SUMMARY TALK ON CYCLOTRONS

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Abstract

This paper reviews the present status and the apparent trends of cyclotron construction. An outlook of existing facilities and of the major technological achievements, including the operation of meson factories, is given. A discussion is also made of the "place" which cyclotrons hold today in science, both basic and applied. The future trends are presented according to the visible scientific needs and the different design approaches.

Introduction

This seventh A.V.F. Cyclotron Conference comes after more than fifteen years of continuous development in the art of isochronous cyclotron building. As a result of the many technological achievements these same years have witnessed the cyclotrons gaining an established place both in fundamental and applied science. The coming into operation of meson factories last year marks perhaps the highest point reached so far by cyclotron technology, a point which we can proudly celebrate in this Conference. At the same time, new and ambitious machines are in the building process or on the designers drawing boards.

The first aim of this paper is to review what has been accomplished so far, trying to underline those features which in the writer's opinion characterize today's state of this field. The emphasis will therefore be not so much on the detailed discussion of technological aspects, to which many papers at this and previous Conferences have been dedicated, but rather on an overall picture of where we stand now and the reasons for it.

The second aim is to look at the perspectives which open up in the medium-range future. Again, since the major technological topics are extensively dealt with at this Conference, this paper shall deal more with the different apparent trends of cyclotrons future, and, to some extent, with the rationale behind them. A short discussion is made of the major projects now under way, with the purpose of underlining the differences in the conceptual approaches to this third generation of machines.

As it looks today, the development towards the bigger and costlier machines of the future will also have some impact on the size and attitudes of the average users-builders cyclotron community. Some of the foreseable implications will also be briefly discussed.

The Growth of Cyclotrons: Figures

A.V.F. cyclotrons did start out at the beginning of the 60's as basic research (i.e. nuclear physics) oriented machines, as the new accelerating technique which they compounded promised unprecedented beam intensities and quality at a fairly low cost, in a substantially poorly known region of proton and other light nuclei energies. The potential of cyclotrons for applied research did show up however in a surprisingly short time scale, short, that is, if we consider that one or two decades at best are needed in most fields for basic research fall-out to reach the applied research field. In the case of A.V.F. cyclotrons several factors played together to reduce this time scale. Among them:

- the extensive work in applied science, particularly isotope production, carried out with conventional low energy cyclotrons.
- the established tradition in the use of long lived isotopes obtained through reactors by medical people and biologists and the recognized fact that short-lived, neutron deficient isotopes, obtainable with cyclotrons, would be a powerful new tool.
- the pioneering work made since several years by various groups(1) in individuating new means of cancer therapy.
- the growing importance of radiation damage for material science and nuclear reactors studies.(2)
- the willingness of several industrial groups in embarking at a very early date in the enterprise of making an industrial product out of what is basically a physics laboratory tool. That took some courage on their part and in this sense our mostly

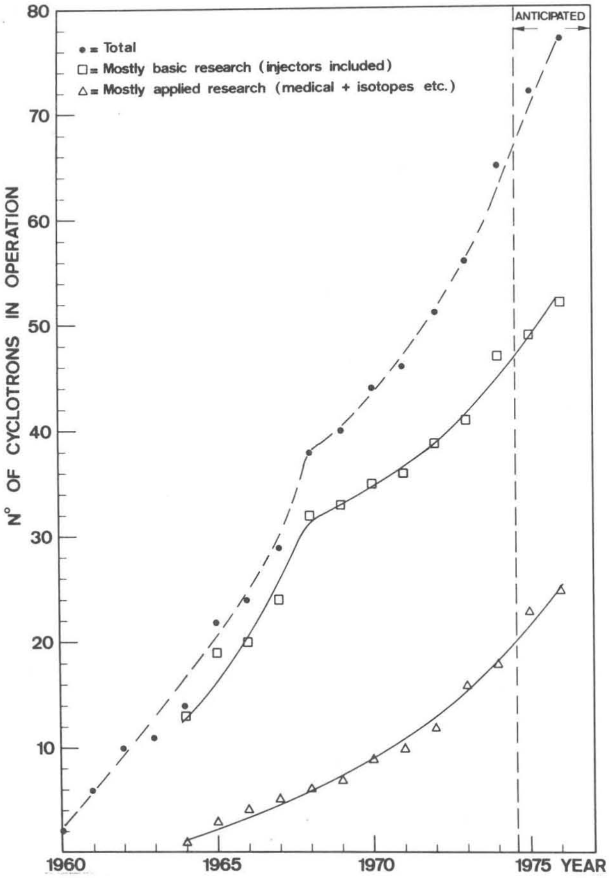

Fig. 1 Number of operating A.V.F. cyclotrons during the past 15 years

Proc. 7th Int. Conf. on Cyclotrons and their Applications (Birkhäuser, Basel, 1975), p. 19-26

academic community owes them something.

