The History of Cyclotrons in Japan
(Banquet Speech)

Y. Hirao

Institute for Nuclear Study, University of Tokyo
3-2-1 Midori-cho, Tanashi-shi, Tokyo 188, Japan

The shorter is the dinner speech, the more pleasant is the dinner party. But, the subject of my talk is the history of cyclotrons in Japan and the history is of more than fifty years.

General Background

Firstly I'd like to mention about the general background before cyclotrons in Japan. In 1917, 15 B.C.(before cyclotrons), the RIKEN was established in Tokyo as a private institute for physical and chemical researches. Fifteen years later, the Osaka University was established by getting together many young and excellent scientists grown up at the RIKEN and other universities in 1932, 0 B.C. In the meantime, the big earthquake around Tokyo in 1923, the world's financial panic in 1929, the Manchurian Incident in 1931 etc. were the typical social events.

Concerning nuclear physics, firstly Rutherford discovered the artificial nuclear disintegration in 1919, and at the end of this period, various kinds of scientific events were all present out such as discovery of deuterium by Urey, concept of neutron by Chadwick, proton-neutron configuration of nucleus by Heisenberg, discovery of positron by Anderson, truely artificial nuclear disintegration by Cockcroft and Walton, invention of cyclotron by Lawrence. People thought with enthusiasm, "the era of nuclear physics has come !". Both RIKEN and Osaka University, therefore, became the two centers in Japan in early days of nuclear physics.

At RIKEN (IPCR)

At RIKEN, firstly in 1932, Y. Nishina constructed the Van de Graaff generator and obtained 600 kV. But it was too weak for Japanese humidity to utilize in nuclear physics. In 1933, he constructed the Cockcroft-Walton generator and observed positron-spectrum from artificial radioactivities by cloud chamber and then started researches by D-D neutrons with R. Sagane et al.

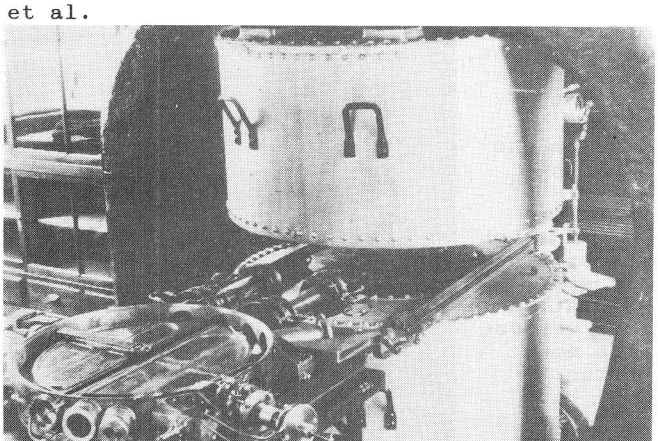


Fig.1 The first Japanese cyclotron at RIKEN, 26 inches 23 tons, obtained the first beam of 3 MeV deuterons in 1937.

In 1935, Nishina and Nishikawa groups were assembled as a laboratory of nuclear physics supported by several private companies, and immediately construction of small cyclotron was started by them, whose magnet was converted from a Poulsen arc magnet and had a diameter of 26 inches and a weight of 23 tons. The first beam of 3 MeV deuterons was obtained in April 1937. This year, the War of Aggression into China occured.

This small cyclotron was actively used in nuclear physics and in biomedical applications. Studies on beta-spectra of radioactivities with cloud chamber, radioactivities of thorium bombarded by neutrons for searching transuranium, fission products of thorium and uranium bombarded by neutrons, these were typical works in nuclear physics. At the same time, early biomedical studies were also carried out such as assimilation of sodium-24 by plants, genetic studies of irradiation of silkworm nits, leucopenia by irradiation and the effect of pentose nucleic acid, photosynthesis by using radioactive carbon, which was planned again by S. Tomonaga just after the World War II.

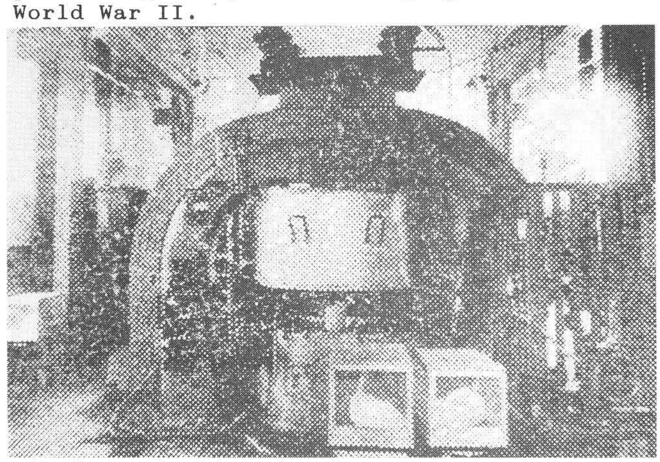


Fig.2 Early biomedical experiment at the RIKEN small Cyclotron. In the foreground may be seen rabbits inside boxes

On the other hand, just after the completion of the small cyclotron, Nishina started the construction of larger cyclotron, in 1937. At that time, E. Lawrence was going to construct the 60 inch cyclotron, and he made another same magnet for Nishina with his courtesy. It was much cheeper than in Japan. After arriving at Japan, its pole face was machined at Ishikawazima Shipyard, and was installed at RIKEN in June 1938. This magnet of 200 tons with simply enlarged rf structure from the small cyclotron was to accelerate 9 MeV proton. But it was not able to accelerate enough ions. The reason of such performance was as follows: n-value at large radius was too high to accelerate, corresponding minimum dee voltage should be much higher than of achieved, evacuation speed was too low to maintain vacuum pressure during acceleration, etc. Although the intensity was quite faint and unstable, its energy was the world's highest at that time. Many physicists were very much eager to use, but Nishina did not

