about 2 m (6 ft) above the normal high-tide line. Amchitka is the island closest to the epicenter of the main shock.

The primary shock of the Rat Islands earthquake on 4 February 1965 was felt at Shemya airbase, some 300 km northwest of the epicenter. Some damage to runways and buildings was reported. As the Aleutian Islands between Shemya and Adak are uninhabited no other land reports were made, but the ship S.S. *Ohio*, some 150 km from the epicenter, reported that the primary shock was felt. Members of the U.S. Coast and Geodetic Survey field party, which set up and operated the temporary seismograph station on Amchitka Island, reported feeling a number of the aftershocks of the Rat Islands earthquake. There was very little surface evidence of terrain damage from the primary Rat Islands shock or its many aftershocks.

On 30 March 1965, an aftershock of magnitude (M_s) of 7 to 7¼ occurred south of the primary shock of the Rat Island series. This shock was followed by another sequence of shocks with current counts (not yet complete) showing 60 events on 30 March, 30 events on 31 March, and 15 events on 1 April.

In summary, large aftershock sequences, such as those recorded for the Prince William Sound earthquake of 27 March 1964, and the Rat Islands earthquake of 1965 (when well-recorded by both local and distant seismograph networks) will provide new data on major tectonic trends in seismically active areas.

Although the structure of the Aleutians has been considered that of a typical island arc, the data presented here suggests that the seismicity of the area is very complex. North-south trending fracture-zones which divide the island chain into very large fault blocks are proposed to explain the very sharp limits of observed aftershock activity along the island chain. St. Amand (*5*) and Menard (*6*) have discussed similar structures in other parts of the Pacific Ocean.

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Half-Lives of Argon-37, Argon-39, and Argon-42

Abstract. *The half-lives of three argon isotopes have been carefully determined, with the following results: Ar^{37}, 35.1 ± 0.1 days; Ar^{39}, 269 ± 3 years; Ar^{42}, 32.9 ± 1.1 years. By combining the Ar^{42} value with earlier data, a cross section of 0.5 ± 0.1 barn is calculated for the reaction, with thermal neutrons, $Ar^{41}(n,\gamma)Ar^{42}$.*

Accurate half-life values of the argon isotopes are needed for various applications in cosmochemistry (*1*) and in nuclear chemistry and physics (*2*). For example, Ar^{37} and Ar^{39} have been determined in many meteorites in order to study possible variations of cosmic ray intensity in time and in interplanetary space (*3*).

Various values for the Ar^{37} half-life (*4*) have been reported. Weimer, Kurbatov, and Pool, who reported 34.1 ± 0.3 days, prepared the Ar^{37} by various methods including $K^{39}(d,\alpha)$, $Cl^{37}(d,2n)$, and $Cl^{37}(p,n)$ nuclear reactions. These investigators followed the decay of the activity with an air-ionization chamber for as long as seven half-lives. Miskel and Perlman (*5*) prepared the Ar^{37} from calcium metal by the $Ca^{40}(n,\alpha)$ reaction, and arrived at a value of 35.0 ± 0.4 days. They used gas proportional counters and also a special ion chamber. Kiser and Johnston (*6*) followed the decay of the K Auger-electron peak with a proportional counter and multichannel analyzer for 70 days, and they reported a value of 34.30 ± 0.14 days. In view of the spread of values between 34.1 days and 35.0 days it was considered desirable to restudy the half-life of Ar^{37}.

There is only one reported determination of the Ar^{39} half-life. Zeldes *et al.* (*7*) found a value of 265 ± 30 years. Their samples were obtained from the $K^{39}(n,p)$ reaction by intense neutron irradiation of KCl. They made the radioactivity measurements with a calibrated magnetic-lens beta-ray spectrometer and found the number of Ar^{39} atoms by volumetric measurement and mass-spectrometric determination of the isotope ratios. A preliminary determination of the Ar^{39} half-life made in this laboratory yielded a value of 325 years (*8*).

