McGill University

# THE USE OF FIELD TRIPS
# TO PROVIDE A REAL-LIFE DIMENSION
# TO PHYSICS IN SECONDARY SCHOOLS

by

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## ABSTRACT

This monograph attempts to demonstrate the value of field trips or out-of-class activity as a supplement to the PSSC physics program. This type of activity gives a real-life dimension to a theory-oriented science study. Such a supplement was incorporated into the physics class of PSSC students at Lasalle Catholic Comprehensive High School in 1976-77. Two types of field trips were undertaken - individual and group. Analysis and evaluation of the activity are presented in the light of the goals of education; this necessarily involves the cognitive development of the student.

## RESUME

Il s'agit ici d'une monographie se rapportant au programme de physique PSSC et qui se propose de démontrer qu'il est important d'ajouter des activités supplémentaires aux cours réguliers. De cette façon l'enseignement théoretique du sujet est en relation plus étroite avec la réalité concrète du monde physique. Un tel complément pédagogique fut incorporé au programme d'étude d'un groupe d'élèves au "Lasalle Catholic Comprehensive High School" lors de l'année scolaire 1976-77. Ces activités extra-murales furent entreprises individuellement et collectivement par les élèves. L'analyse et l'évaluation des résultats obtenus sont présentés en fonction des objectifs pédagogiques poursuivis. Ceux-ci

impliquent nécessairement le développement cognitif de l'individu.

## ACKNOWLEDGMENTS

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## LIST OF ILLUSTRATIONS

# CHAPTER 1

## INTRODUCTION

It is seldom that a year elapses without the emergence of new ideas or new methods in the field of education. These new arrivals, often enough, are the result of either minor or even fundamental changes in the philosophy of education. Conscientious educators are ever alert to these changes in anticipation that they might augment the quality of their teaching or, at least, that they might provide solutions to current problems.

Physics is one area which had remained remarkably aloof from basic change until the second half of the twentieth century. The content of the high school physics course remained nearly constant for over sixty years except for supplements of technological information necessitated by new advancements. However, about twenty years ago, in answer to the cry of learning by inquiry and discovery, a new high school physics course came on the scene. It was produced by the Physical Science Study Committee and the course soon became known as PSSC physics. There was greater emphasis placed on laboratory work than in the traditional physics course. Fewer topics were treated, but at greater depth. Much less attention was paid to technological applications. There is general agreement that it is a definite improvement for better-than-average students.

Since the late sixties, much has been written to sing the praises of individualized instruction packages. The system using these is often referred to as a Personalized System of Instruction (PSI). In this system the student works by himself at his own pace, from study guides, with the teacher ever present to provide individual attention.

PSSC has been in operation at Lasalle Catholic Comprehensive High School (LCCHS) for eight years. For two months during the 1975-76 school year PSI was used as the method for learning PSSC. The results were encouraging enough to introduce the PSI method into full scale operation in 1976-77. It was apparent, however, that certain undesirable aspects of PSSC, particularly the lack of relevant application of concepts and laws, were aggravated by the use of PSI. Still there was no question of abandoning PSI, since the positive aspects were important. Instead, a remedy was studied and introduced to obviate the deficiency.

In past years a limited use of the field trip or out-side-the-classroom activity has been employed by this writer to add interest to the physics program. It was thought that a more organized, more extensive and better integrated use of such activities might answer the deficiency already mentioned. Therefore field trips were introduced as part of the physics program.

This monograph outlines some deficiencies encountered in PSSC physics taught by the mode of PSI. It describes how field trips were used to treat these deficiencies.

Also presented is the rationale to justify field trips as a means of contributing to the goals of education, while simultaneously promoting the cognitive development of the student.

# CHAPTER 2

## THE GOALS OF EDUCATION

Over the past twenty years there has been indication that science education is moving toward a fuller view of teaching by emphasizing greater concern for the development of the total person. The National Science Teachers' Association (NSTA) shows this concern in its policy position for the 70's (1970:1). It defines the general goal of science education thus:

> The major goal of science education should be to develop scientifically literate and personally concerned individuals with a high competency for rational thought and action.

Further, the NSTA expands its definition by detailing the qualities of a scientifically literate person as one who:

> Uses knowledge of some of the major concepts, laws and theories of science in his interaction with other people and his environment;
>
> recognizes the limitations as well as the usefulness of science and technology in advancing human welfare;
>
> understands the interrelationships between science and other facets of society, such as social and economic development.

In the past it has been common for science teachers to view their responsibilities as being concerned with teaching only the accumulated facts of science. It is not infrequent that teachers today fall into the same error. The NSTA places a much greater responsibility on the science teacher. Not only are the accumulated facts to be known, but the laws and concepts are to be adequately understood. Even more, the manner in which the student can use his science knowledge or, at least, recognize its use in everyday life, is a measure of the success he has achieved in his science education. The "everyday life" aspect of science education is a particularly important point. The NSTA stresses the learning, the understanding and the appreciation of science in the outside-the-class environment, be it immediate or remote.

Although more in focus today, this relevance-to-life dimension of science has frequently been spoken of by outstanding educators in the past. Harvard's Alfred Whitehead (1929:13) decries the emphasis on memorized facts and claims that "a merely well-informed man is the most useless bore on God's earth." He maintains (1929:34) that real science education "should begin as well as end in getting hold of the subject matter [the facts] as it occurs in nature [real life] ."

Earlier still, in 1892 William James (1958:53) advised teachers to be patient with the mind which is weak in reproducing facts on examinations, for "it may, in the long examination which life sets us, come out in the end in better shape than the glib and ready reproducer, its passions being deeper, its purposes more worthy."

While calling for greater total development of the student and more social awareness, the NSTA position in no way militates against the general goal of education - cognitive development. A "high competency for rational thought" is a key phrase in its basic definition. The U.S. Education Policies Commission specifies that "the rational development of the mind ... is the common thread of education (Silberman, 1970:11)."

Since mental development ranks foremost among educational goals, the teacher must know and attempt to understand the general framework and the operation of this development. Happily, the area of cognition, because it does permit empirical exploration, is one in which substantial research has been undertaken. The methods of study are quite well defined and evaluated. As a result many investigators have formulated specific stages of developmental change. Perhaps the most noteworthy is the Swiss psychologist Jean Piaget. His theory on mental development will be outlined in the next chapter.

# CHAPTER 3

## PIAGET AND COGNITIVE DEVELOPMENT

For over fifty years Jean Piaget and his associates at the Genetic and Epistemology Institute in Geneva have studied how the human mind develops. The formidable quantity of literature from Piaget's research is testament to this activity over the past half century. From this extensive research Piaget evolved his theory of cognitive development. He offers four stages to this development (Hyde, 1970:26-27):

1. Sensorimotor - (birth to two and a half years). This is a period of discriminating and labelling. The child is mainly directed by physical stimuli. Thought proceeds from present sensations. There is no permanence in objects. Time is now and space is the immediate environment.

