev. Lett., **83**, 18 (1999).
[5]C. Wallner, T. Faestermann, U. Gertsmann, W. Hillebrandt, K. Knie, G. Korschinek, C. Lierse, C. Pomar, G. Rugel, Nucl. Instr. and Methods **172**, 333 (2000).

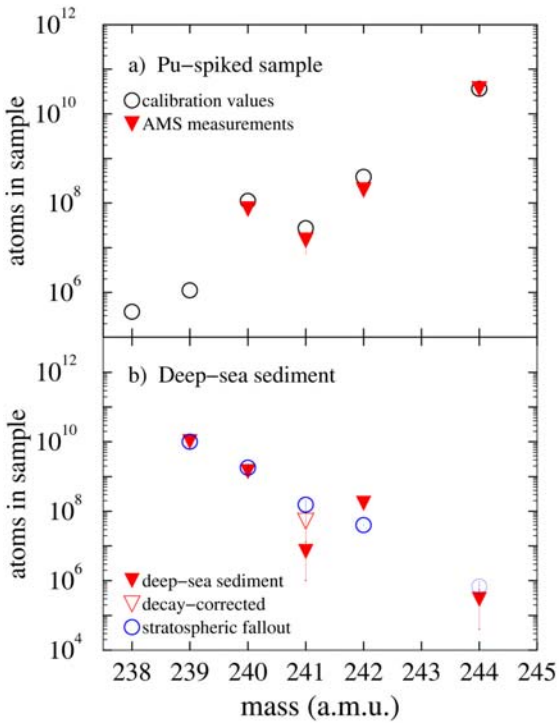

Fig. I-62. Isotopic distribution of plutonium (solid triangles) measured by AMS for: (a) a calibration sample containing 3.7 × 10^{10} ^{244}Pu atoms. The open circles show the distribution measured by alpha counting of a thin source. The AMS results were normalized to the number of ^{244}Pu atoms obtained from the alpha counting. (b) The plutonium fraction extracted from the 1.020-kg deep-sea dry sediment. The AMS results were normalized to the combined number of ^{239,240}Pu atoms measured by alpha spectrometry. The open circles represent the expected Pu isotopic distribution of nuclear-bomb stratospheric fallout.

f.4. Search for the First Excited Level in the ^{229}Th Nucleus (I. Ahmad, K. Bailey, Z.-T. Lu, C. Law, D. L. Bowers,* and D. G. Graczyk*)

The first excited level of the ^{229}Th nucleus was deduced to be 3.5 ± 1.0 eV above the ground-level.[1] Considering nuclear excitation energies are typically in the 10^4 - 10^6 eV range this would be by far the lowest known nuclear excitation energy, both extremely unique and unexpected – even lower than the atomic ionization energy. This state, if confirmed, could be used to study the interactions of the nucleus and its surrounding, as well as novel ways to achieve nuclear excitation (such as visible lasers).

This experiment was designed to test the validity and clarify discrepancies from a number of recent experiments.[1,2,3,4] Rather than using ^{233}U samples for observation, isotopically and chemically pure ^{229}Th samples were used. The ^{229}Th samples were observed within hours of production (via ^{233}U alpha decay), which should leave a large number of ^{229}Th in the first excited state for our observation. Our experiment also includes very low detection thresholds due to cooled, low-background photo-multiplier tubes.

We extracted freshly produced ^{229}Th atoms from a 250 mg isotopically pure ^{233}U (^{232}U/^{233}U < 10^{-9}). We allowed the ^{229}Th to accumulate for approximately 15 hours in the ^{233}U solution before being chemically separated. The ^{229}Th sample had an alpha activity of 20 Bq (there were no other detectable radioisotopes in the sample), and was dissolved in HCl (12 M) and placed in a quartz cell for observation. The sample was placed in the photon detection system approximately one hour after the chemical separation.