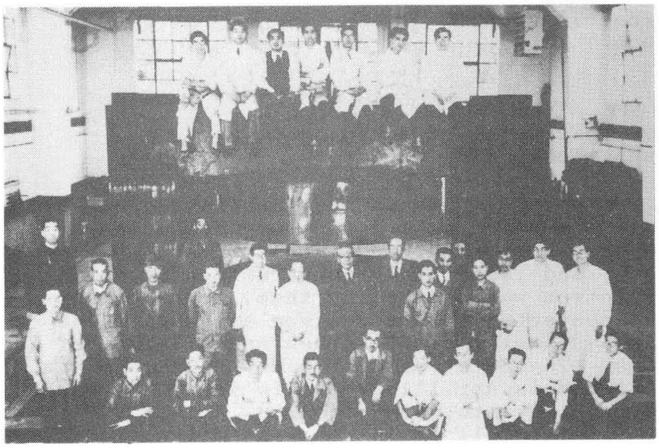


Fig.3 The 200 ton magnet for the 60 inch cyclotron. R.Sagane, 5th person from the right sitting at the front, T.Yazaki, Y.Nishina, H.Nagaoka the 11th to 9th standing at the middle, in 1938.

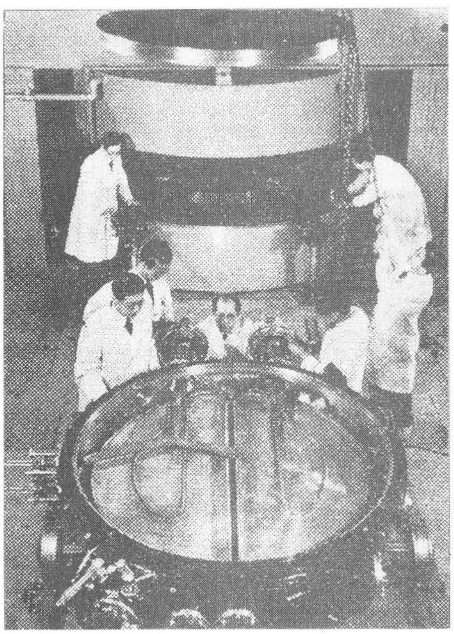


Fig.4 The old accelerating chamber for the 60 inch cyclotron, simply enlarged from the small cyclotron. In the background is seen the 60 inch cyclotron magnet.

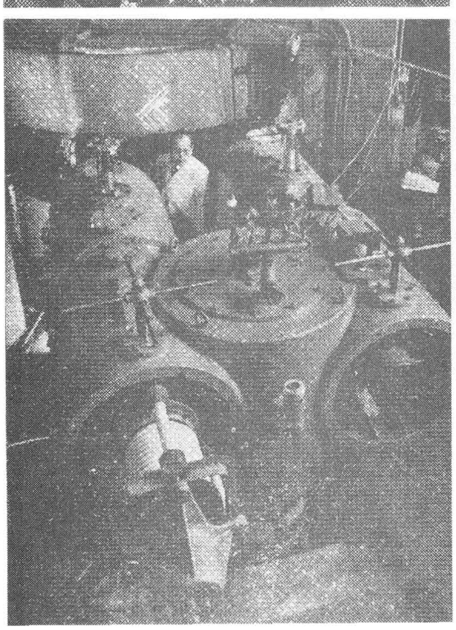


Fig.5 The improved rf resonator and vacuum pump for the 60 inch cyclotron. In the left foreground is seen the insulator for deflector high voltage. In the center is Y.Nishina standing.

agree to use and was going to improve it. T. Yazaki and others visited LRL to learn how to improve it and were surprised at the completely different design of rf resonator and evacuation system. They got all of the blueprints with the courtesy of Lawrence and Cooksey. The rf and vacuum systems were newly made considering the design at LRL, and then the proton beam of 9 MeV, 4 μA was obtained in February 1944, when the World War II had come to the last part. Radioisotope production for radioluminous paint, application of radioisotope to metallurgy, and then measurement of enrichment of uranium isotope and researches of basic data for utilizing atomic energy such as cross sections of neutron absorption and fission were performed till the end of the War. The cost of the 60 inch cyclotron was ¥ 0.3 M. corresponding to ~ 7 M$ at present.

At Osaka University

Now, I'd like to turn my talk to the history at Osaka University. In 1933, S. Kikuchi moved to the newly established Osaka University from Nishikawa group at RIKEN as an associate professor. At that time, he was enough young, aged 31, to open up the new field of nuclear physics.