A lower limit of 3.5 years was placed on the half-life of Ar^{42} (*9*) when its preparation was first reported. Although no other determinations have been published, preliminary data obtained at this laboratory several years ago showed that the Ar^{42} half-life is approximately 30 years.

The half-life of Ar^{37} is of such length that it may readily be determined from the course of its decay. The Ar^{37} was prepared by the reaction $Ca^{40}(n,\alpha)Ar^{37}$. Calcium carbonate (180 mg) was irradiated in the Brookhaven reactor for 3 hours. The sample, in a vacuum system, was dissolved in dilute hydrochloric acid in the presence of mixed carrier gases consisting of argon, krypton, and xenon. Argon was separated and purified by gas chromatography and by gettering with hot titanium metal. (This procedure has a decontamination factor from krypton of at least 10^5.) Samples of the argon were placed into five conventional proportional counters (1.9 cm inside diameter; 30 cm long), and the counters were then filled with P-10 gas (90 percent argon : 10 percent CH_4) to a pressure of one atmosphere. Plateaus of these counters showed two distinct levels corresponding to K-capture and to the sum of K- and L-captures. The counters were operated near the high-voltage end of the sum level. The decay of Ar^{37} was followed for 175 days, about five half-lives. The decay curves were analyzed by a least-squares method (*10*). The results from the five counters were 35.23 ± 0.06, 35.20 ± 0.06, 34.98 ± 0.05, 35.16 ± 0.05, and 35.11 ± 0.05 days, from which an average value of 35.14 ± 0.05 was obtained. In order to allow for possible systematic errors the value has been rounded off to 35.1 ± 0.1 days. Analysis of the decay curves gave no indication of a longer-lived component. Further evidence concerning the purity, with respect to radioactivity, of the gas can be derived

Table 1. Disintegration rates, atom ratios, and half-lives of argon isotopes; dpm, disintegrations per minute.

Sample	dpm			Atom ratios		Half-life*	
	Ar^{37}	Ar^{39}	Ar^{42}	Ar^{39}:Ar^{37}	Ar^{42}:Ar^{37}	Ar^{39} (yr)	Ar^{42} (yr)
103A	116.0×10^6	163,600	28,790	3.96	0.081	270	31.4
126	104.2×10^6	107,600	17,880	2.77	.057	258	31.9
127	64.4×10^6	77,040	12,010	3.28	.062	264	32.0
128	17.3×10^6	60,100	9,820	10.4	.216	288	36.6
129	16.9×10^6	104,500	17,440	17.3	.350	269	32.6
3	3.93×10^6	5,910		4.29		274	
8	1.59×10^6	2,111		3.65		265	
5	0.914×10^6	1,104		3.42		272	
Ni	1.74×10^6	720		1.17	.0372	272	
Fe	1.04×10^6	613		1.55	.101	253	

* Mean values: Ar^{39}, 269 ± 3; Ar^{42}, 32.9 ± 1.1.

from another experiment in which Ar^{37}, 4×10^5 dpm (disintegrations per minute), prepared in the manner described was placed in an envelope surrounding a thin-wall counter. The counting rate observed corresponded to less than 1 dpm per 3×10^5 dpm of Ar^{37}.

The half-lives of Ar^{39} and Ar^{42} may be obtained from a mixture of Ar^{37}, Ar^{39}, and Ar^{42} by measuring the atom ratios, Ar^{37}:Ar^{39} and Ar^{37}:Ar^{42}, and the activity ratios of these same isotopes. From these data and the half-life of Ar^{37} one can calculate the half-lives of the other two isotopes. It is to be noted that this method involves the determination not of absolute numbers of atoms, but only ratios.

Spallation of titanium was chosen as a convenient process for the preparation of adequate quantities of all three isotopes, Ar^{37}, Ar^{39}, and Ar^{42}. A set of titanium foils which had been outgassed (vacuum at 500°C for 2 days) to remove adsorbed atmospheric argon was irradiated with 380-Mev protons in the Nevis cyclotron for 56 hours.