2. Preoperational - (two and a half years to seven years). The child is not yet capable of carrying on mental operations such as combining, separating or ordering. He is ego-centric, finding it difficult to understand views other than his own. His thought processes are not reversible. He has very limited concepts of time - past, present or future. At this stage he is beginning to use language to represent thought.

3. Concrete operational - (seven years to eleven

years). At this stage the child is able to perform operations. Thought is mainly limited to thinking about objects or situations. His understanding of space and time is greatly expanded. He is capable of reversible thinking. He analyzes and is aware of variables.

4. Formal operational - (eleven to fifteen years). The child is capable of hypothetical and propositional thought. He has become a reflexive thinker, that is, he can think about his thinking. Probability becomes understandable. He can do ratio and proportions.

Not only has Piaget proposed these stages of mental development, but he has explained the manner through which this development comes about. Barbel Inhelder, Piaget's co-worker (Siegel, 1968:vi), pinpoints the core concept of Piaget's Theory of Cognitive Development by stating that Piaget holds "that knowledge is not a reflection of reality, but the result of active interaction between the subject and its environment."

Piaget says that an individual is born with very rudimentary guides which,through physical stimuli, organize the child's environment and thinking. These he calls mental structures. The continual changing of these structures underlies the process of intellectual growth. These structures are constantly being built and rebuilt. This is done by the "active interaction between the subject and his environment". In the interaction his present mental structure guides the child's thought and behaviour. Frequently the interaction presents a contradiction, a pattern which does not fit the present mental structure.

Therefore, it must be revamped or replaced. Continued investigation and inquiry enables the child to change (accomodate) his former mental structure. This new structure is now used and built upon or changed as before. The whole process is called equilibration or self regulation.

In building mental structures Piaget considers three main factors: experience, social transmission and maturation. Experience means contact with the environment. This contact will cause present structures to be enforced or it will offer contradictions to set the equilibration system in action. Social transmission means that that the child must interact with others in order to move from an ego-centered to a truer and more objective frame of reference. Maturation means that the structure requires time to grow and mature. The more interaction with objects or people the child has, then the faster and firmer the structure is built.

Therefore, to foster intellectual development as Piaget explains it, there must be continuous input from the environment to be acted upon by the existing cognitive structure. The input is accomodated to the structure creating, in effect, a new structure. It is the change which takes place in the structures which constitutes learning.

Most of the above deals with cognitive development alone. But a number of the qualities of the scientifically literate person are in the affective domain. Still it would be erroneous to think of these areas (cognitive and affective) as separate entities in science education. Piaget insists on the fundamental unity of the cognitive and affective domain. The child's ego-centricity, for example, which is an affective trait is a function of the crudity of his mental structures. As the child develops cognitively his ego-centricity will change and even disappear. The equilibration process involving social transmission causes the individual to modify his thinking. A more objective thought structure is produced. This necessarily presents different values and imposes new obligations. In this way cognitive development is inescapably intertwined with the development of the total person.

An awareness of the child's level of cognitive development should be of paramount importance to the teacher. Then of prime concern should be the designing of experiences to guarantee that the students have an opportunity to perform desirable mental operations at their stage of development.

# CHAPTER 4

## PSSC AND THE GOALS OF EDUCATION

The impact of Piaget's philosophy is being more and more felt in North American education. Greater emphasis is being placed on learning by inquiry and discovery under the guidance of the capable teacher. David Hawkins of the University of Colorado suggests that this teaching-learning process can best be described as a triangular relationship of the teacher, the child and the "stuff", sometimes called the "I, thou, and it" relationship(Silberman, 1970:217).

It has commonly been assumed that the physical sciences, and physics in particular, are the areas where such a relationship is prevalent. Laboratory work under teacher guidance is used in the science curriculum. But commendable as this may seem, there are some telling deficiencies.

Young (1976:500) exposes the deficiencies as he plays down these laboratory activities, explaining that they "fail to be an integral part of social life". He cites the laboratory as a "room full of special rules" and further charges that "all too easily the lab world is experienced as a closed one". Such an atmosphere must certainly be found wanting in a system where the development of the total person is the objective. What Young has ascribed to science in general is quite apropos to physics and PSSC physics in particular. PSSC physics is primarily a laboratory-oriented course. But the experiments seldom illustrate real-life applications of physics concepts. Instead they are aimed strictly at the concept itself and the theory of physics. For example, the concept of work in simple applications with machines is never to be found in PSSC. However, more abstract concepts like those found in Newton's Second Law are much in evidence. Note the titles (Haber-Schaim, 1975:34,37,44) of the following experiments:

Experiment No. 20: Changes in Velocity With a Constant Force

Experiment No. 21: Dependence of Acceleration on Force and Mass

Experiment No. 24: Centripetal Force

As can be seen, these are experiments on highly abstract concepts with very little offered, either in the lab or text, which relates to the everyday life of the student. In the section on Magnetism, there are no demonstrations or experiments to simply "show" the magnetic fields around magnets. The authors seem to be of the idea that the students will grasp the idea intuitively from the diagrams in the text. Yet after offering such inadequate concrete preparation for such an abstract concept as magnetic field, the authors proceed to require its mathematical elaboration in two different experiments. Even more, in the Electricity section, all basic experiments on induced electromotive force have been formally eliminated, not to mention the more practical applications in motors and generators. The approach is restrictive and theoretical. Consequently, physics is assimilated very objectively, quite unrelated to the student's environment.

What further aggravates this lack of relevance is the practice of teaching physics by referring to the ideal. Throughout his learning of physics, the student is made to "neglect friction, consider no other force, suppose a uniform slope, ignore gravity, etc." This is hardly conducive to promoting the concepts of physics in everyday life.

Professor E. Eisner manifests the absurdity of the situation. He says "the world is full of physics, but these courses do not appear to make it obvious to the pupils in general. A recent popularity poll for evening classes put physics at the bottom and understanding physics in the home at the top (Peters, 1976:497)."

Dewey (1966:47) expresses a similar thought in a rather beautiful manner. He reminds us that confronting the laboratory or laboratory equipment is not enough. He argues that cognitive development is enhanced when there is confrontation with things that are rich in experience and association with people. "As a matter of fact", he says, "there is no contact with things except through the medium of people". He would have us learn such concepts as acceleration by using an automobile out-of-doors rather than a small cart moving in a science laboratory.

If the restricted subject matter learnt in the isolation of a "closed world" called the physics laboratory is the target of criticism here, it is certainly not the only target. The major censure is reserved for what the American psychologist J. McV. Hunt calls the "problem of the match", that is, the appropiate relationship between what is to be learned, the way it is to be learned, and the stage of development of the learner (Silberman, 1970:217).