If we now look at the present state of cyclotron building and at how it developed along the years, the result is certainly impressive. One naive, but perhaps significant parameter, is the number of operating facilities. This is displayed in fig. 1 as a function of time, both for the total number and the two separate terms which add up to it, namely basic research oriented and applied research oriented cyclotrons. The distinction comes from a somewhat arbitrary partition based on 70% or more machine time dedicated to basic research, or viceversa. These data have been constructed out of a careful study of past Conferences data sheets, as compiled by F.T. Howard, implemented by private comunications and so on. Shut-down facilities as well as facilities turned over to a different category of users have been taken into account. Some errors have undoubtedly been committed but this picture should be close to truth till 1976.

We have a total of about 70 facilities in operation today, and they should become 77 by the end of 1976. The figure shows some interesting features:

- the total number of cyclotrons increased at a very fast pace up to about 1968, and at a slower rate afterwards.
- although the point at the year 1968 could be wrong by some units, the two other curves, of mostly basic and mostly applied oriented cyclotrons, show indeed that their number increased after that year at an almost equal pace.
- the number of applied oriented facilities increases by doubling roughly every 4 years, at least so far.

In order to better appreciate the increasing role of "dedicated" cyclotrons fig. 2 shows their number as a percentage of total, again a function of time. The line drawn in the figure is merely a guide to the eye. From 1964 to 1975 we went from 7% (just one cyclotron, the Philips-Duphar machine) to over 30%.

Another illuminating point of view from which to look at cyclotron growth is that of particles energy. Among the various parameters which could be selected, and since the vast majority of machines in operation today accelerates also protons, the maximum available proton energy has been chosen. The resulting hystograms, centered at 5 MeV equally spaced intervals, are presented in fig.3, again separated among the two major uses.

A striking, although well known characteristics, is the sharp difference in the energy spectrum covered in the two cases. While more than 80% of applied research oriented machines lie within 30 MeV max. energy, only 45% of the nuclear physics oriented machines do so. Among the latter we count also some low energy H^- machines used basically as injectors to Tandems and therefore for ultimate energies well in excess of 30 MeV. In fact most of the recently commissioned cyclotrons have protons energies higher than 50 MeV, not to mention of course the meson factories.

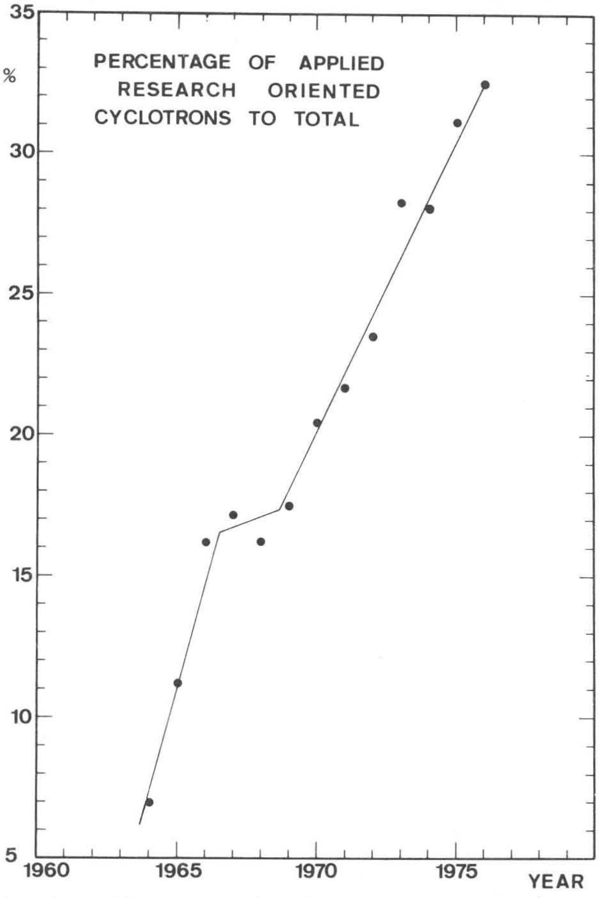

Fig. 2 Applied research oriented cyclotrons, in percentage to total, as a function of the year.