Samples of Ar^{37} and Ar^{39} were also prepared by low-energy reactions in the Brookhaven Graphite Reactor: $Ca^{40}(n,\alpha)Ar^{37}$ with CaF_2 as the target, and $K^{39}(n,p)Ar^{39}$ with KF as target. After irradiation, the two different fluorides were mixed in suitable proportion and, wrapped in copper foil, were transferred to the vacuum line of the mass spectrometer.

A third source of Ar^{37} and Ar^{39} was iron and nickel foils irradiated by 2.9-Gev protons at the Brookhaven Cosmotron.

The samples were transferred to a high-vacuum system and melted in a molybdenum crucible at about 1900°C. The evolved gas was purified by hot titanium; it was then admitted to an all-glass high-sensitivity mass spectrometer (*11*). The ion currents corresponding to the different argon isotopes were measured several times.

The mean corrected atom ratios (Table 1, columns 5 and 6) for samples 103A, 126, 127, and 128 were corrected for a mass-dependent sensitivity of the mass spectrometer of 3.5 percent per mass unit. This value was obtained from measurements with atmospheric argon on the assumption that the natural-abundance ratio of Ar^{40} to Ar^{36} is 296. For the other samples shielding was applied around the multiplier until the sensitivity of the spectrometer was independent of mass. Under this condition the measured ratios for atmospheric argon agreed with natural abundance within an experimental uncertainty of 2 to 3 percent.

In measuring the activities of the three argon isotopes advantage was taken of the differences in their radiations. The Ar^{37} decays only by electron capture and emits very soft x-rays and electrons. Its emissions can be counted only by introducing the sample internally into a counter. Ar^{39} emits 0.57-Mev β-rays; it can be counted by placing it outside a counter having a thin wall (or window) which does not transmit the Ar^{37} radiations. Finally, Ar^{42} may be determined by measuring either the β-rays or γ-rays of its K^{42} daughter, whose half-life is 12.4 hours.

After the mass-spectrometric measurements had been made, the argon was condensed at −195°C on a standard amount of charcoal (50 mg) in a standard flat-bottom glass tube (12 mm outside diameter). The low temperature was maintained for 2 to 5 days to allow the K^{42} daughter to deposit on the charcoal and grow almost to saturation. Then the argon was transferred to another portion (50 mg) of charcoal in a second standard tube. The first tube was detached from the vacuum line so that the γ-rays of the K^{42} within could be counted. At least two samples of K^{42} were collected from each sample of Ar^{42}.

The 1.52-Mev γ-rays of K^{42} were detected by a NaI crystal (7.5 by 7.5 cm) which was shielded from stray radiations by about 10 cm of lead. The glass tube containing the K^{42} on charcoal was positioned in a reproducible manner several millimeters from the flat face of the NaI crystal. Between the detector and the source a copper plate (2.7 g/cm^2) was interposed to absorb the β-radiation. A single-channel analyzer, set to include nearly all of the 1.52-Mev peak, was used. The background count was 10.5 ± 0.5 count/min. Decay of the K^{42} was followed continuously for several days, and the activity at time of separation from the Ar^{42} was computed by a least squares procedure (*10*). Duplicate K^{42} samples gave results corrected to saturation activity which were in excellent agreement. The detection efficiency of the system, $(6.9 \pm 0.1) \times 10^{-3}$, was carefully determined by counting thin, nearly weightless K^{42} samples with a 4π beta-counter and also with the γ-counter (column 3, Table 2).

For the other measurements of the argon activities, approximately 2.5 cm^3 of argon carrier was added, and the mixture was purified by gettering with hot titanium.

Ar^{39} and Ar^{42} were both determined from the same sample taken into the envelope surrounding a thin-wall counter. After the daughter K^{42} had been allowed to grow to equilibrium, the gross counting rate, resulting from contributions of Ar^{39}, Ar^{42}, and K^{42} (no Ar^{37}), was measured. The argon was then removed from the counter, and the decay of the daughter K^{42} was followed. The counting rate of the K^{42}, after adjustment to the time of removal of gas from the counter, was subtracted from the gross counting rate to yield the counting rate of Ar^{39} and Ar^{42} combined.