Weigh the degree of difficulty of the PSSC subject matter against the mental development of the student and a rather sorry imbalance emerges. It is not unfair to say that in PSSC physics the student must operate at the formal operational level in order to comprehend the concepts. Renner (1976:219) says "our research has shown that 66% of Oklahoma high school seniors still occupy the concrete operational stage." In a study more pertinent to this paper Rener (1976:222) states "our data have shown upon two separate occasions that between 70 and 90% of those who elect secondary school physics are formal thinkers." This percentage appeared to be unduly high, but another study of Renner's clarified the issue. It is obvious that most of the formal operational students of which Renner spoke were still operating very much at the concrete stage. Renner (1972:295) found that in a group of fifty-eight students in the formal operational stage only fourteen (about 24%) could be called fully formal operational.

If we were to project these figures to a physics class of thirty students, then about 80%, or twenty-four students, would be formal thinkers, and six of the thirty would be fully formal operational. Thus the majority of the class members are not fully formal operational and so often work at the concrete level.

Eugene Chiapetta (1976:257) strongly supports Renner when he says that "formal operational thinkers demonstrated that they had a great deal more understanding of concrete concepts that formal concepts in science." So it appears that many who can operate at the abstract level have the potential for considerable improvement in this area of operation.

Herein lies the dilemma. PSSC relentlessly demands operating at the formal level. Even the reading level of the PSSC text is rated grade twelve or first year college.[1] And while Renner (1972:26) emphasizes that the teacher must "provide experiences commensurate with his [the student's] language and maturity level", we must remember that some of the students are as yet incapable of formal thought and a large percentage of the remainder of the students are just entering the formal operational stage.

In spite of this criticism of PSSC physics, most authorities still agree that PSSC has its place for the advanced class. The obvious implication is to attempt to eliminate the deficiencies in order to adequately give the enrichment which PSSC can provide.

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[1] The reading level of the PSSC Physics text was so rated by the guidance department at LCCHS.

# CHAPTER 5

## PSSC AND PSI

The personalized system of Instruction (PSI) is one which has found favor in many educational centers. In 1967 there began in the United States a four year development plan aimed at initiating individualized learning. The system was to span grades one through twelve and eventually was to be extended to teachers' college (Weisgerber, 1971:2). It is not the purpose of this paper to weigh all the merits or demerits of individualized instruction. However, a summary of its operation at LCCHS is inserted here to indicate that a program which uses PSI to teach PSSC physics, advantageous as it might be, may require adjustments in order to provide more opportunity to acquire scientific literacy.

Fundamental to PSI is the premise that students should advance at their own pace and receive help to meet their individual needs.

Here are the mechanics of the method as used at LCCHS during 1975-76 and 1976-77. The students were given study guides which provided the basic theory and text book readings for a section; explanations and sample problems were offered; guided problems followed; then text book and supplementary problems were assigned; when all this was completed, the student was given a formal written test; if success was achieved the next study guide was taken and the process continued; failure meant restudy and retesting.

Teacher and students were happy with the method. Yet, because of the highly abstract material of the text plus the rigid (read, study, take notes, do problems, do tests and retests) academic mode of PSI, the problem of relevance became more discernable. PSI was definitely encouraging a personal sense of responsibility and producing good study habits. The students liked it. But there was something missing. Even the lecture system of former years was superior from the standpoint of some exposure to real-life physics. This is because in the lecture system efforts to make concepts more real were exerted with constant references by the teacher to their application in the home and industry.

In PSI most students wanted enough information to push on. The brighter students wanted to complete as many packages as fast as possible; the slower student was constantly striving to keep pace with the suggested norm. Besides, the teacher now had little time to offer supplementary information. Indeed, a scientifically literate individual would be hard pressed to surface under such a program.

Without abandoning PSSC or PSI an intelligent supplement to the present program had to be attempted. Perhaps Renner (1976:222) had such a supplement in mind when he made the following outline for designing a physics course:

1. Selection of the concepts which represent the content to be taught.

2. Provision for laboratory experiences which provide information the instructor can use to invent the concepts.

3. Teacher-student interaction during which the concepts are invented.

4. Determination of other events, objects and/or situations which can be explained with the invented concepts.

Our present course had all of the above, but was weak in the fourth - "events, objects,etc." And it was this weakness which accounted for many of the shortcomings detailed already. However, there are very few programs which, when put into operation, do not reveal areas of weakness. It becomes the obvious duty and challenge for the teacher to remedy the situation. The Plowden Committee, a Parliamentary Committee in England, put it this way: "The teacher's task is to provide an environment and opportunities.... There has to be the right mixture of the familiar and the novel, the right match to the stage of learning the child has reached (Silberman, 1970:218)."

In designing an exercise to treat the weaknesses already mentioned, other factors had to be considered. That is:

1. The exercise had to be primarily one of "doing" by the student.

2. The teacher's role should be one of guiding and encouraging the student.

3. The exercise had to be sufficiently general so as to accomodate all of the students, not only intellectually but physically and financially as well.

4. The exercise had to allow for student involvement with any topic in the physics program.

5. Safety precautions had to be stressed and observed.

6. Adequate time had to be allotted to allow for serious work and yet guarantee that the students' other subjects did not suffer.

Past experiences provided convincing arguments that out-of-class excursions or field trips had considerable potential in regard to fulfilling the above criteria. Therefore, I decided to have each student conduct two seriously planned field trips - one an individual field trip, the other a group field trip.

# CHAPTER 6

## THE FIELD TRIP INTRODUCED

Field trips, conducted for the purpose of enriching a student's current studies and broadening his views of life, have long been accepted as pedagogically sound. Dewey (1906:16) recognized the value of real-life experience and was against viewing subject matter as a substitute for it. To him, content alone without foundation in experience is soon lost. It is without motive for retention, since the "formalness" of logical ideas and organized mathematical relations imparts insufficient mental impact to guarantee permanency.

Education will necessarily be more complete when the community becomes a virtual laboratory for school work. Harrison (1970:9) tells us that "the cloister idea of education is out.... This does not detract from the great importance of education in school, but underlies the idea that education at home, in the club, in the theatre, the museum and the library is just as fruitful." Hammerman (1952:4) points out that text-book knowledge is second hand: "It is always the person who sees, discovers or explores a situation who gets the most out of it. Such learning is faster, is more deeply appreciated and is retained longer."

There is a general tendency for field-trip literature to favor such disciplines as geography, history, biology and geology. Be that as it may, the broad factors which make field trips desirable in these areas are also very applicable to physics.

If the literature on physics field trips is sparse, it is not because such endeavours are rare occurrences. My own experience is that physics teachers frequently engage in outdoor excursions. A common opinion is, however, that much more could be achieved from such activities which often involve time to arrange, and considerable energy and expense to pursue. In the year (1976-77) I was determined to use these occasions more beneficially.

In mid-September, when the students were sufficiently familiar with PSI, we used a class period to discuss the PSSC physics course. Most of the students expressed that they liked the subject and that they were happy with the PSI method. The general consensus, nevertheless, was that physics was difficult and they sensed little of the practical in it. They rarely were aware of any physics principles at work in their day-to-day lives. Physics was not relevant to them.