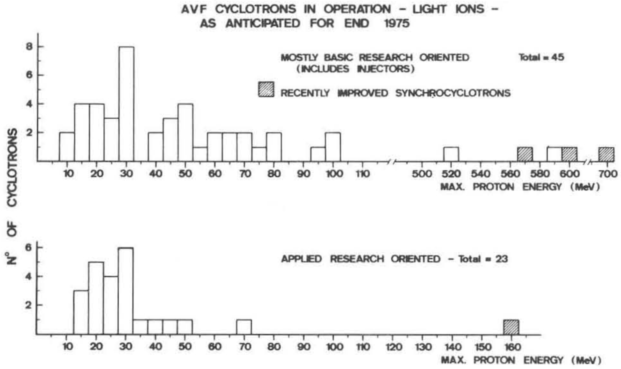

Fig. 3 Distribution of cyclotrons (year 1975) among basic and applied research uses, as a function of max. proton energy

The increasing statistical weight of applied research facilities does not mean therefore that the cyclotron is relinquishing his primary role as a tool for basic research. Rather, and perhaps as it should be, there is a natural subdivision between the two fields, with physics oriented cyclotrons heading towards higher energies and different particles (heavy ions). This, in turn, means costlier and bigger machines, and therefore fewer in number. The numerical trend which is already apparent today should in fact continue if both research lines are to be healthy and productive.

The Growth of Cyclotrons:Technological Achievements

In this section we want to restriet ourselves to the main technological developments concerning "conventional" AVF cyclotrons, since meson factories are better dealt with separately. In more than a sense it could be said that cyclotrons builders have been better than their words, and to a large extent this is the basis of the success that cyclotrons have so far enjoyed.

Important progress has been made in:

- beam quality
- beam intensities
- reliability and easy operation of machines.

Of course a host of technical developments contributed and we shall comment them in due course. It is very hard to give an exact idea of the progressive improvement in beam quality which took place. Data are not always reliable and are sometimes difficult to interpret.However, for the sake of illustration, fig.4 shows for a few examples the external beam current achieved per mm.mrad of radial phase space. The data are normalized to 50 MeV proton energy. Roughly speaking, progress shows up as an increase of a factor of 10 over approximately a decade. Single turn operating machines stand in a class by themselves, of course with limits of a few uA on the maximum beam current.

Another look at the situation, now from the point of view of beam power, is provided by fig. 5.

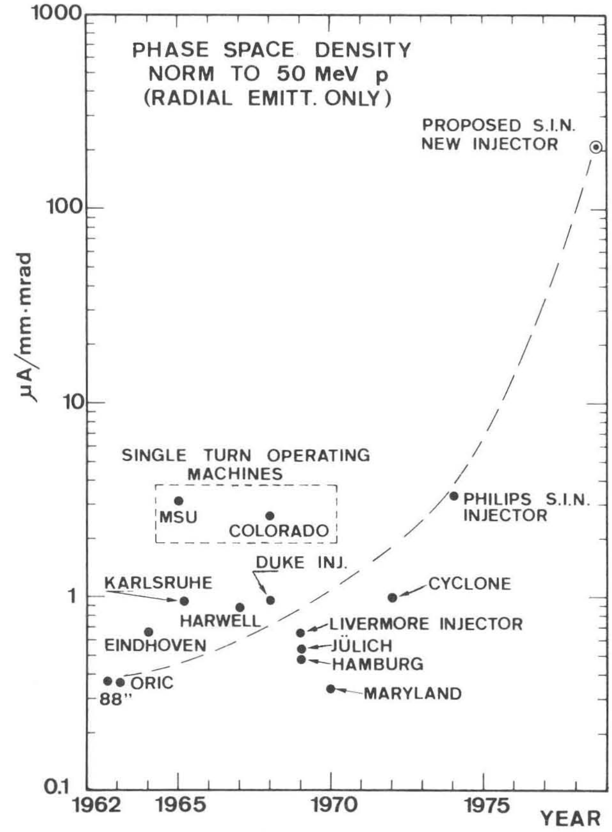

Fig. 4 Examples of improvement in the phase space beam density, normalized to 50 MeV protons, occured during the years

Typically most cyclotrons run confortably in the range of 1 to 3 KW. A beam power of 7 plus KW has been proved feasible by the SIN Philips cyclotron, and that has been indeed a remarkable accomplishment.

All told, we are probably not too far away from realistic upper limits of beam density and beam power, which one could set at about 5 uA per mm.mrad for the former (at 50 MeV) and around 7-10 KW for the latter. We are in fact pretty close, for proton and other light ions beam densities, to the scaled down limit of present cyclotron ion source luminosities on one side, and to the point where space charge effects start having a considerable weight on the other.

In fact, looking for a future new injector, the S.I.N. group, aiming at a factor of 10 more in beam power, and roughly a factor of 60 more in phase space density (i.e. 1 mA at 72 MeV p, within 4 mmrad and 150 keV FWHM energy spread) decided that the most practical solution would be a two stage machine.(3) The project, which is presented at this Conference, calls for an electrostatic generator, injecting into a 4 separated sectors cyclotron.