The detection efficiencies of these counters for Ar^{39}, Ar^{42}, and K^{42} were measured with a mixture of Ar^{39} and Ar^{42} which was standardized as follows. Portions were taken into conventional gas proportional counters, and after a period of several days, to permit

Table 2. Disintegration rates of Ar^{42}.

Sample	Ar^{42}		Mean rate (dpm)
	β-counting (dpm)	γ-counting (dpm)	
103A	28,050	29,520	28,790
126	17,500	18,250	17,880
127	11,850	12,170	12,010
128	9,510	10,130	9,820
129	17,300	17,580	17,440

equilibrium to be established between Ar^{42} and its daughter, K^{42}, the gross counting rate of Ar^{39}, Ar^{42}, and K^{42} was measured. The counter was then evacuated and immediately refilled with P-10 gas in order to measure the contribution of K^{42} alone. The Ar^{42} content was determined in separate samples taken into tubes containing 50 mg of silica gel. These tubes were immersed in liquid nitrogen for several days to allow the saturation activity of K^{42} to be deposited in the silica gel. The silica gel was transferred to a small platinum crucible and treated several times with concentrated hydrofluoric acid to volatilize all of the silica. The residue was taken up in water and transferred to a thin plastic film for 4π-counting of the K^{42}. A small correction, 2 percent, (determined in a separate experiment), was applied for a slight loss in the transfer of the K^{42} to the plastic film.

The efficiencies of the six envelope-type counters used in these experiments ranged from 6.5 to 8.0 percent for $Ar^{39,42}$ and 17.0 to 22.5 percent for K^{42}.

The Ar^{39}-detection efficiency of these counters was measured separately with Ar^{39} prepared by means of the reaction $K^{39}(n,p)Ar^{39}$. The efficiency for Ar^{39} detection was within 2 percent of the efficiency for counting a mixture of Ar^{39} and Ar^{42}. This is not unexpected since the β-endpoint energies of these two isotopes are nearly the same (*12*).

The Ar^{37} detection efficiency of these counters was less than 3×10^{-5} percent as measured using Ar^{37} prepared by the reaction $Ca^{40}(n,\alpha)Ar^{37}$.

The Ar^{42} results (column 2 of Table 2) obtained by β-counting are the means of from three to six replicates taken on each sample. The Ar^{42} disintegration rates from β-counting are slightly lower than those from γ-counting and probably reflect a difference in the calibrations of the two methods. The mean values, column 4, are those shown in column 4 of Table 1 and were used in calculating the Ar^{42} half-life.

The Ar^{39} results are shown in column 3 of Table 1 and again are the mean values of three to six replicates on each sample.

The Ar^{37} disintegration rates were obtained from samples of the argon mixture taken into conventional gas proportional counters (1.9 cm inside diameter, 30-cm cathode length), which were then filled to one atmosphere pressure with P-10 gas. Small corrections to the gross counting rates were made for the relatively small contributions of Ar^{39}, Ar^{42}, and K^{42} (Table 1, column 2). End effects of these counters were less than 1 percent by comparison of counting rates with those measured in a similar counter having a cathode 76-cm long. Therefore, the active volumes of the counters were taken to be the cathode volumes (*9, 13*).

From the atom ratios, Ar^{39}/Ar^{37} and Ar^{42}/Ar^{37}, and the disintegration rates, values for the Ar^{39} and Ar^{42} half-lives were calculated. These are shown in the last two columns of Table 1. The mean values are 269 ± 3 years for Ar^{39} and 32.9 ± 1.1 years for Ar^{42}. By consideration of possible systematic errors in the mass spectrometry, in sample transferral, and in measurements of counter efficiencies the accuracy of the Ar^{39} half-life is estimated as 3 percent and that of the Ar^{42} half-life as 6 percent.