Our detection system consisted of two UV sensitive PMTs. The sample was placed between the two PMTs on a pneumatic sled. The system is sensitive to photons with wavelengths from 210 nm (determined by absorption in the HCl) to 800 nm (PMT window material), or 1.5 - 5.9 eV. The sled was operated with a period of 45 s, to allow for background counting with a sample in the system. The PMT's were cooled to approximately 0°C in order to reduce the dark counting rate.

Compared with the dark counting rate of 1000 cpm, we were able to detect significantly higher count rates with the ^{229}Th sample inserted (1500 cpm), however, this difference did not vary significantly with time and was several orders of magnitude below expectations. This would indicate that the photons being observed were not from a low-energy nuclear transition in ^{229}Th, but from α and high-energy γ decay of ^{229}Th and its daughter products.

There are several possible reasons for our inability to verify this low energy state. The photon energy could be outside of our detectable limit, or the lifetime of the state could be extremely long or short compared with our expectations.

In future we plan to use phototubes with lower dark currents and reduce the time between the chemical separation and the start of the measurement.

*Chemical Technology Division, ANL

[1] R. G. Helmer and C. W. Reich, Phys. Rev. C **49**, 1845 (1994).
[2] G. M. Irwin and K. H. Kim, Phys. Rev. Lett. **79**, 990 (1997).
[3] D. S. Richardson *et al*., Phys. Rev. Lett. **80**, 3206-3208 (1998).
[4] R. W. Shaw, J. P. Young, S. P. Cooper and O. F. Webb, Phys. Rev. Lett. **82**, 1109-1111 (1999).

f.5. Search for X-Ray Induced Acceleration of the Decay of the 31-yr Isomer of ^{178}Hf Using Synchrotron Radiation (I. Ahmad, D. S. Gemmell, E. F. Moore, J. P. Schiffer, J. Banar,* J. A. Becker,† A. Kraemer,† A. Mashayekhi,‡ D. McNabb,† G. G. Miller,* L. N. Pangault,* S. Rundberg,* S. D. Shastri,‡ T. F. Wang,† and J. B. Wilhelmy*)

Releasing the energy stored in an isomeric nuclear state in a controlled way with an atomic or electromagnetic trigger is an attractive speculation: the energy gain is on the order of the ratio of nuclear/atomic energies ~MeV/keV. Nuclear isomers, therefore, represent an opportunity for stand-alone energy source if suitable schemes for trigger and control of energy release could be identified. Potential applications include space propulsion as well as very bright gamma-ray sources.[1]

Recently, reports of triggered decay of a ^{178}Hf isomer induced by x rays delivered by a dental x-ray machine were made.[2,3] Enhancements of 1-2% in the isomer decay rate were reported for several gamma-rays in the decay cascade (Fig. I-63). The reported integrated cross section for the decay was 10^{-21} cm^2-keV, so large as to demand new physics. We sought to verify these claims using the intense photon flux available at the Advanced Photon Source facility.

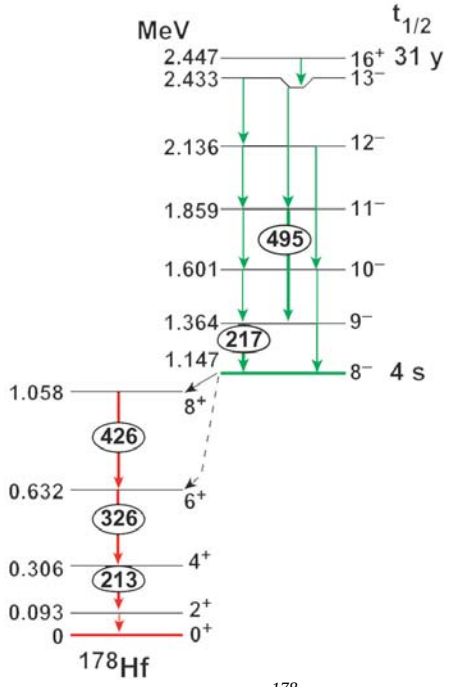

Fig. I-63. Energy level diagram showing the decay of 31-y ^{178}Hf isomer. Transition energies are given in keV.