While the heavy ions field is perhaps too young and fast developing to foresee limits on the intensities and states of charge, one should pay some tribute to the exceptional progress made in the acceleration of polarized particles. Just about 10 years ago we were still talking in terms of a few nanoamperes of polarized protons on target.(4) Now, with the success of axial injection systems, currents of hundreds of nA, up to 1 uA have been reported(5,6)

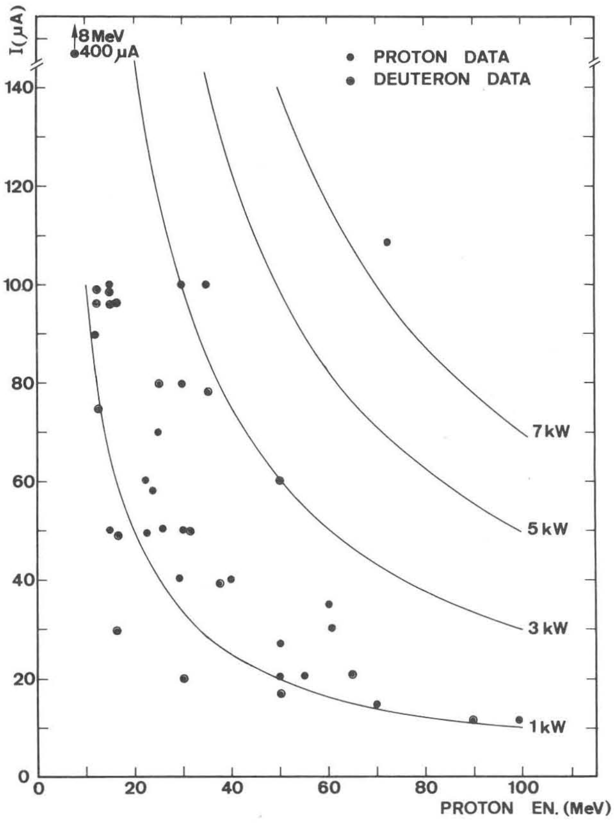

Fig. 5 External beams intensity, as a function of particle energy. Contour lines refer to constant beam power, in KW

Among the factors which contributed to these successes one should list:

- extensive studies of ion sources, both of normal and polarized ions, carried out in the past decade.
- the development of external injection systems, mostly axial, now in use at more than 10 facilities throughout the world.
- the intensive studies of factors influencing center region performance, both for the electrodes geometry and space charge effects.
- the improvement in magnetic field and R.F. regulation systems, where a solid factor of 10 has been gained. In fact stabilities of $1x10^{-5}$ and $1x10^{-4}$ are now achievable, respectively, for the two parameters. Cyclotrons made therefore a very good use of progress made in independent technologies.

Machine reliability also increased during the years and the efforts in computer control, with the ultimate goal of automation, are now starting to pay off. There will be a session on this topic at this Conference, so there is no need to go into any detail here. This feature is going to play an increasing role in the future, for the applied research oriented facilities as well as for the others. The reason for the interest in the former field are nearly obvious, and one might quote that the Amersham cyclotron already runs for more than 100 hours continuosly without operator assistance.(7) However, computer control will be increasingly important also for basic research oriented facilities as shrinking operating budgets and lack of personnel make feel their weight.

The Growth of Cyclotrons: Meson Factories

The recent (1974) operation of AVF meson factories is the most spectacular achievement of the cyclotron art. The possibility of building meson factories, stimulated by the new field of physics opening up because of their superior beam intensity and quality, has been around since more than 12 years.(8) As it looks today, the situation is presented in Table 1. (The Los Alamos facility (LAMPF) is not considered only because it is a bit outside the scope of this paper).

The SIN and TRIUMF facilities have both reached their design energy. Present operation is at lower beam intensities than the ultimate goal, but this is mostly due to a sensible regard to activation problems, and nothing will prevent reaching those goals in the near future. The two machines have entirely different characteristics as everybody knows, and much more about them is told in papers given at this Conference.(9,10)

In terms of technological progress their operation has these meanings:

- S.I.N. has proved, and that was a first, the soundness of the separated sector cyclotron concept, together with a remarkable achievement in the development of R.F. cavities, which they run up to 600 KV peak voltage. Injection, acceleration and extraction were managed through very careful studies but no unknown problems did really materialize.
- TRIUMF proved the soundness of extending the concept of "single pole" AVF cyclotrons to much higher energies, with a six sector geometry, and fully exploiting the possibilities of H^- acceleration with two simultaneous extracted beams at total 100% efficiency. It may be recalled that this particular problem was the subject of discussions at earlier conferences(11) and the emerging opinions would not always agree. Also here external injection, axial in this case, was handled by a careful study and it proved successful. Extraction did not constitute of course any problem.