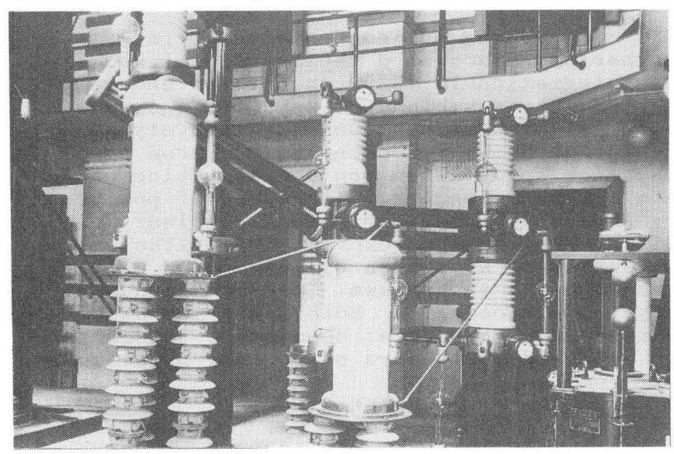
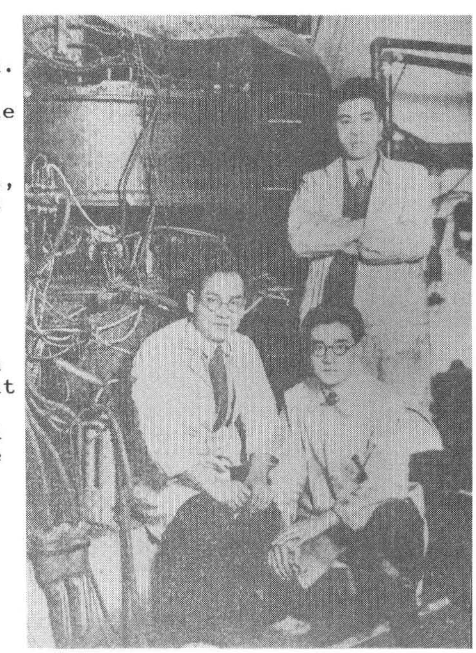


Fig.6 Cockcroft-Walton Generator at Osaka Univ. in 1933.

Fig.7 The Osaka 24 inch cyclotron. S.Kikuchi is standing at the back, J.Itoh and Y.Watase, from the right, are sitting at the front, in 1938.
Itoh was one of the inventors of microtron. Afterward Itoh was a prominent solid state physicist, and Watase was one of the most important cosmic ray physicists in Japan.



At first, he built the Cockcroft-Walton generator and competed with the group of Fermi in the researches by D-D neutrons. His group, H. Aoki and K. Husimi, carried out the measurements of gamma ray energies and intensities on the inelastic scattering of fast neutrons by various kinds of nuclei, and also the similar measurements on the slow neutron capture. These experiments already showed some evidence of the nuclear magic number and were a kind of pioneering works of nuclear spectroscopy.

In 1935, he made a plan of cyclotron construction and obtained the fund of ¥ 0.1 M, corresponding to ~ 2 M$ at present, from a private science foundation. The construction was finished in 1938. This cyclotron had a diameter of 24 inches and a weight of 25 tons, and was able to accelerate deuterons of 5 MeV, 20 μA. Researches were concentrated on the observation of radioactive products by a 180° focusing beta-spectrometer. Kikuchi and his coworkers, Y. Watase, J. Itoh, E. Takeda and S. Yamaguchi, showed that the positron spectrum of nitrogen-13 agreed well with Fermi distribution, instead of Konopinski-Uhlenbeck theory which had given good agreements with cloud chamber experiments. They also carried out the world's first experiments of gamma-gamma angular correlation.

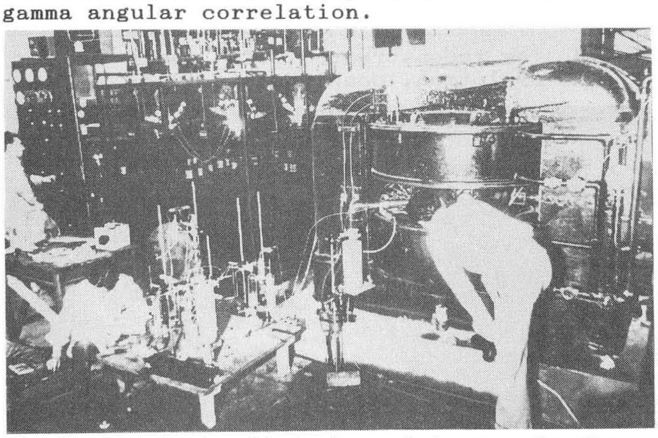


Fig.8 The Osaka 24 inch cyclotron. In the foreground are S.Kikuchi, J.Itoh and Y.Watase, from right to left.

In 1940, he began to construct the Van de Graaff generator with K. Husimi and T. Wakatsuki, in order to make more precise experiment of neutron-nucleus interaction. But this work was interrupted by the War.

At Kyoto University

The third group was B. Arakatsu and his coworkers, K. Kimura and Y. Uemura. They had began nuclear physics with the Cockcroft-Walton generator at Taiwan,in 1934. After moving to Kyoto University, in 1936, they built the same machine again and carried out the studies on nuclear photo-distegrations of various nuclei by high-energy gamma rays produced by lithium-proton and fluorine-proton reactions. Neutron breeding by fission of uranium, biomedical effects of neutrons etc. were also studied.

In 1940, five years later than RIKEN and Osaka University, they started the construction of cyclotron. The magnet had a diameter of 39 inches and a weight of 80 tons. It was to accelerate deuteron up to 10 MeV. But, the social situation was already very bad and Japan was going to rush headlong into the War. Progress of the construction became slower and slower, and only the magnet was barely completed at the end of 1944, at almost the final stage of the War. The coil had never been installed.

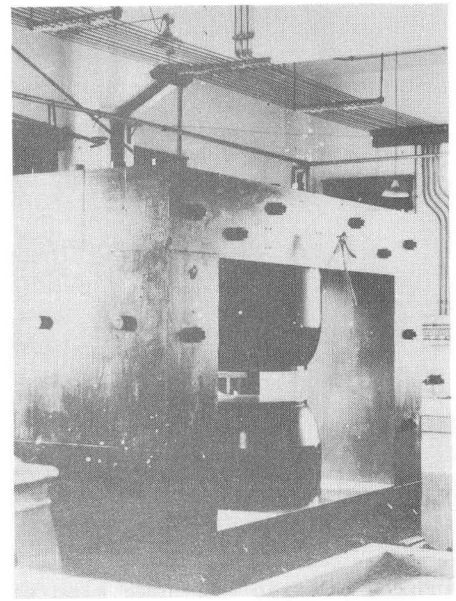


Fig.9 The magnet yoke of the Kyoto 39 inch cyclotron. The new year's decoration of sacred straw rope is seen on the top yoke. Arakatsu and his coworkers celebrated the new year's day, 1945, in front of this magnet yoke.