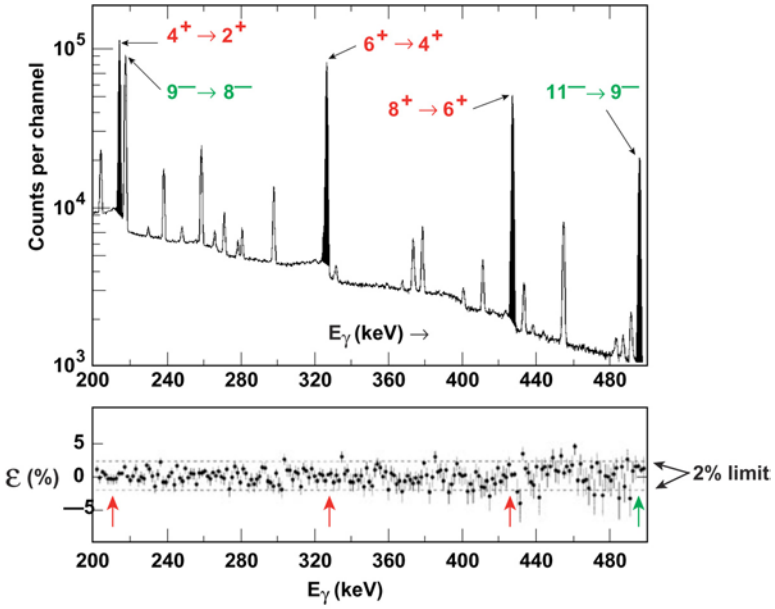

Fig. I-64. Gamma-ray spectrum showing transition in the 200 - 500 keV range in the decay of ^{178}Hf isomer. The lower part shows the difference in spectrum between the first half and second half of the 22-s beam-off data.

Samples of HfO_2 containing ~10^{15} atoms of the 31-y ^{178}Hf were irradiated at the SRI CAT 1-ID in March 2001. Samples were fabricated at LANL using material chemically isolated from LANSCE/LAMPF target/beam stop. The undulator 1-ID was operated with maximum taper (5 mm) in the gap and two average settings: 15 mm and 20 mm. This arrangement generated a smooth "white" photonflux peaking at 2×10^{15} photons/keV-s at E_{ph} = 16 keV and extending up to 100 keV. The beam was mechanically chopped to form a pulse train of 11-s beam-on and 22-s beam-off during irradiation intervals of 8 h for each of the three samples. Two Low Energy Photon Spectrometers (LEPS) were used to measure the gamma-ray spectra of the ^{178m}Hf source. The Hf K x rays produced by fluorescence of Hf atoms by the beam were used to monitor the beam flux. The experimental signal of triggered isomer decay is an increase in the yields of ^{178}Hf gamma rays above the background gamma rays of the sample.

The intensities of gamma rays were measured both during beam-on period and beam-off period for the gamma rays decaying through the 4-s isomer. For the latter analysis, the off-line spectra were divided into two 11-s spectra. The difference of the two spectra will show if there were any population of the 4-s isomer during irradiation. Figure I-64 shows the spectrum and the difference measured. The bottom part of the figure shows the difference between the two spectra. As can be seen, within the statistics, there is no enhancement.