As the discussion progressed, the students began to see where physics principles were being demonstrated to them daily. There was physics all around them - at home, at school, indoors and out, in their parent's occupation, even in their own bodies. It was agreed, though, that their present course in physics did little to associate physics with this reality. They concluded that it would be a definite improvement to incorporate some of this real-life physics into their present program.

The following day the physics field trip plan was introduced. My own enthusiasm seemed to provoke a marked zest in the students. I was happy to have had some recent out-of-class experiences on which to draw.[1] The lively give and take of the class discussion made it relatively easy for the "medicine to go down". The two field trip assignments were well received. It was on this occasion that the class affectionately dubbed them "the mini" and "the maxi", which terms I will employ now and then in the following pages.

The mini involved each student in the organizing and conducting of his own field trip. A report on it was due in mid- November. It would consist of some 2000 words or equivalent (on tape, movie, etc.).

The maxi was to be organized and conducted by the class in mid- March. The report from the maxi was due in mid- April and 4000 to 5000 words or equivalent were expected.

In both cases a maximum of two students could group to complete the report. These two assignments would form 15% of their school physics mark.

It seemed proper to assign at this time, the topics for the major field trip(s) to be undertaken in the spring. Doing so, further clarified the type of activity for those still somewhat hazy about it. The topic or tour to be conducted in mid- March was (1) Beauharnois - a Hydro Quebec power project, or, (2) the McGill Synchrocyclotron, for those who wanted a greater challenge.

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[1] Some activities in which I directly participated the previous year are: (1) visits with some of my science classes to the Dow Planetarium and the Lachine Water Filtration Plant, (2) a tour of the Rutherford Museum at McGill under the capable guidance of Doctor F. Terroux, (3) participation in a survey Physics course in which each of the lecturing professors conducted a practical session in their specific labs and areas of research, (4) visits during summer vacation to the Ontario Science Centre in Toronto and the Museum of Science and Technology in Ottawa, (5) delivery of two after-supper lectures and conduction of two outdoor astronomy sessions with a group of our school's biology students at Mont St. Hilaire, Que., on a three day live-in, field-study session.

The students' questions and suggestions demonstrated a more-than-expected interest and receptiveness to the project. We completed the discussion by summarizing what we might expect to derive from fulfilling the assignment. Their thoughts were summarized as basic objectives for their tasks. These were:

1. to produce a greater understanding of physics (its laws, theory and concepts) by seeing physics in situations more relevant.

2. to encourage and promote individuality and creativity.[2]

3. to promote scientific literacy.

Finally, to prevent any ambiguity a formal statement of the assignment was issued:

1. Each student in Physics 552[3] is to conduct a field trip or out-of-class excursion.

2. This activity must involve physics principles, concepts, laws, etc.

3. The student is to observe people or apparatus demonstrating or applying such principles, concepts, laws, etc.

4. Preferably the activity should show the use of such principles, concepts, laws, etc., in the real-life world of home, industry, research, entertainment or even sports.

A heavy emphasis was placed on what the completed report should contain. There had to be a detailed description of the tour or excursion. Specific and direct reference from the tour to physics

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[2] Throughout this paper, individuality and creativity will be used collectively, because of the pronounced overlap in the meaning.

[3] the last half of a two-year PSSC physics course offered to level five students.

theory had to be included. The theory could be treated to whatever degree of sophistication the student was able to muster. The relevance of the exhibit to mathematical relations or physics formulae was highly encouraged. This description of the tour and its relation to theory was to comprise about seventy per cent of the assignment. What to include in the remaining thirty per cent was left to each student's bent and choice, as long as it had a thread of coherence with the overall topic.

The format or method of doing the assignment was not rigid. This was an area where creativity and individuality could be freely and widely portrayed. Some ideas put forth were: essay with diagrams, tape recordings, video presentations (photographs, slides, overhead transparencies, movies), programmed study format, models or exhibits of their own making as a supplement, etc.

Those who had definite ideas about something different were free to discuss it with the teacher. Considerable leeway was permitted those who had good proposals and were keen about carrying them out.

This was the exercise assigned to a PSSC class of twenty-six senior high school students at the beginning of the 1976-77 school year.

# CHAPTER 7

# THE PROJECTS

The period between the date on which the project was assigned and the deadline for completion was one of significant activity. It was an interval during which I observed and participated as guide, encourager and resource center. It was obvious that in completing the assignment the class as a whole was examining into much of the spectrum of science. A refreshing enthusiasm, unfamiliar to the usual physics routine, emerged to meet this new endeavour.

Physics concepts were reviewed and analyzed; projects were sought out which would demonstrate these concepts. The library was harvested of ideas and explanations in anticipation of the trip; it was then revisited to confirm statements or clarify still cloudy observations before final framing of the report.

This chapter will contain a listing of the topics and a brief résumé or explanation of the work performed. Following the résumé are a few words specifying succinctly the important procedures employed to accomplish the field trip and draw up the report.

Some activities, which were eventually abandoned, are briefly mentioned because of their important contribution to the objectives established earlier.

The words in quotation marks, unless otherwise referenced, are direct quotes from the student's work. Some student photographs and sketches are also included.

## THE MINIS - TITLES

1. Radioactivity and Rutherford
2. Conservation of Energy
3. Electrical Energy
4. The Theory of Relativity
5. Conservation of Energy and of Momentum
6. Aerodynamics
7. The Electromagnetic Spectrum and the Doppler Shift
8. The Vanier Arcade
9. The Laws of Reflection
10. The Ballistic Pendulum
11. Calculating the Circumference of the Earth
12. Tides
13. Remote Sensing
14. No project (two students)

Total: 13 projects from 26 students

## THE MINIS - RÉSUMÉS

1. Radioactivity and Rutherford

This topic, suggested during the assignment discussion, was quickly taken up by four students. Since the library of the school and that of the city of Lasalle did little to supplement their scant knowledge of Rutherford, they anticipated that a visit to McGill University's Rutherford Museum would answer the need. They arranged an interview and tour with the museum curator, Doctor F. Terroux who was recently retired from the Physics department at McGill. I was asked to be present at a session one day after school; preparations were taking place for the rendez-vous with Doctor Terroux. Knowledge that Doctor Terroux was a former student of and close friend to Doctor Rutherford added to the interest of this group. Aside from the assignment, they were enthused by the prospect of (1) visiting the renowned University of McGill, (2) listening to achievements of one of the most renowned experimental scientists of all time, while observing the very building and surroundings where his experiments were performed.

The realization of the visit was every bit up to the expectations of the students. They evidently established immediate rapport with Doctor Terroux.

A somewhat unfortunate setback transpired during the tour and interview. The boys had brought along a tape recorder which they plugged into the electrical outlet at the beginning of the interview. To their dismay they soon discovered that "at world-famous McGill, an institution renowned for its contribution to science," they could not find an outlet that worked. The emergency batteries proved to be weak. Consequently their taping was too garbled to be of much use. Undaunted, after arriving home, the foursome went through a debriefing session and re-enacted on tape the complete proceedings. One of them portrayed Doctor Terroux.