When Ar^{42} was first prepared (*9*) by the successive reactions $Ar^{40}(n,\gamma)Ar^{41}(n,\gamma)$ a lower limit of 0.06 barn was set on the thermal neutron cross section of Ar^{41}. Now that the Ar^{42} half-life is known, this cross section can be recalculated. It is 0.5 ± 0.1 barn.

The argon isotopes produced in meteorites by cosmic rays have been used to determine the variation of cosmic ray intensity in time and space. In general, the amounts of two nuclides of different half-lives produced by cosmic ray interactions on matter are measured in a meteorite; these amounts are compared to the production cross sections for the same nuclides produced by high-energy accelerator-protons. Since most radioactive nuclides in the meteorites are at equilibrium with their rates of production by cosmic radiation, the rates of disintegration of these nuclides at the time of fall are equal to their production rates. On the other hand the targets which are bombarded artificially are irradiated for periods that are short relative to the half-lives, and to determine the production rates from the accelerator-produced disintegration rates it is necessary to know the half-lives. If F is a factor denoting a change in cosmic-ray intensities such that F being equal to 1.00 indicates constancy, it can be expressed as

$$F = \frac{A_i}{A_j}\frac{t_j}{t_i}\frac{a_j}{a_i}$$

where A_i and A_j are activities of nuclides i and j measured in a meteorite, a_i and a_j are the activities of the same nuclides produced in an accelerator bombardment of duration short relative to the half-lives, t_i and t_j.

In the case of Ar^{37} and Ar^{39}, the 35-day Ar^{37} measures the average intensity of cosmic rays during the last part of the meteorite's trajectory before impact. On the other hand, the 269-year Ar^{39} measures the average cosmic-ray intensity over the entire orbit which presumably extends into space between the orbits of Mars and Jupiter. In a previous paper (*14*) it was concluded that cosmic rays are constant in space. The new values of the half-lives determined here indicate that there is a gradient of about 7 percent per astronomic unit (*15*).

The energy of the beta radiation of Ar^{42} has not been directly measured. However, Jarmie and Silbert (*12*) have studied the energy spectra of the protons from the $Ar^{40}(t,p)Ar^{42}$ reaction and have deduced an energy difference of 0.58 ± 0.04 Mev between the ground states of Ar^{42} and K^{42}. From this value and the Ar^{42} half-life a log(ft) value of 9.0 is found if one assumes that the β-emission is entirely from the 0^+ ground state of Ar^{42} to the 2^- ground state of K^{42}. This value is within the range expected for a first forbidden transition.

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Solar Activity during the First 14 Months of the International Years of the Quiet Sun

This report is the third in a series of studies, by the staff of the McMath-Hulbert Observatory, of solar activity during the International Years of the Quiet Sun (IQSY). It brings together solar data for the interval January 1964 to February 1965 inclusive.

The first 14 months of IQSY have included a minimum in solar activity, insofar as solar activity is measured by sunspot number, the area and intensity of calcium plages, and daily flux at 2800 Mcy/sec (Table 1 and Fig. 1). According to these three parameters the interval May to November 1964 was flanked by periods of increased solar activity, and July 1964 was the quietest month within the interval.

During the first 14 months of IQSY, activity of cycle 19 diminished but did not cease (Fig. 2). Old-cycle spots and plages continued to form in both the northern and southern hemispheres, and on 5 February 1965 a bright flare of importance 2+, with concomitant bursts at radio frequencies, occurred in an old-cycle region at 08°N, 25°W. A proton event, polarcap absorption, was reported as starting on 6 February.

These 14 months also witnessed a marked increase in the number, size, and duration of plages and sunspots at high latitudes and with polarities (when known) appropriate to the new cycle. The number of days per month on which new-cycle spots were visible rose to levels attained in the past four cycles only after minimum in the cycle had been passed (see Fig. 3). In July 1964, Giovanelli reported that his studies of old- and new-cycle spots indicated that, after that date, the number of new-cycle spots would, on the average, exceed the number of old-cycle spots. This prediction has been borne out by observations in succeeding months.