By analyzing the spectra measured with beam-on and beam-off conditions, we obtained an upper limit for the integrated cross section. Our upper limit of the integrated cross section for 20-60-keV photons is 2×10^{-27} cm^2-keV (Fig. I-65), which is five orders of magnitude lower than the published value. Results of this experiment were published.[4]

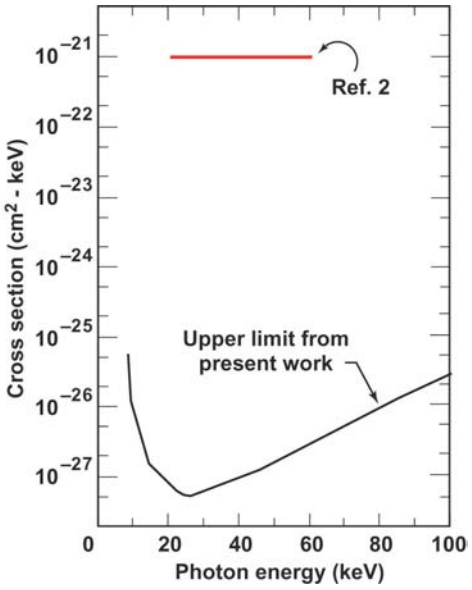

Fig. I-65. Upper limit of the cross section for the photon induced deexcitation of the 31-y ^{178}Hf isomer through the 4-s isomer. The upper horizontal line shows the value reported in Ref. 3.

*Los Alamos National Laboratory, †Lawrence Livermore National Laboratory, ‡Advanced Photon Source, ANL

[1]Science **283**, 769 (1999).
[2]C. B. Collins *et al*., Phys. Rev. Lett. **82**, 695 (1999).
[3]C. B. Collins *et al*., Laser Physics **9**, 8 (1999).
[4]I. Ahmad et al., Phys. Rev. Lett. **87**, 072503 (2001).

f.6. Melting of Crystalline Confined Plasmas (J. P. Schiffer)

The behavior of confined plasmas, such as occur in ion traps, was studied in simulations. For an infinite array of charges it was known for some time that a phase transition from liquid to solid behavior occurs at a well defined temperature, defined by the dimensionless parameter that scales the temperature with density

$$\Gamma \equiv (q^2/a_{ws})/kT$$

where $a_{ws} \equiv 1/\rho^{1/3}$ is the Wigner-Seitz radius. The phase transition for infinite Coulombic matter occurs at $\Gamma \approx 173$. For finite confined systems, the ordering is not the body-centered cubic form that is seen in infinite matter, instead they form an ordered state with concentric shells, with hexatic order of equilateral triangles within the shells.[1] In any case, finite systems do not have sharp phase transitions. Molecular Dynamics simulations were carried out by running