After the World War II

In 1945, the War finished and Japan was governed by the General Head Quarter of the occupation forces. In November the occupation forces destroyed the two cyclotrons at RIKEN and threw away into the Tokyo Bay. To remove the bigger one, they took over five days. In December, the other two, Osaka and Kyoto, were also sunk under the Osaka Bay. The beta-spectrometer at Osaka was also destroyed by misunderstanding a joke of Kikuchi. At the end of 1946, Drs. Kelley and Fox arrived at their posts in GHQ as science attache. Someday, Nishina, Tomonaga and other many young physicists discussed with Fox about basic research of nuclear physics. He said as follows: "It is too early to begin nuclear physics researches again, considering the Japanese economical situation. All of Japanese are hungry. If I were a Japanese, I would take a shovel together with the hungry compatriot." Young Japanese physicists were quite disappointed and were decreased their high spirits. It was found afterward that

Fig.10 In the fall of 1945, Nishina tried to dissuade the armies of the occupation forces from destroying the 60 inch cyclotron, but dismantling proceeded as shown in the next figure.

Fig.11 The RIKEN cyclotrons was thrown away into to Tokyo Bay. Photo shows the rf resonator of the 60 inch cyclotron, being thrown from the ship.

Fox's opinion was some kind of answer for the confidential request of Nishina to cool down eagerness among young Japanese physicists.

In 1951, Lawrence came to Japan suddenly. He visited RIKEN and inspected remaining facilities. He had known also the existence of another Poulsen arc magnet at RIKEN. In the meeting at Science Council of Japan, JSC, he suggested strongly the reconstruction of cyclotron of moderate size. He came suddenly and suddenly back after one week. On his departure, he left his words "Just work hard and study, just work hard and study !"

After many discussions among S. Kaya, S. Tomonaga, K. Husimi et al., following to the Lawrence's suggestion, small cyclotron (26 inches, 23 tons) by the use of another Poulsen arc magnet at RIKEN by a support of the Ministry of International Trade and Industry and another small one (44 inches, 45 tons)by the use of the remaining power supplies for magnet and rf systems at Osaka University by a support of the Ministry of Education, Science and Culture were decided to construct. At the same time, Kyoto University planned also to construct a small cyclotron (41 inches, 80 tons) by supports of private companies. (I was a graduate student at Osaka University.) These three cyclotrons were completed from 1953 to 1955. The first one was used to produce medical short-life isotopes and to study radiation effect for highly polymerized compounds. The other two cyclotrons have been used actively for various researches of nuclear structure and nuclear reaction, so far, through many times of improvements.

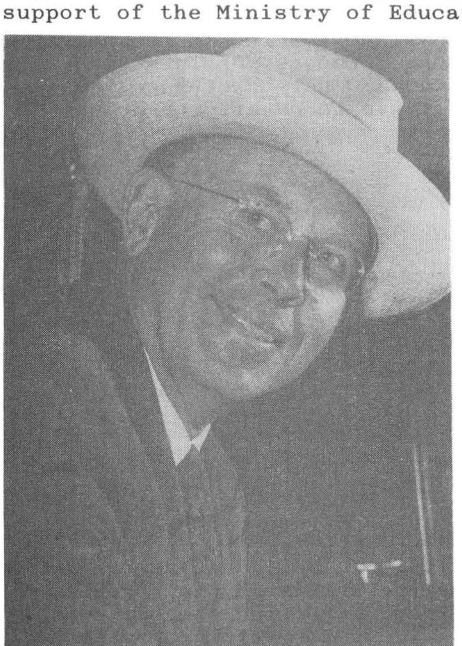


Fig.12 E.Lawrence. In the car starting to the Tokyo Air-port, he left his words "Just work and study! Just work and study!" for Japanese young physicists, 1951.

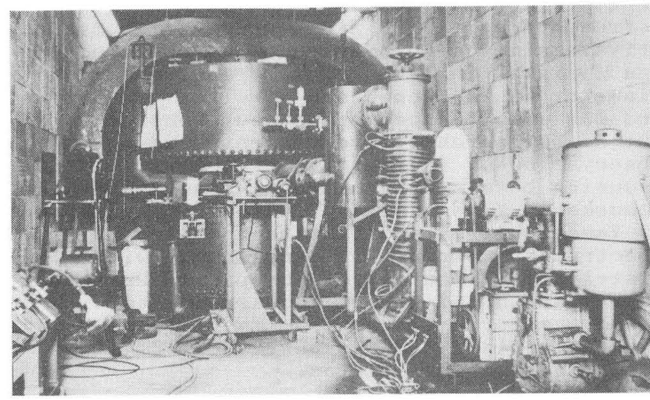


Fig.13 The reconstructed RIKEN small cyclotron, completed in 1953.