Some other undertakings of this group were: (1) they set up a cloud chamber such as is found in the Introductory Physical Science course (Haber-Schaim, 1972:133), (2) they took some good quality photographs of cloud-chamber tracks, (3) they experimented with a more complex cloud chamber, (4) they used a geiger counter and radioactive minerals.

The final product was an essay describing the trip to McGill, the history of radioactivity (including Rutherford's work), and a profile of Doctor Terroux. They presented some of their own experiments with the cloud chamber and geiger counter as part of their research on radiation and radioactivity. Photographs and diagrams were included plus the garbled and improvised tapes. Two groups did this project, each with its own research and essay, but they used the tapes and photographs in common.

- essay, interview, tour, experiments, tapes and pictures.

2. Conservation of Energy

Two students presented a structure which they had built to study mechanical energy. It was roughly patterned on the apparatus used by James Joule to illustrate the mechanical equivalent of heat (Barton, 1967:78). References were made to the Churchill Falls project[1]. An uncle of one of the students who was an engineer on the project provided them with some technical data. Mention of the dam and of the pendulum were used in conjunction with their own constructed model to demonstrate energy conversion. The production of electrical energy was explained with direct reference to the Churchill Falls project. Graphs of the experimental results obtained from their model were included.

- essay, model, experiments.

[1]Churchill Falls in Labrador is an electrical power project of the Government of Newfoundland. Quebec has a long-term contract for the purchase of this power.

3. Electrical Energy

This one student gave in a fifteen-page essay (with diagrams) on the meaning of electric current, electrical energy, and electrical power. Electrical power was explained from bicycle-generator models which he had used at the Ontario Institute of Science and Technology in Ottawa. He states:

> For example, in the museum, there is a bicycle device which when pedalled turns a generator which, in turn, produces electricity to light a vertical series of lights. As the rate of mechanical energy increases (faster pedalling) the illumination of the lights progresses, one by one, vertically upwards.

The student also experimented with the telephone magneto in the physics laboratory to demonstrate this increase of electrical energy with the increase of mechanical energy (faster cranking of the magneto). The faster the magneto was cranked the brighter the connected light bulb would glow. From his observations he indicated some of the factors involved in induced EMF.

- essay, visit to the science museum, lab experimentation.

4. The Theory of Relativity

One boy, who said he was always fascinated by the subject of relativity very much wanted to have the opportunity to work at it. He felt that he could "figure out a way" to do a project that wasn't just a theoretical essay. There was no denying his enthusiasm. Every few days saw him with a different book on the subject - Relativity for the Million, The Universe and Dr. Einstein, etc. Added to this was a barrage of questions about time dilation, frames of reference and even tachyons. Dicussions with his peers on these topics were quite commonplace. He could not accept the velocity of light as absolute. He insisted that if Einstein expected his followers to wrench their thinking violently from the current "logic" of the day, then he should offer the same freedom to others who might, in future, challenge his absolutes. He was acquiring a "gut feeling" for the subject, but the field trip aspect was still to be dealt with. As the deadline approached he realized his predicament. His opening paragraph tells it all:

> It is rather difficult to go on a field trip where one can strongly experience relativity in the sense of time dilation, mass augmentation and volume decrease. Therefore, I have chosen as my field trip a show at the Dow Planetarium entitled 'Einstein's Universe'.

He presented an essay review of his readings with examples from the Planetarium show[2]. He proceeded to explain the importance of "frames of reference" in relativity, telling of how the program in the Planetarium illustrated this by an experiment with the projector.

> The sky was projected and two planets were made to revolve around each other. From an outside observer's point of view it was nearly impossible to determine which planet was moving and which was not - due to a lack of a fixed frame of reference.

The basic predictions made by the theory of relativity were outlined, some equations were explained and graphs were drawn to illustrate the effect of velocity on mass, length and time.

- essay, visit to the Dow Planetarium, considerable reading and debate.

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[2] The Dow Planetarium, the first major planetarium in Canada, is located in downtown Montreal and is operated by the city of Montreal.

5. Conservation of Energy and of Momentum

This student's first attempt was a rather interesting project on conservation of energy, using the family car. Although many measurements were taken with specific purposes in mind, the essence of the procedures was to determine the efficiency of the vehicle. Data was taken in accelerating to thirty miles per hour, decelerating to a stop, and from the ascent of a slope of known height at constant speed.

It was a simple matter to calculate the energy input. There was no trouble determining the quantity of gasoline consumed from a full tank. The energy rating of gasoline (about $4,8 \times 10^7$ J/kg) was a readily available statistic from science handbooks.

However, after many trials the student was discouraged by the inconsistency in his results. He maintained that there were just too many variables and he abandoned the project. It was replaced by a home lab on conservation of momentum in one and two dimensional collisions. This activity was performed using plastic pucks on an air table hockey game. Strobe light photographs were taken of the collisions. From these vectors were drawn and conclusions made.

- essay, home experiments, strobe photographs.

6. Aerodynamics

An interview with N.G. Zarifah of Rockwell International provided the inspiration for this paper on aerodynamics. The basic forces of flight, namely,lift, gravity, thrust, and drag were explained with the help of pencil sketches and references to the interview. Also included was a pictorial history of flight development. - essay, interview and pictures.

7. <u>The Electromagnetic Spectrum and the Doppler Shift</u>

A project on this topic evolved from much thought on a variety of astronomical subjects. The two boys involved are camera bugs with a bent toward astronomy. After class they were offering and discussing an idea a day, almost. To mention some examples: (1) they wanted to take pictures of the moon each night at the same time, and from them determine its velocity around the earth, (2) they expressed interest in determining the height of a mountain on the moon - after reading of such an undertaking in a Project Physics Book (Holton, 1972:135), (3) they suggested they might find the spin speed of Montreal on the earth by taking a time-exposed picture of some known star and measuring the amount of blur from the time exposed. They finally settled on the Doppler Effect in Astronomy. They searched several libraries from which special illustrations were photographed. The sonic Doppler Effect was illustrated on audio-tape. A friend sounded his car horn continuously and its approach and departure were recorded on tape. The frequency change in sound waves was related to similar changes in electromagnetic waves. Excellent photographs of red shift and blue shift lines of star spectra were copied from books. They arranged an interview with Dr. J. Dumas of the Dow Planetarium. He explained and reemphasized some of their findings. Dr. Dumas also pointed out to them the part which the Doppler Shift plays in explaining some of the basic theories of the universe. These pupils asked to be excused from the formal written essay. Instead they arranged, at my convenience, a comfortable chair beside a slide projector and tape recorder. The presentation took about three-quarters of an hour.

- ideas, ideas, pictures, slides, taped interview and commentary, car horn experiment.