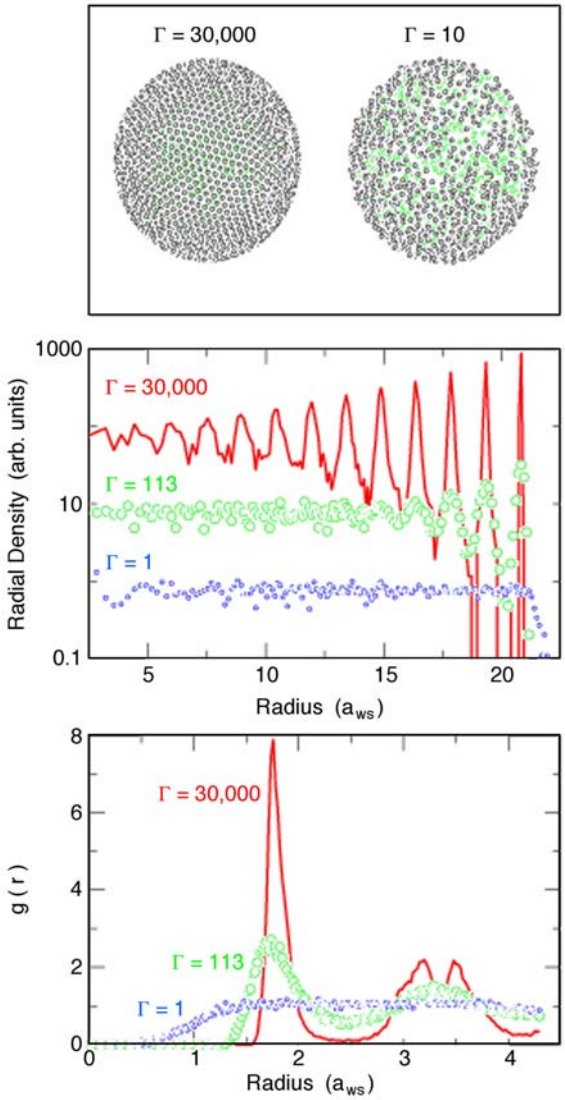

Fig. I-66. On top the outer two layers of ions are displayed for a 10,000 ion system. The ions in the outermost layer are shown in black, the next layer in grey. On the left, a cold ordered array is shown, while on the right a disordered one at high temperature, with the ions in different shades corresponding to similar radial intervals. The middle box shows the radial density within the ion cloud at three different temperatures with the vertical scaled displaced for visibility. On the bottom, the correlation function g(r) is shown at three temperatures. For the lower two boxes the distance scale is in units of the Wigner-Seitz radius.

finite systems for long periods of time, to establish an equilibrium state for a given temperature. The total potential energy of the system was extracted, as were the near-neighbor correlation functions, and the diffusion rates. In Fig. I-66 the properties of 10,000 ions are displayed at several temperatures, from liquid to very cold.

The total energy of the system of 10,000 ions as a function of temperature, and the corresponding specific heat for an infinite system published previously[2] is displayed in Fig. I-67. It is clear that both systems display similar behavior, but the transition is less sharp in the finite system and the temperature at which the transition takes place is slightly lower. The transition temperature coincides with the point where the rate of change in the correlation function and that in the diffusion rate are the steepest, as expected. The diffusion rates within a shell are higher than between shells, and the ratio seems to be largest near the melting point. The shift in the melting temperature seems to depend on the size of the system, as is displayed in Fig. I-68. The decrease in melting temperature seems to depend linearly on the fraction of ions that are in the surface layer. Qualitatively similar behavior was observed for the melting of finite atomic clusters,

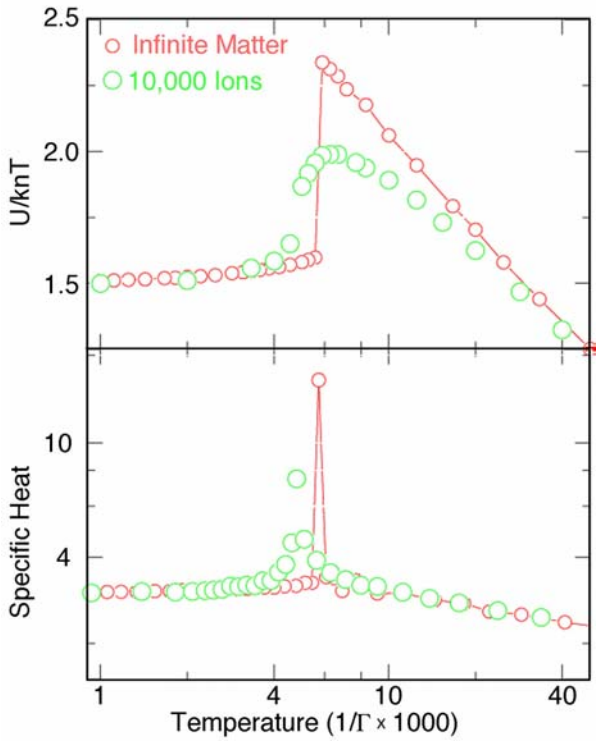

Fig. I-67. The total energy of a system of charges is shown on top for an infinite system of ions from Ref. 2 as open circles and for a 10,000 ion system as solid dots. The lower plot is the corresponding specific heat. Note that at low temperatures both approach the value of 3.0. The temperature scale is in units of 1/Γ.

[1]A. Rahman and J. P. Schiffer, Phys. Rev. Lett. **60**, 511 (1988).
[2]R. T. Farouki and S. Hamaguchi, Phys. Rev. E **47**, 4330 (1993).