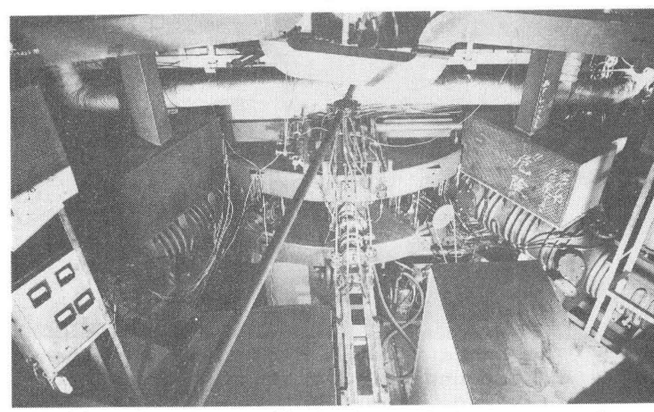


Fig.14 The Osaka 44 inch cyclotron, completed in 1954. This was moved to hilltop from downtown riverside after submerged by the big typhoon in 1961.

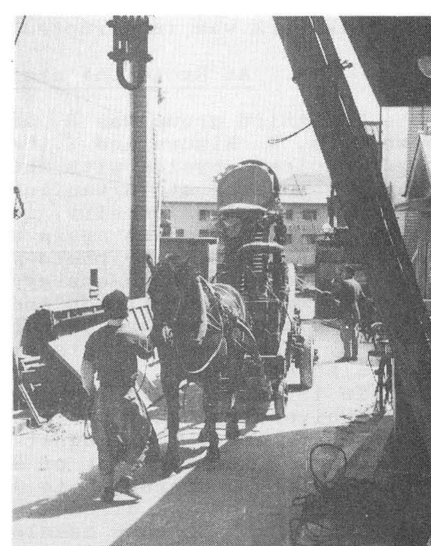


Fig.15 The 16 inch oil diffusion pump of the Osaka cyclotron. Most of the transport were only one horse power in 1953. At the right is seen the wooden pole of crane.

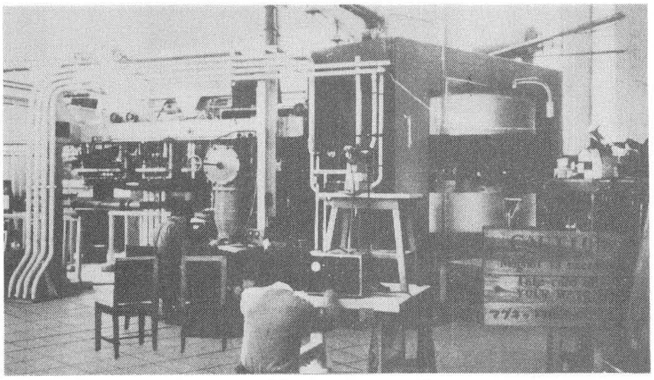


Fig.16 The Kyoto 41 inch cyclotron, completed in 1955 and afterward improved in 1973

About the INS

Following to the start of the constructions of these three cyclotrons, nuclear physicists mainly around Tokyo wanted to have a facility for nuclear physics which can produce mesons. After long and many discussions, establishment of a new institute were proposed to the government by the Science Council of Japan which has some big accelerators and is opened to the whole country. As the first accelerator, a cyclotron of 60 inch class was decided depending on the opinion of Kikuchi who just came back from Cornell University. The new institute was named Institute for Nuclear Study, INS, and belonged to the University of Tokyo. The cyclotron was designed by H. Kumagai, who was the same person as previously described Aoki. He made a proto-type machine with widely variable magnetic field before the construction. The main cyclotron had two modes of acceleration with one magnet (63 inches 280 tons) one of which was of fixed frequency (FF) and another was of frequency modulated (FM). This cyclotron was completed as the FF in 1957 and then as the FM in 1958. The former was highly appreciated as a widely variable energy machine (E_p =7.5~15 MeV) and the latter as of high extraction efficiency at the radius of n=0 (E_p =57 MeV). This facility had carried out the important contribution to nuclear physics researches for more than ten years. In 1966, the similar but much improved machine of the FF mode only (84 inches 340 tons) was completed at RIKEN, which was able to accelerate not only light ions but also heavy ions to extend the researches to many other fields. These cyclotrons were all classical ones, whereas many sector-focusing cyclotrons had already been constructed in the world.

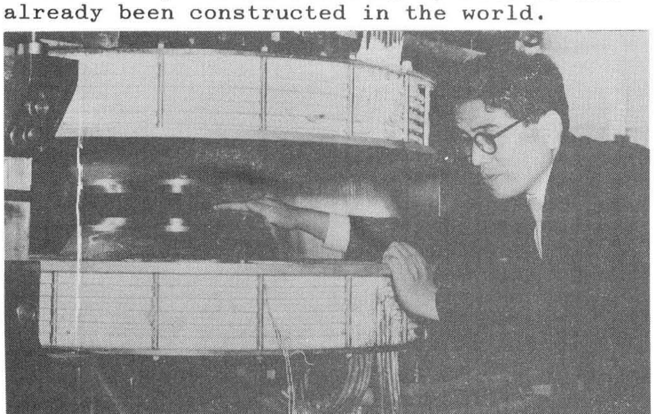


Fig.17 H. Kumagai and his proto-type magnet for the INS 63 inch cyclotron, 1955.

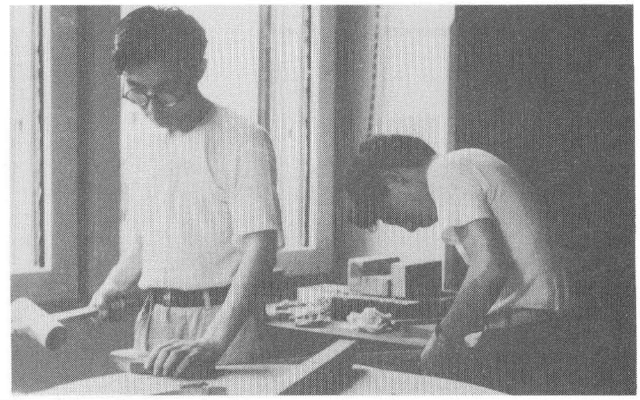


Fig.18 Coil winding works for the proto-type machine. At the left is S.Suwa who was later the 1st director of KEK.