8. The Vanier Arcade

The arcade refers to a series of science exhibits and on-the-spot experiments set up by Avrum Dunsky, a physics teacher, at Vanier CEGEP. The arcade is in the main thoroughfare of the Physics Department. About twenty physics activities are available to all interested passers-by.

Two students visited the CEGEP on two occasions and worked with all the exhibits. In their report, they confined themselves to detailing only three of the exhibits. These are: (1) the Hidden Target, (2) the Puzzle, (3) the Door Bell.

In the Hidden Target a shape is hidden under a black disc which is free to rotate in $90^{\circ}$ turns. A ball is launched at the target from the different positions. The size and the shape of the target can be determined by analyzing the deflections.

The Puzzle has four balls in channels which slope toward the center. The idea is to get the four balls to the outside edge of the channels simultaneously.

The Door Bell involves the energy conversions of a steel ball. A motor-driven elevator raises the ball up a narrow channel located on the left of the exhibit. From the top the ball is released and wends its way through the energy conversion areas as shown in Fig. 7.1.

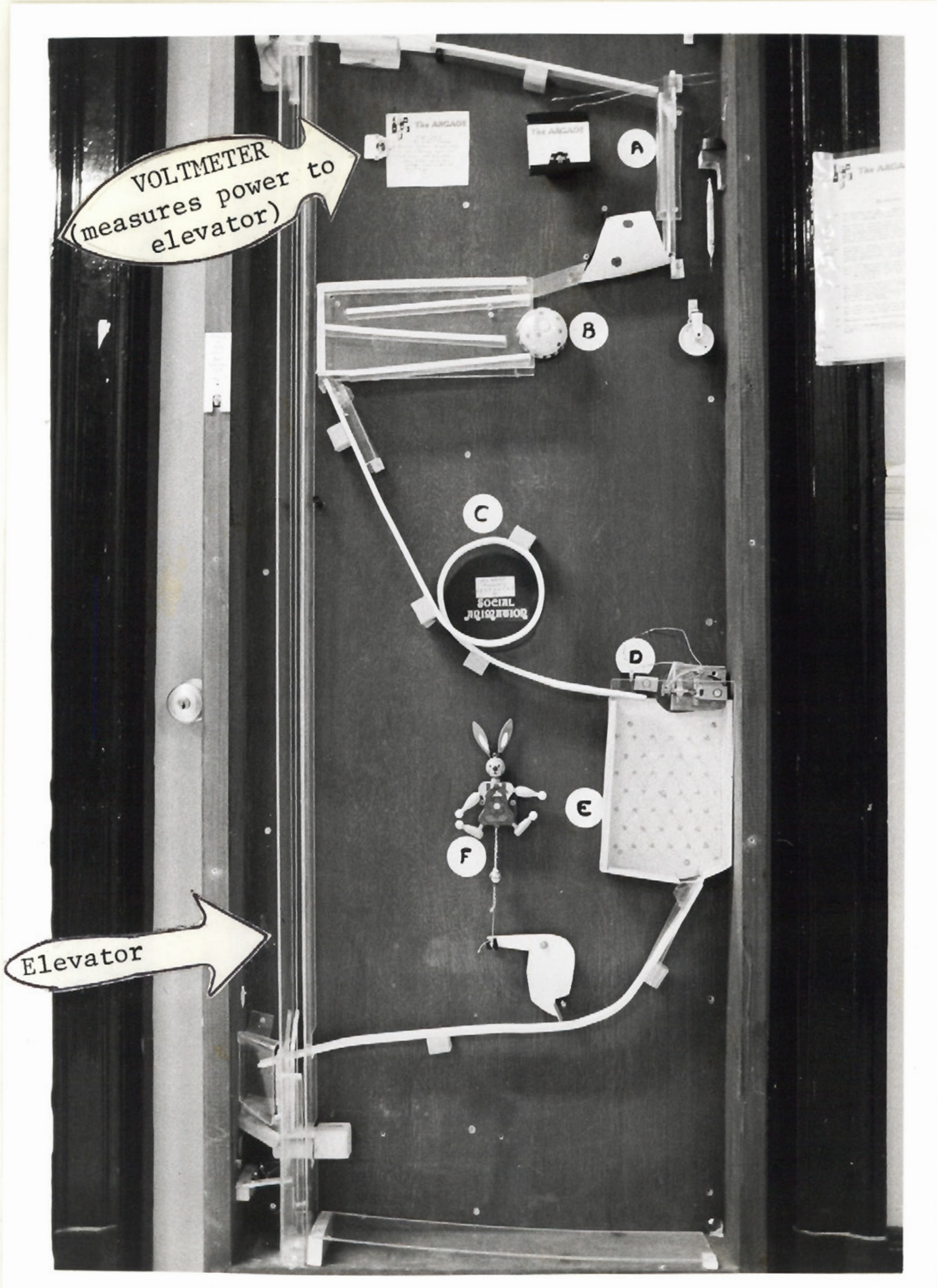


Fig. 7.1 -- The Door Bell (Courtesy of Mr. Avrum Dunsky)

A -- Electromagnetic Induction
- ball pulls magnet through coil
- meter deflects

B -- Bell

C -- Loop the Loop

D -- Piezo-Crystal
- flashes neon bulb

E -- Probability Nail Bed

F -- Jumping Rabbit

During one of their visits the students interviewed Mr. Dunsky. Part of their paper presented the benefits of such science displays. They commented positively upon them as "pedagogical instruments devised to promote interest while increasing knowledge."
- essay, slides, photographs, interview, tour.

9. The Laws of Reflection

Again, this was a second-choice undertaking. Many hours had been spent attempting to study the efficiency of insulation in a house. Time did not allow this student the opportunity to resolve the problem of inconsistent (again) results. However, many precise observations were recorded of heat input (using electric heaters) and heat loss before taking up this less demanding project on reflection.

Some of the ideas experimented with were derived from a visit to the Ontario Science Center in Toronto and the Ottawa Museum of Science and Technology. At the Toronto exhibits, there is a sound display using parabolic reflectors to focus and reflect sound. When speaking from the focal point of a huge parabolic reflector, one can be heard at the focal point of another such reflector about fifty metres away.

Our school lab has two fairly large (35 cm of arc) parabolic reflectors with which this student experimented using sound (a ticking watch), light and heat at the focal point.

The completed report was in modular form. There were objectives, theory, detailed explanations using ray diagrams, suggested experiments, problems and post test.
- modular report, experiments, visit to science museums.

10. The Ballistic Pendulum

The idea of making and experimenting with the ballistic pendulum was presented to the teacher after these two students came across it in their library searching. It was accepted and extreme caution was urged. One October Saturday they proceeded to a property in the Laurentians. They arranged their equipment as shown in Fig. 7.2.