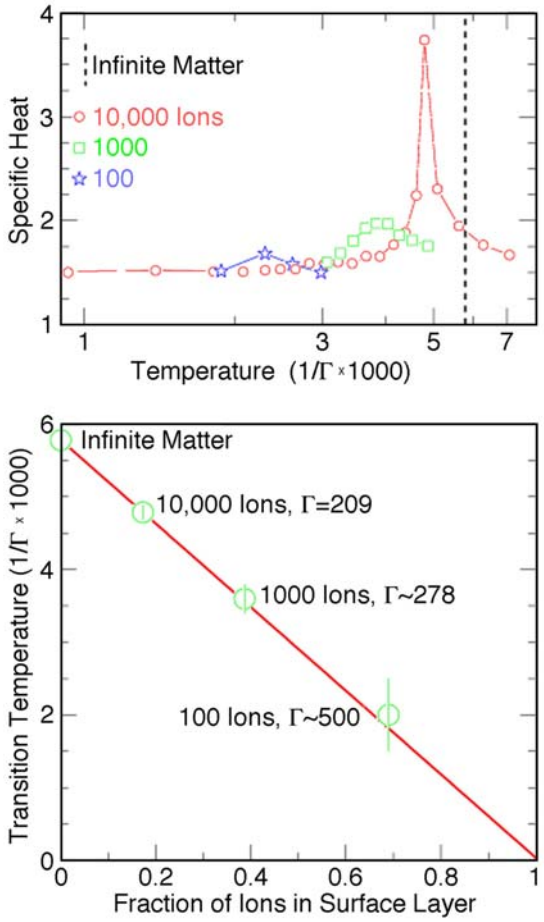

Fig. I-68. Specific heat plots of the type that was shown in Fig. I-67 for 10,000, 1000, and 100 ions. The lower plot shows the temperature at which the specific heat has its maximum value, as a function of the fraction of ions that are in the outermost shell.

f.7. The Transition from Infinite to Finite Systems in Crystallized Coulombic Systems
(J. P Schiffer)

Cold systems of charges in an infinite array show body-centered cubic (bcc) order in their lowest-energy configuration. However, finite arrays of charges confined in a harmonic potential, such as is provided by ion traps, show a different form of ordering with equally spaced concentric shells, with the surface density constant in each shell and the form of order within each shell forming equilateral triangles, as far as this is possible.[1] In very large clouds, with over 100,000 ions, bcc order was observed experimentally, but until recently simulations did not show this type of order.[2]

Recently Totsuji *et al.*[3] reported simulations in which this transition regime was observed. They started with an array of bcc ions of the anticipated density and of the shape (spherical) consistent with the confining potential, and then allowed this system to relax in Molecular Dynamics simulations. The present effort is to investigate this transition regime further, in order to better understand this transition regime. Simulations starting with bcc order were carried out for different numbers of ions and these were allowed to propagate forward in time until a minimum in potential energy was obtained. For a large number of ions (100,000) this process takes a long time, and the simulation is still running and improving (reaching lower total energy) after 3 months. In Fig. I-69 the state of the system is shown using angles between nearest neighbors to determine whether an ion was in a bcc or other

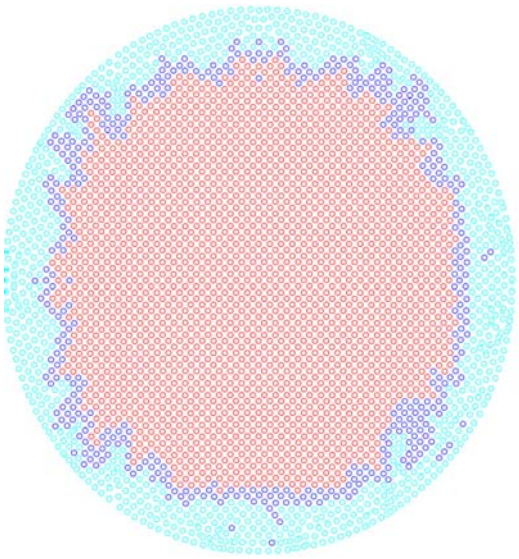

Fig. I-69. The configuration of about 100,000 (99,809) ions that were started from bcc order, progressing toward lower total energy in a molecular dynamics simulation. A central slice of ions is displayed, with all ions shown in light blue, the ions with all 24 angles to nearest neighbors having the bcc value to ± 1 degree of the bcc value shown in red, and those with 12 of the angles being correct shown in dark blue.