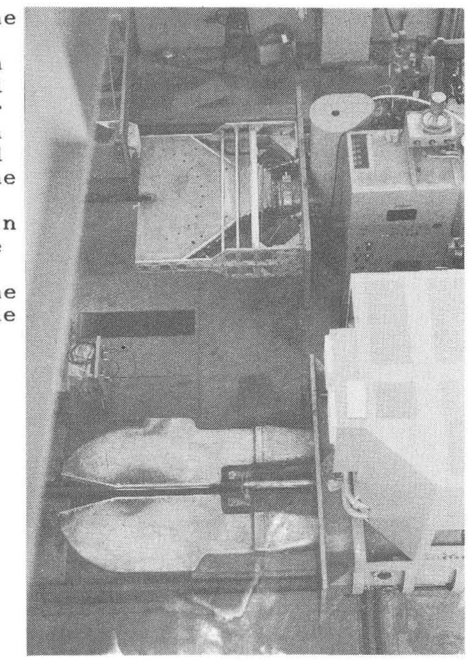


Fig.19 The dees of the INS 63 inch cyclotron. In the foreground is the one for FF mode and in the background is seen the one for FM mode. The housings in which they are mounted are moved along the rail toward the magnet at the left, out of the field of view.

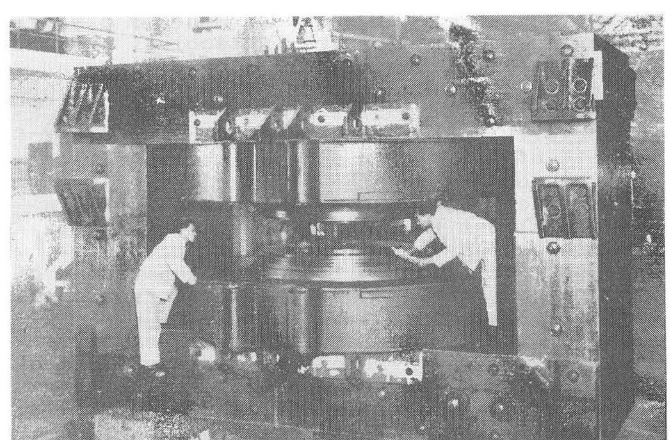


Fig.20 The magnet of the INS 63 inch cyclotron, before mounting the vacuum chamber, 1956.

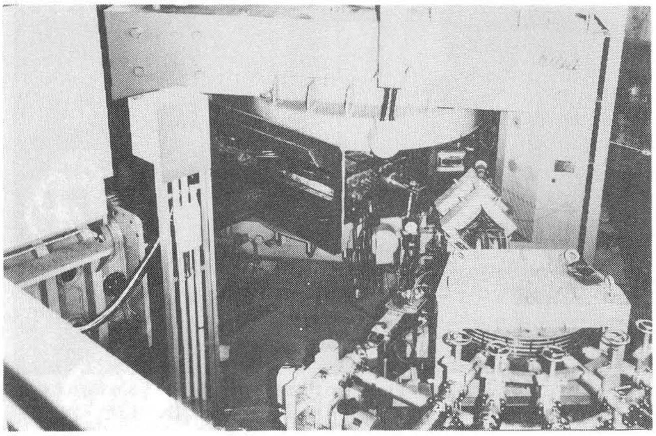


Fig.21 The RIKEN 84 inch cyclotron, completed in 1966.

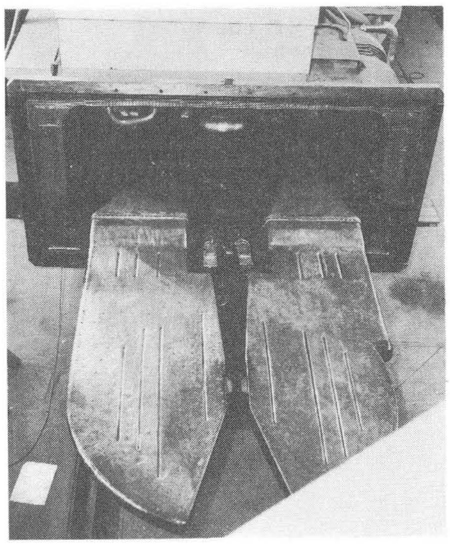


Fig.22 The dees of the RIKEN 84 inch cyclotron. The housing is moved toward the magnet which is scarcely seen in the fore-ground.

AVF Cyclotron

(I moved from Osaka University to INS in 1967.) The first sector-focusing one in Japan was the INS-SF cyclotron which was started to construct in 1969. One year later, Research Center for Nuclear Physics, RCNP, Osaka University, got more fund to construct a bigger cyclotron, after very long waiting time. So far cyclotrons were made by electric companies such as Toshiba, Mitsubishi etc. But, suddenly, these electric companies in Japan did not like to make cyclotron any more at that time. I wonder if they were in a financially very serious situation such as of boycott of television sets at unreasonable cost by the Japanese Housewives' Federation. We were not able to find any maker in Japan and had almost to return the fund. Finally, one new company, Sumitomo Heavy Industries, gave us good response. The top management of this company thought that the cyclotron should not be difficult to make because of a simil-arity of the name to cycloid gear reducer (~ decelerator) which is one of main products of this company. Through our explanation, they understood the complete difference and big misunderstanding. Then, they thought from the outside appearance that the cyclotron should be similar to a press machine. A press machine engineer was called to design cyclo-tron. Fortunately, both the INS-SF (K68) made by Mitsubishi Electric Corporation and the