The foregoing considerations all suggest that the minimum between cycles 19 and 20 occurred in mid-1964. If it did, it was a minimum without long intervals of solar quiet and with a relatively small number of days

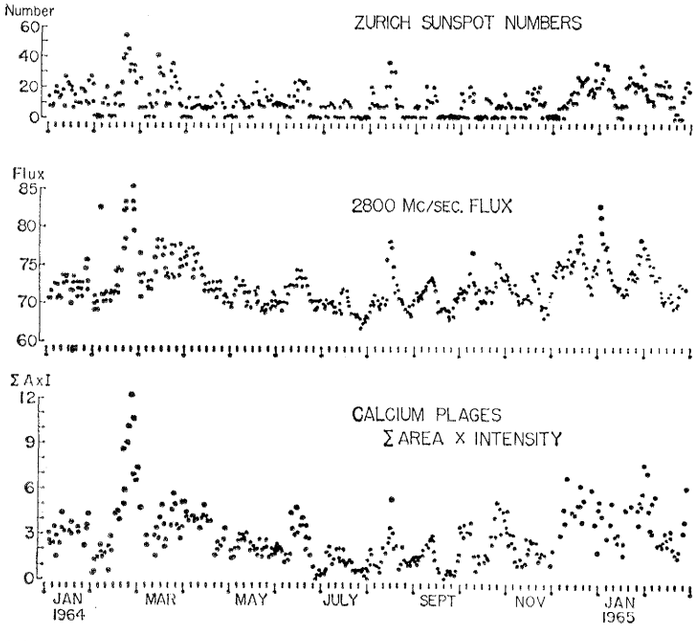

Fig. 1 (above). Daily values of Zurich sunspot number, flux at 2800 Mcy/sec (Ottawa) adjusted to an orbital distance of 1 astronomical unit, and summed values for area time intensity of the calcium plages (McMath-Hulbert Observatory) for the 14 months January 1964 through February 1965.

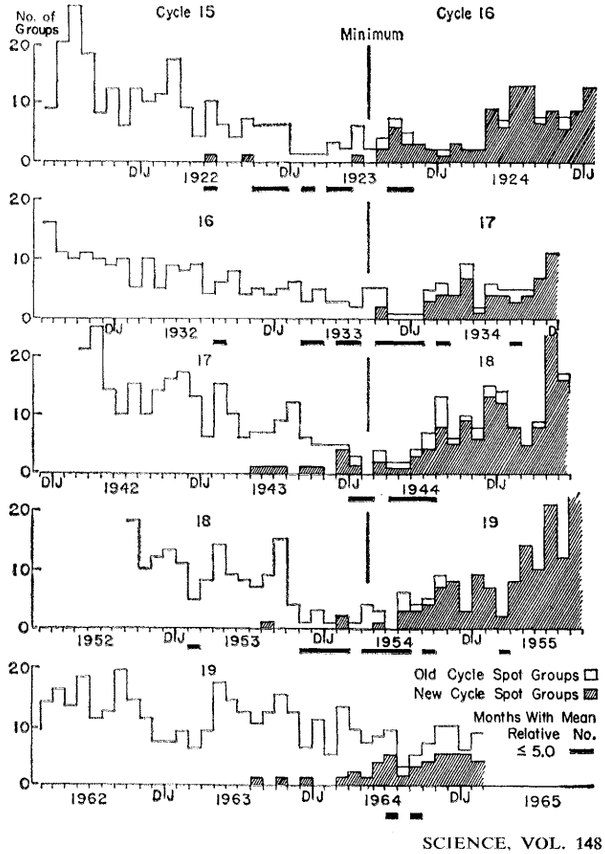

Fig. 2 (right). Number of old-cycle and new-cycle sunspot groups per month and the months with mean relative Zurich sunspot number ≤ 5.0 for years centered on four preceding solar minima and for 1962 through February 1965. The time of "minimum" as indicated by the smoothed monthly means of Zurich relative sunspot numbers is shown by a vertical line.