environment. In a bcc lattice one ion (taken as a center of its cube) is surrounded by 8 nearest neighbors forming the corners of the cube. Lines to adjacent corners from the center should form an angle of 70.529 degrees. There are 12 possible angles corresponding to the 12 edges of the cube. The next 6 nearest neighbors are the ions at the centers of adjacent cubes. Lines drawn to these form 90 degree angles. The 14 nearest neighbors of each ion were identified, and then all possible angles were computed within the 8 nearest, and the 6 next-nearest ions. The figure displays the location of ions, with different colors designating those with all 24 angles within 1 degree of the bcc criterion, those with 12 ions satisfying it, and all ions. This simulation is still progressing to lower energies as the bcc order is gradually replaced in the outer regions.

[1]A. Rahman and J. P. Schiffer, Phys. Rev. Lett. **57**, 1133 (1986); D. H. E. Dubin and T. M. O'Neil, Phys. Rev. Lett. **60**, 511 (1988).
[2]X. P. Huang *et al*., Phys. Rev. Lett. **80**, 73 (1998).
[3]H. Totsuji *et al*., Phys. Rev. Lett. **88**, 125002 (2002).

f.8. Precision Measurement of the ^{62}Ga Half-Life

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As part of the program to extend the set of high-precision superallowed Fermi emitters to heavier systems, we remeasured the half-life of ^{62}Ga. An accuracy of about 0.05% is required for this particular application, about an order of magnitude better than previous results. This measurement will then complete the set of measurements required (branching ratio, half-life and Q-value) and presently underway to determine the ft-value and together with calculated corrections provide the heaviest point for which a full high-precision data set is available to improve the CVC and CKM unitarity test.

To obtain the required accuracy it was necessary to develop a dedicated detector and electronics system. A 4π gas counter was built for this application (Fig. I-70). The counter is made of 2 independent halves that close around a tape transport system bringing in the short-lived activity. The counter has thin aluminised mylar windows separating the chambers from the tape system. The counter is operated with P10 gas at just above atmospheric pressure. Both halves were characterized independently with sources and found to have similar plateaux. They were therefore biased together and the signals extracted together to behave as a single 4π

counter. The signals from the counter were sent through a preamplifier and a timing filter amplifier followed by a discriminator firing 2 independent gate generators which provide long fixed deadtime for each event. The overall efficiency of the counter and electronics for high-energy betas was in excess of 90%.

This system needed to be installed at a location where a high-intensity high-purity ^{62}Ga beam at low-energy is available. Within the framework of GSI Experiment U183 it was shown that a monoisotopic beam of ^{62}Ga can be delivered by the GSI on-line mass separator with an intensity of 1200 atoms/s. A proposal was therefore put forth to the GSI PAC for beamtime to perform this measurement (and a branching ratio measurement). The proposal was accepted and the half-life measurement was run in December 2001. The activity was produced by a ^{40}Ca beam at about 4.8 MeV/u degraded by a 2.7 mg/cm^2 Nb degrader before impinging on a thick ^{nat}Si target. The recoils are stopped in the catcher of a high-temperature FEBIAD source and extracted as a singly charged ion beam. The beam is mass separated and then implanted on a tape transport system.