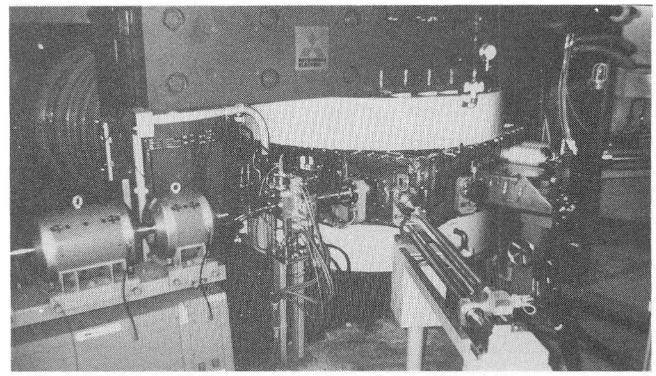


Fig.23 The INS-SF cyclotron (K68), completed in 1973.

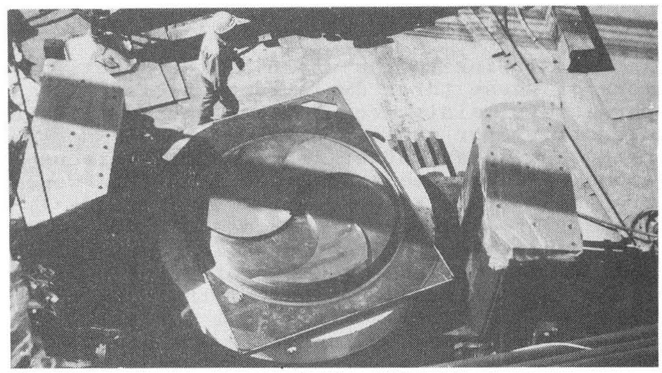


Fig.24 The magnet of the INS-SF cyclotron with the bottom plate of vacuum chamber, removed the top yoke.

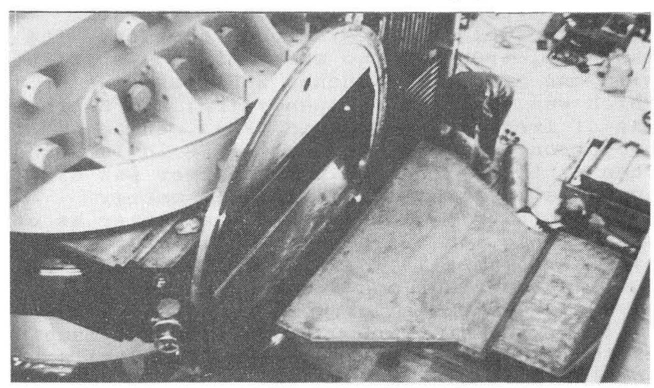


Fig.25 The RCNP-AVF cyclotron (K120), completed in 1973.

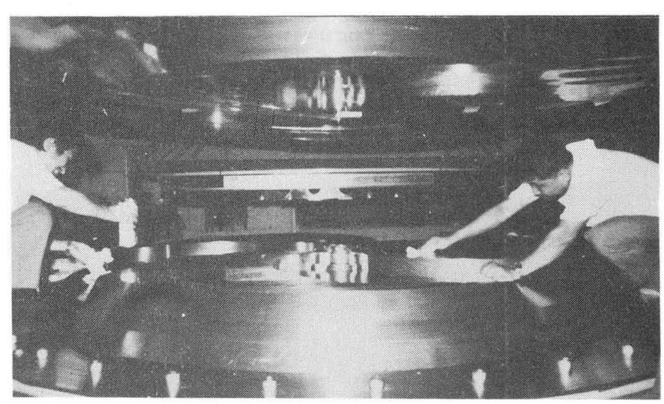


Fig.26 The view of pole gap of the RCNP-AVF cyclotron. At the left and right are M.Kondo and A.Shimizu who are coating the pole-tips with diffusion-pump oil.

RCNP-AVF (K120) made by Sumitomo Heavy Industies were completed successfully in 1973 as the two central facilities for nuclear physics researches. The capabilities of the latter including the installed various experimental apparatus have been particularly appreciated as one of the world's heighist.

Since then, the new comer as the cyclotron maker, opened up by the beautiful misunderstanding, has been developed into powerful maker of various accelerators. Medical cyclotron at National Institute of Radiological Science (NIRS), Chiba (K110), and multipurpose cyclotron at the Cyclotron and Radioisotope Center (CYRIC), Tohoku University, Sendai (K50), have been well operated with excellent results as presented in this Conference.

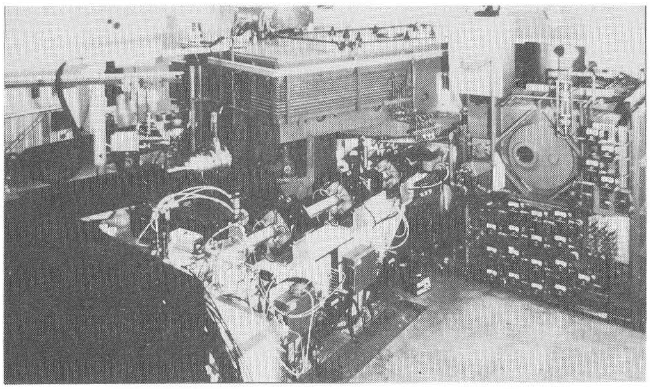


Fig.27 The NIRS Medical cyclotron (K110), completed in 1974, which was designed by Thomson CSF and mostly manufactured by Sumitomo Heavy Industries.