Table 1 Meson factories today

LOCATION	STATUS	MAX. EN. (MeV) GOAL - ACHIEV.	INTENSITY (μA) GOAL - ACHIEV.	FEATURES	REMARKS
S.I.N. VILLIGEN	OPERAT. (1974)	590 - 590	100 - 27	2 stage, 8 sector magnet, 4 cavities (600 KV peak), 6th harmonic operation fixed energy.	72 MeV inject. has operated at 100 μA - 1 mA injector planned
TRIUMF VANCOUVER	OPERAT. (1974)	500 - 520	100 - 0,1	H^- acceleration 6 sectors two 180° dees (85 KV) axial injection at 300 KeV variable energy (180 - 520 MeV)	Two simultaneons beams available
CERN GENEVA	OPERAT. (1974)	600 - 604	7 - .6 (at 1/16 pulse rate)	Rotary condenser modulator 450 cycles/sec. 1 Dee, 30 KV peak Hooded arc source 70% extraction efficiency.	Acceleration of light ions being studied -
DUBNA	1975	700 -	25 -	4 sectors, 77° spiral added 1 Dee, 50 KV peak 600 cycles/sec. 50% extraction efficiency expected	Axial injection and polarized ion source to be installed.
NEVIS	1975	570 - 570	20 -	3 sector, 35° spiral added - 300 cycles/sec. 1 Dee cold cathode source 70% extraction efficiency expected	Energy increased from original 380 MeV to 570 MeV -

The other meson factories listed in Table I are the modified synchrocyclotrons which are now coming or about to come into operation, namely the CERN, DUBNA and NEVIS facilities. It is proper to mention them here, not only because of the natural overlap in the research field covered by truly AVF facilities, but also because these modification programs did in some way or another benefit from AVF cyclotrons technology. In fact two of them (NEVIS, DUBNA) added respectively three and four spiralling sectors to improve axial focusing and to provide a radially increasing field, which would in turn reduce the range of modulation frequencies. This opens up the possibility of a sharp increase in Dee voltage and therefore the benefits of an hooded ion source and a factor of 8 to 10 increase in the pulse rate.

The CERN facility retains the weak focusing principle of the original syncrocyclotron,(12) but its designers have nevertheless gone to great pains in order to increase the dee voltage over the required frequency range.

As a result, converted syncrocyclotrons promise to be very useful in future years. The much better hooded arc sources and the higher extraction efficiencies expected will produce an order of magnitude improvement over previous performance. All together, we may therefore conclude that the hunt for advanced sources of pions and muons, with which to probe the nucleus and its constituents, has succeeded in catching its prey.

The Place of Cyclotrons in Science

As a reflection on the previous listing of statistics and technical achievements, one might righfully ask about the real place that cyclotrons hold in science today.

Such a question has no easy and indisputable answers since so many factors enter the picture. However, there are no doubts that the relative low cost vs. performance of cyclotrons has enabled a number of moderately budgeted users to provide themselves with a modern and advanced research tool.

This appears to be true for both nuclear and

Table 2 Distribution of AVF cyclotrons operation among different institutions

TYPE OF INSTITUTION	N° of CYCL.	%
UNIVERSITIES	37	≈ 51
NATIONAL LABORATORIES (OR OTHER NATL-LIKE INSTIT.)	20	≈ 28
MEDICAL SCHOOLS- (NATL. OR LOCAL) HOSPITALS	10	≈ 14
INDUSTRIES	5	≈ 7
TOTAL	72	100 %

applied physics users, and it becomes quite natural if we, as physicists, realize that what we call "applied research" is most often "basic research" for somebody else, who belongs in any sense to the scientific community.

To support this statement, Table II shows the distribution of operating cyclotrons among different institutions, on a world wide basis, as of end of 1975. The table shows that a relative majority of cyclotrons (51%) is operated by Universities, which have always been, and the writer hopes will continue to be, the backbone of scientific research. In fact, if one adds up the cyclotrons operated by medical shools and hospitals (14%), which are very much university-like institutions, one arrives at a hefty 65%. National Laboratories or the like make up for 28% of the total and they do have of course an almost exclusive right to host the bigger and costlier installations like the meson factories. The 7% allotted to industries, with 7 facilities, is bound to increase, as short-lived isotopes gain a larger share of the potential market.

It is very difficult to judge the quality of scientific production due to cyclotrons, and to some extent also its quantity. Limiting ourselves for the moment to nuclear physics research and to its quantitative aspect, I tried to envisage a parameter which could at least represent the trend over the years.