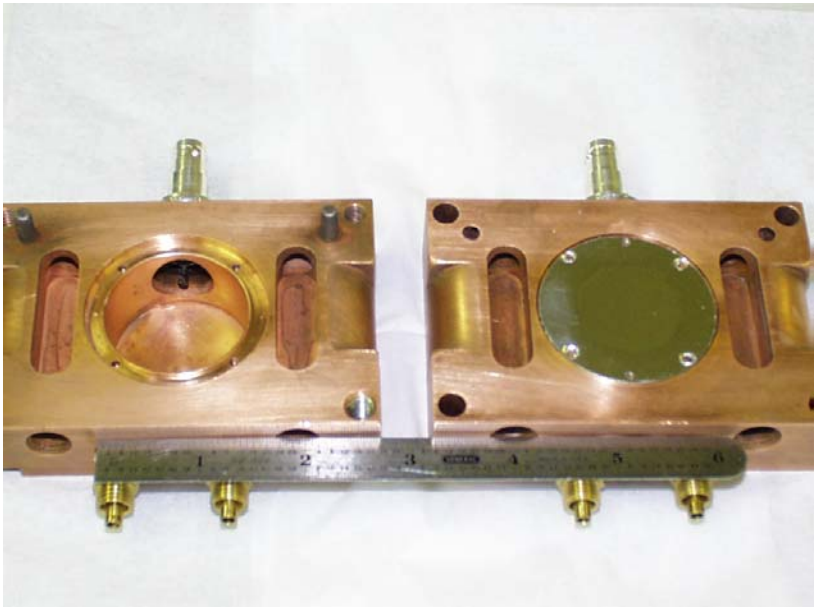

Fig. I-70. Picture of the 4π beta counter used for the experiment. The two halves shown here (one with window, the other with the window removed) surround the tape transport system carrying the activity.

The activity was accumulated on the tape for about 350 ms before being moved 20 cm (about 150 ms) to the center of the beta-counter where a long (10 to 14 half-lives) counting cycle begins where each beta event is multiscaled to create a decay curve per cycle. The mass separator beam is deflected away during the counting cycle. This cycle was repeated about every 2 seconds for about 4 days with brief interruptions for tape rewinding and accelerator tuning. In this fashion, a total of about 20 millions beta events were obtained in well over 10^5 independent decay curves. The average collection held between 100 and 300 ^{62}Ga atoms by the time the counting started. A germanium detector was used to monitor contaminant activity and none were present at a level sufficient to affect the measurement.

The data sample accumulated is of extremely high-quality, taken under conditions selected to minimize systematic effects and with all important parameters well controlled. It is currently being analyzed and we expect a final error bar at the 0.03% level, well within the required 0.05%.

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f.9 A Bragg Scattering Method to Search for the Neutron Electric Dipole Moment

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Polarized neutrons will undergo several thousand Bragg reflections in a slot cut in a perfect silicon crystal and the rotation of their polarization by the interaction of the neutron electric dipole moment (EDM) with crystalline fields in the silicon will be measured.[1] We hope to achieve a sensitivity several times better than the best previous experiment, which finds that the EDM vanishes with an uncertainty limited by systematic errors to around 1×10^{-25} e-cm, and equally importantly to do that in an experiment with very different systematic errors. Progress includes the development of a suitable slotted silicon crystal and the experimental demonstration of reflectivity of 0.99998 for each Bragg reflection.

In a preliminary experiment, we are now attempting to measure the neutron magnetic dipole moment (MDM) in the same way, using the interaction of the moving neutron's effective EDM, equal to v/c times the MDM, with the crystalline electric field. The MDM measurement, which requires only a few hundred Bragg reflections because it looks for a much stronger effect, should test the principles of the EDM experiment in an easier case. We have now produced a suitable slotted silicon crystal for the MDM experiment and tested it successfully at the Missouri University Research Reactor. A solenoid to provide the necessary magnetic guide field is under construction and a proposal for the MDM experiment has been written.

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[1]Argonne National Laboratory Physics Division report PHY-9814-TH-2001, March 2001