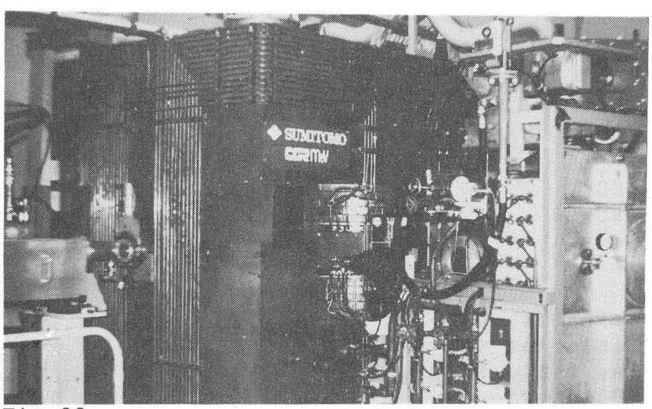


Fig.28
The CYRIC cyclotron (K50) at Tohoku Univ., completed in 1978, which was made by Sumitomo Heavy Industries with a technical cooperation with CGR MeV. They also made many other cyclotrons named CYPRIS (K70, K20, K16) for isotope production.

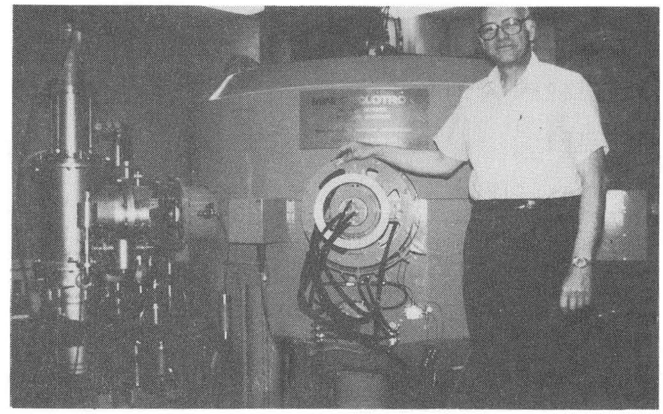


Fig.29 The MINI-Cyclotron (K20) at BNL, made by Japan Steel Works. They also made many BABY Cyclotrons (K14) in hospitals.

Another new comer, Japan Steel Works, has been making many small cyclotrons named BABY and MINI (K20, K14) for application also as presented in the poster session.

On this Conference, the newest Ring Cyclotron at RIKEN (K540) has been completed successfully and is going to be utilized in various research fields and applications, as seen on the tour. It would be the world's biggest so far and even in future.

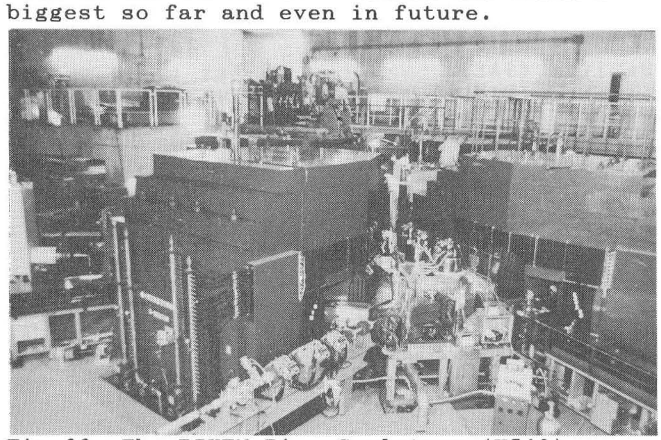


Fig.30 The RIKEN Ring Cyclotron (K540), completed just before the Conference.

Finally, I'd like to show a picture. This is a new concept of Cyclotron!

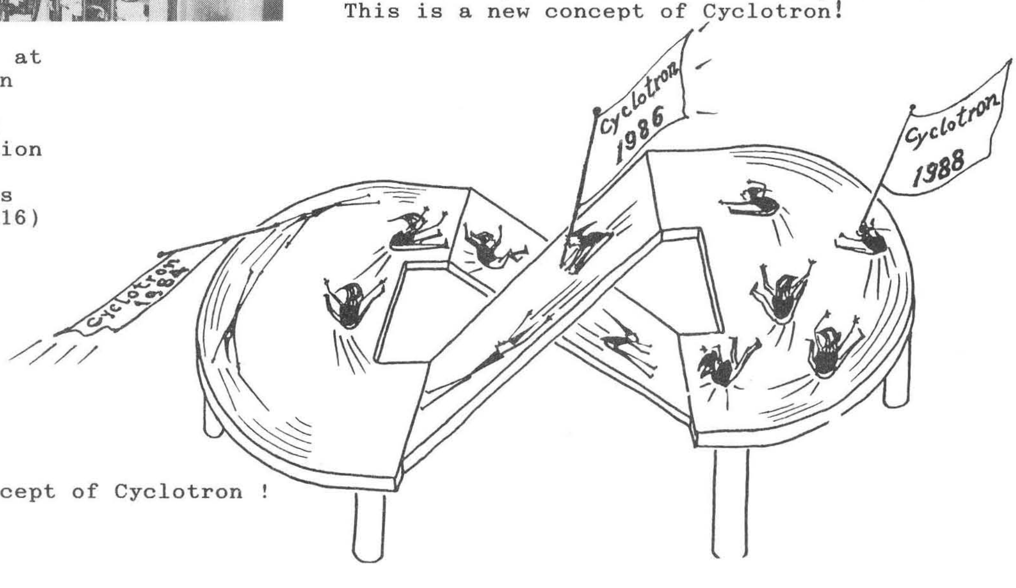


Fig.31 New Concept of Cyclotron !