An admittedly rough indication can be had from the number of experimental nuclear physics papers published on "Nuclear Physics" and "Physical Review" every year, trying to subdivide them according to the accelerator type or other kind of basic tool used. This painstaking research has been mostly carried out by Dr. E. Fabrici, University of Milan, to whom the writer is deeply indebted, and it spans a period of ten years, from 1964 to 1974.

The results are shown in fig.6 on top for the total, and on bottom for the distribution of papers according to the use of different facilities. The signs of the crisis which has hit science, and has brought about a net decrease in the support of basic research, are all too evident. After a peak around 1971 the total number of papers decreased, going back in 1974 to something like 1968 levels. The same is true for cyclotrons and electrostatic machines as well, while research with reactors, radioactive sources etc. declined more rapidly. A look to fig.7, which reports the percentage distribution, shows a somewhat different picture, although basically consistent. The percentage of experiments made with electrostatic machines keeps going up, that of reactors and radioactive sources steadily down. Cyclotrons produced papers are, percentage wise, decreasing after 1971.

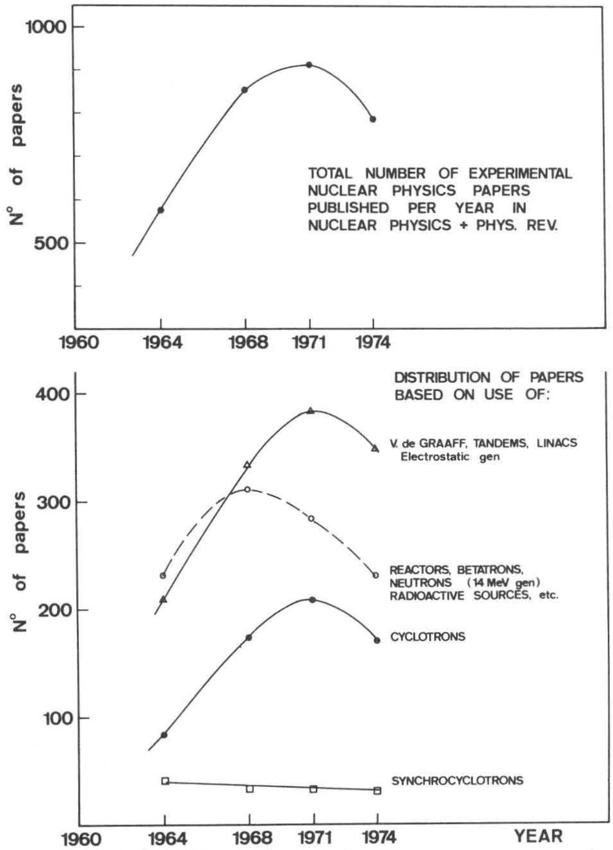

Fig. 6 Total number of experimental nuclear physics papers (top) and subdivided according to use of different facilities (bottom), published per year in Nucl. Phys. and Phys. Rev.

The picture which emerges from these data should be taken "cum granu salis" since quantity is certainly no substitute for quality and the two Journals considered here are of course not the only ones where original nuclear physics work is published. Also, errors could have been committed in the survey. However, some conclusions can be drawn:

- even taking into account the time lag which exists between the "initial operation" of a cyclotron and the time when a Laboratory begins producing research, the trend of published papers bears no resemblance, in the 70's, to the increasing number of machines.
- cyclotrons do suffer, nowadays, from a shortage of budget, or scientific manpower, or both. In fact they were harder hit than the smaller machines, which constitute the vast majority of electrostatic accelerators.
- it looks therefore that, in a way, the cyclotrons are under-utilized as far as basic research goes.

One could argue that the worldwide push towards "applied" uses could be partially responsible for this trend. On the other hand the fraction of beam time devoted to these uses in nuclear-physics oriented facilities never surpasses 30% and is more likely to be around 15% to 20% on the average. If

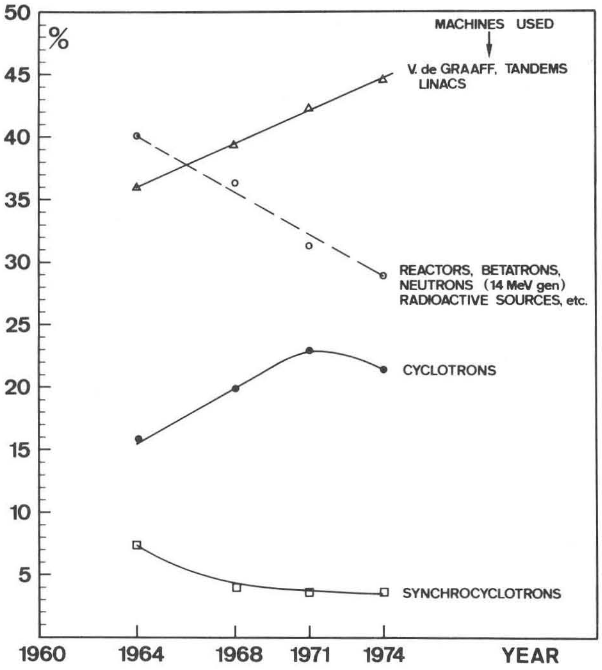

Fig. 7 Percentage distribution of experimental nuclear physics papers, according to use of different facilities, published per year in Nucl. Phys. and Phys. Rev.

one looks to the curves of fig.1 then such an explanation cannot really hold.