An 8 mm movie was filmed of all proceedings. The students fired a 22 bullet into the block of wood and the wood rose in pendulum fashion. A large graduated piece of wood was placed in a position beside the wood pendulum to be used for measuring the height risen. Five trials were taken by shooting the bullets from five different distances. All distances were indicated on the film including the rise of the pendulum. The boys measured the mass of the block and the bullet. They determined the height which the pendulum rose by reading this measurement from their film. Then they used the laws of conservation of momentum and energy to derive the formula:

$$v = \left(\frac{m + M}{m}\right)\sqrt{2\,g\,h}$$

Here v is the initial velocity of the bullet; m is the mass of the bullet; M is the mass of the block; g is the acceleration due to gravity; and h is the change in height of the block. They calculated the velocity v for every trial and took an average. Their results were very close to that specified by the manufacturer.

- essay, experiment performed in the Laurentians by a ballistic pendulum of their own making, 8 mm film.

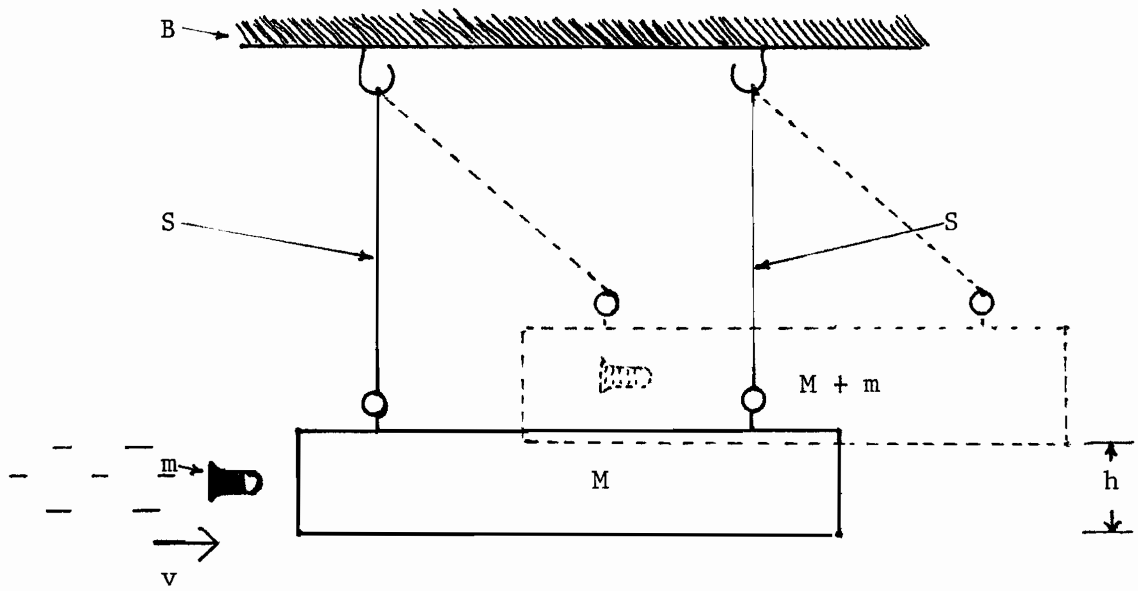


Fig. 7.2 -- The Ballistic Pendulum

B -- Branch of a tree

S -- Supporting strings

M -- Block of wood

m -- Bullet

v -- Velocity of the bullet

h -- Change in height of the block

11. <u>Calculating the Circumference of the Earth</u>

This project was based on an exercise performed over two thousand years ago by Eratosthenes, a Greek mathematician. The students assured me that physics theory would be included in this highly mathematical project. Their sketch, Fig. 7.3, reproduced below will enable the reader to visualize the method used; it will also serve as an aid to show the development of the equations.

On Noverber 7, 1976 (a sunny day with some clouds) the two experimenters placed a plumb line (CB) outside in the sun, and observed its shadow length (AB). From this setup they were able to determine the value of $\theta'$, the angle formed by CA and CB. CA is the line from the top of the plumb line to the end of the shadow.

They reasoned that "since all rays of the sun arrive parallel to each other, then AC is parallel to OD. Therefore angle $\theta$ is equal to angle $\theta'$ (OC is a transversal) and

$$\frac{\theta^{o}}{360^{o}} = \frac{BD}{\text{Circumference of the earth (E)}}$$

or

$$\frac{\theta'^{o}}{360^{o}} = \frac{BD}{E} \qquad (1)$$

where BD was the distance from Lasalle to the location due south where the sun was directly overhead, i.e., where a plumb line would cast no shadow." This distance was arrived at by finding the parallel of latitude where the sun's rays would strike vertically on that particular day. Then, from a map, the north to south distance from Lasalle to that parallel was determined. This distance (BD on the