It is perhaps too early to evaluate in similar quantitative terms the "production" of cyclotrons dedicated to applied research, and, in any case, much more difficult. To the writer's best knowledge, however, this kind of activity is still expanding at a very fast rate, although it can hardly be measured in terms of published papers. It will take perhaps another few years in order to evaluate the real impact which cyclotrons will have had on such various topics as patients therapy, diagnostics, activation analysis, environmental science and material science. It is in any case undisputable that the low cost and easy operation of cyclotrons have allowed a number of institutions to start programs in these directions. In many cases these institutions can only afford a limited technical support staff and the modern cyclotrons certainly allow that.

Altogether, from a generally satisfactory outlook which bears all the marks of a field in expansion, the only sober note which emerges is that of the relative decline in the amount of nuclear physics research.

Should this trend continue it would indeed be serious. It is of course obvious that in a will established realm of science, like nuclear physics, experiments tend to be more elaborated and time consuming so that more effort has to go in for a comparable output. Still the fact remains that probably the available scientific manpower and financial support, or maybe even people enthusiasm, are undersized with respect to available facilities.

One could be confident that the new machines will to some extent reverse this trend. This is to be hoped for, because a healthy and expanding fundamental research is ultimately the best background for an equally productive applied one.

A Look to the Future

A) - Conventional machines

The most likely trend is a continuous increase in the number of applied research facilities, where computer control and automation will play an increasing role. It is unlikely that major technological advances will be made in beam intensities and qualities as far as light ions (p,d, He^4) are concerned. One could instead expect that the effort on internal heavy ion sources will push forward the present limits by substantial amounts.(13) One should also expect that axial injection systems for heavy ions shall become more efficient than they are at present. In fact internal sources did prove quite competitive so far but there is no reason why external injection systems,using advanced sources, like the electron-beam type should'nt eventually take over.(14)

Further developments are also to be expected in the auxiliary experimental equipment around the accelerator, such as spectrometers, whose building is often a major technological enterprise.

B) - High energy light ions machines

To the writer's best knowledge no new projects in the meson factory range are envisaged for the near future. The number of facilities is probably going to be sufficient, world-wide, for some time to come. Initial interest in still higher proton energies machines, the so called k-meson factories, has not materialized so far in an approved project. Perhaps the time for these very large machines will come only after some exploitation of exsting meson factories and when and if a genuine interest arises in the physics community for this exotic nuclear probe.

One much more likely development in this sector, and in fact a development to some extent already under way, is toward filling the gap between 100 and 500 MeV proton energy. If one remembers the energy distribution shown in fig.2, one sees that no AVF cyclotrons are operating in this energy range, apart from the variable energy beams of TRIUMF.

Since a great deal of interest has arisen in the medical field for exactly this kind of proton energies, especially for therapy purposes, various projects are being studied. They are reported in papers at this Conference, so only a listing is made here.

- Conversion of the Uppsala syncrocyclotron incorporating AVF features (180 MeV).
- Design of a 150 MeV proton medical machine by a Berkeley group.
- Proposal of a 200 MeV separated sectors cyclotron for South Africa, mainly for medical uses.

All possible technical approaches are thereby equally represented. Hopefully at least some of these proposals will have materialized by the time of the next Conference.

Table 3 Multistage heavy ions facilities: operating-in construction-planned

LOCATION - NAME	STATUS	INJECTOR FEATURES	BOOSTER FEATURES
ORSAY (CEVIL – ALICE)	OPER 1965	LINAC – 1.15 MeV/amu	AVF CYCLOTRON K= 75
DUBNA	OPER 1968	CYCLOTRON K= 250	AVF CYCLOTRON K= 156
BERLIN (VICKSI)	1976	V. de GRAAFF. 6 MV	SEPARATED SECTOR CYCLOTRON (4) K= 120
INDIANA (IUCF)	1975	500 KV – DC PLUS SEPARATED SECTOR (4) CYCLOTRON K= 15	SEPARATED SECTOR CYCLOTRON (4) K= 220 (also 200 MeV protons)
LOUVAIN (CYCLONE + INJECTOR)	Started	CYCLOTRON K = 70	AVF CYCLOTRON K= 110
OAK RIDGE (N.H.L.)	1978 (1st Phase)	25 MV TANDEM + CYCLOTRON K= 90 (ORIC)	SEPARATED SECTOR CYCLOTRON (4) K= 310
ORSAY (GANIL)	Study	AVF CYCLOTRON K=25 + SEPARATED SECTOR (4) CYCLOTRON K= 400	SEPARATED SECTOR CYCLOTRON (4) K= 400
CHALK RIVER	Started	13 MV TANDEM	SUPERCONDUCTING CYCLOTRON K= 480
MICHIGAN STATE UNIVERSITY LANSING	Started	TANDEM OR CYCLOTRON	SUPERCONDUCTING CYCLOTRON K= 440
QUEBEC	Study	AVF CYCLOTRON K=20 or TANDEM ?	SEPARATED SECTOR CYCLOTRON K= 485
MILAN	Study	16 MV TANDEM	SUPERCONDUCTING CYCLOTRON K= 400

C) - Heavy ions machines

A flurry of machine design activity has been going on since the last Conference on this subject. Most of the topics involved are covered in a number of papers at this Conference so only a short review is made here.

Interest in heavy ion physics has picked up a substantial momentum in recent years, spurred by theoretical speculations on the existence of superheavy elements and by interesting new phenomenologies in the field of nuclear reactions with heavy ions. Also the filling of a number of voids in the Nuclear Species Chart has considerable interest.

As a result of the demand for higher energies, typically as high a 10-15 MeV/Nucleon for Uranium and 50 to 100 MeV/Nucleon for light. (A$<$50) elements, a number of projects have surfaced.

Despite the competition from linear accelerators (like Super Hilac and Unilac) the cyclotron appears to many as an ideal booster well suited for the post acceleration of beams from other machines. Such "injector" machines range from a Tandem, to a compact cyclotron, to separated sector cyclotrons. All these machines seem to provide reasonable energies and intensities for heavy ions to be stripped at injection into the cyclotron booster.

The present overall situation is shown in Table III. These features show up:

- in comparison with earlier K values (K defined as $T/A = K\,(Z/A)^2$) of 100 to 200, machines are now being designed with K's of 400 to 500.
- preferred candidates for this generation of booster cyclotrons are separated sector and superconducting machines. Hybrid multistage systems (cyclotrons + tandems) are considered, and that wasn't the case just a few years ago.
- designers of separated sector cyclotrons are confident, also on the basis of successful S.I.N. experience, that the design goals can be substantially reached.
- a new technology, that of superconducting cyclotrons, is now appearing. This type of machine seems to meet most requirements for heavy ions acceleration. Many problems, including magnetic field shaping, injection, and extraction, will have to be solved before they come into operation but there is a very high degree of confidence in ultimate success.

The superconducting cyclotron appears a powerful blend of already progressing-technologies. Its construction will then be perhaps more a problem of putting together properly, different pieces of equipment, rather than to develop substantially new ideas.

Concluding Remarks

As it looks now, a new wave of progress is in the making, centered on the design and construction of large heavy-ions machines.

It is very likely that this fact, and just the much bigger physical size of these machines, will in turn change somewhat the typical composition of the scientific community living around a cyclotron.

So far the typical university-size cyclotron has been a facility where the role of builders and users were not readily distinguishable, and in fact they simply corresponded sometime to different periods in the lives of the same individuals.

This is perhaps one of the reasons, maybe not the least one, of the very large output of significant results obtained over the years in basic research, and of the fast fall-out effect on applied research.

Conceivably this is going to change with the bigger machines, located in National Laboratories or the like, and presumably we are heading toward a situation more similar to that of high energy physics. This has certain definite advantages, but also some disadvantages, and this writer is not personally sure of which outweighs which.

Let us hope however that the strict connection and mixing of builders and users, characteristics of the cyclotron field, will keep going for quite a while, because we need it.

Finally, if one tries to assess the reasons why some people (like many of those gathered here) keep alive the cyclotron building tradition in preference of other means of achieving the same goals - e.g., to accelerate heavy ions to very high energies - one is certainly confronted with difficult questions of judgment, and cannot even escape a fair amount of guesswork.

It turns out to be just as hard to summarize one's feelings on the different technical approaches, now evident within the cyclotron builders community, toward the solution of essentially the same problem. To measure in an objective way the pros and cons is very nearly impossible.

Perhaps the only sensible thing to say is that progress in science has been historically generated by the work of people who started doing things "in a different way".

This is exactly what the cyclotron scientific community has been doing and is doing right now.

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