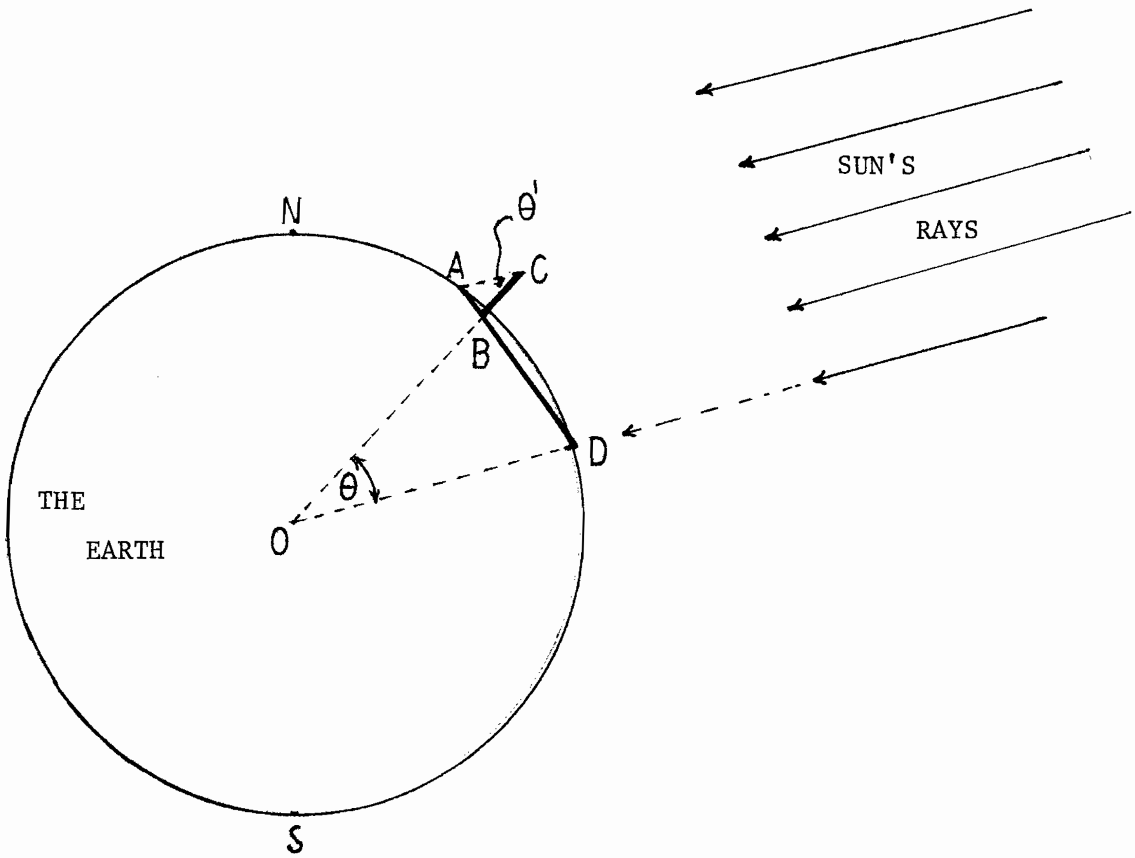


Fig. 7.3 -- Calculating the Circumference of the Earth

POSITIONS

B -- Montreal — Lasalle

D -- Location where a plumb line would cast no shadow at solar noon

O -- Centre of the earth

DISTANCES

CB -- Length of the plumb line

AB -- Length of the shadow cast by the plumb line

OB, OD -- Radii of the earth

BD -- Distance due south of Lasalle where no shadow was cast at solar noon sketch) was found to be 6 369 569 metres. From equation (1) above "the circumference of the earth is 39 025 km."

This circumference was then used to find the radius of the earth, which in turn was used to calculate the speed of rotation of the parallel of latitude on which lay the city of Lasalle. Fig. 7.4 was employed to show the geometry used in establishing the required equations.

In Fig. 7.4 angle $\phi$ = angle $\phi'$

and $P = R \cos \phi' = R \cos \phi$

then $v = \dfrac{2\pi P}{\Delta t} = \dfrac{2\pi R \cos \phi}{\Delta t}$

where $\phi$ is the angle forming the parallel of latitude through Lasalle. This $45.3^{\circ}$ reading was obtained from the "Dorval weather office". $\phi'$ is the angle bounded by the earth's radius to Lasalle and the radius of the parallel of latitude through Lasalle. $2\pi P$ is the circumference of the parallel of latitude through Lasalle. The $\Delta t$ is the number of seconds in one day. Finally v is the speed of rotation of Lasalle.

The value of the speed of rotation of Lasalle was calculated to be 317,87 m/s. The kinetic energy (derived from the earth's rotational motion) of a mass of m kg located in Lasalle was found to be 50 521m joules.

- essay, experimentation outdoors, weather bureau consultation.

12. Tides

This student provided an essay with many sketches and diagrams explaining tides, and how they might be used as an energy source. The idea was extracted from a planetarium show which had a section

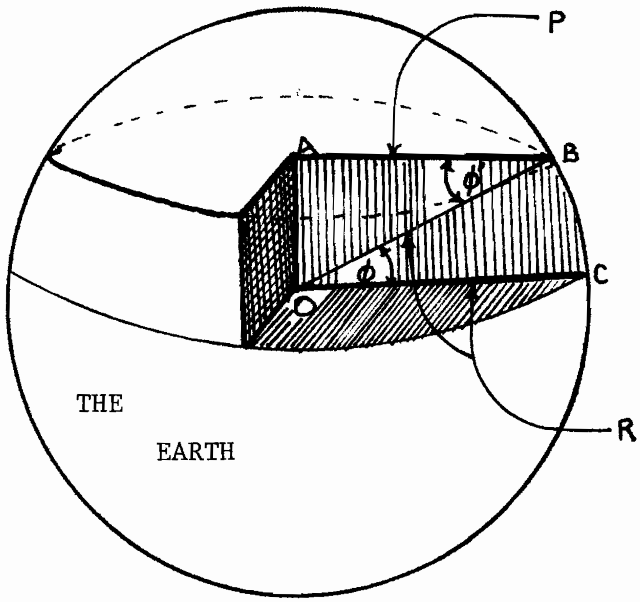


Fig. 7.4--Calculating the
Velocity Due to Rotational Motion

<u>POSITIONS</u>

B -- Location of Lasalle on the earth

O -- The centre of the earth

A -- Centre of the circle formed by the parrallel of latitude which goes through Lasalle

<u>DISTANCES</u>

OB
OC -- Radii (R) of the earth

AB -- Radius (P) of the circle formrd by the parallel of latitude which goes through Lasalle on "celestial influence." Most of his data and charts were loaned by an earth science specialist teaching at "l' Université du Québec." - essay, visit to the Dow Planetarium, interview.

13. Remote Sensing

The electromagnetic spectrum was the object of interest to these four students. It was their hope that the production and use of X-rays would form the bulk of their paper; the rest of the spectrum would be treated less intensively. They foresaw no difficulty in obtaining a tour and interview in the X-ray department of some hospital. Nothing could be scheduled. They appealed for help.

I asked if they would like to arrange a trip to Ottawa on their own to interview a research scientist and to observe his work. Dr. Vincent Thomson is one of a group of Canadian scientists researching the use of certain properties of the electromagnetic spectrum. The students were delighted by this idea.

Dr. Thomson, when contacted, accepted the proposal; he even forwarded some advance reading material to help the group in its preparation.

They left by train one Saturday morning armed to the teeth with questions, tape recorder, cameras, pencils, paper, etc. Dr. Thomson was very considerate in meeting them at the station. He informed me later that: "I knew they meant business because after the car doors slammed shut, during the course of introductions, I heard the tape recorder flicked on."

They proceeded to the research data center where the work is analyzed and evaluated. Pictures are developed here and the


Fig. 7.5 -- Doctor Vincent Thomson at the Centre for Remote Sensing

computers process the data. The crew were very amused to see that a doctor of physics could forget his key and had to climb a fence and crawl in through an unlocked window. They could not resist taking a picture of the event while Dr. Thomson was not looking.

At the data centre, it was explained that a number of scientists were involved in research using the electromagnetic spectrum. Specifically, it was termed "remote sensing" - a process of acquiring data by directing some part of the spectrum toward a selected area and studying the reflection. This is somewhat analogous to the traffic-radar system, when a reflected wave is translated instantaneously into a velocity. The "sensing" was also done by exposing film toward areas which were themselves delivering some radiation. The specific radiations demonstrated were radar, microwave, infrared, ultra violet and laser. A number of the scientists were operating electromagnetic wave projectors from airplanes and taking pictures. At that time Dr. Thomson was researching laser beams to determine the depths of certain lakes. Pictures were taken and notes recorded and questions answered. To make the application more concrete still, Dr. Thomson drove them to the airport. They looked over the plane which Dr. Thomson was presently using. Again the experimental gear was explained. The result was two papers on the electromagnetic spectrum as used in remote sensing. The optical spectrum was used to introduce the topic in both groups. One group, however, chose the complete range of spectra used at the research centre. The other concentrated more on the laser, its theory and application particularly as used by Dr. Thomson.

- essay, tape, pictures, interview, tour.

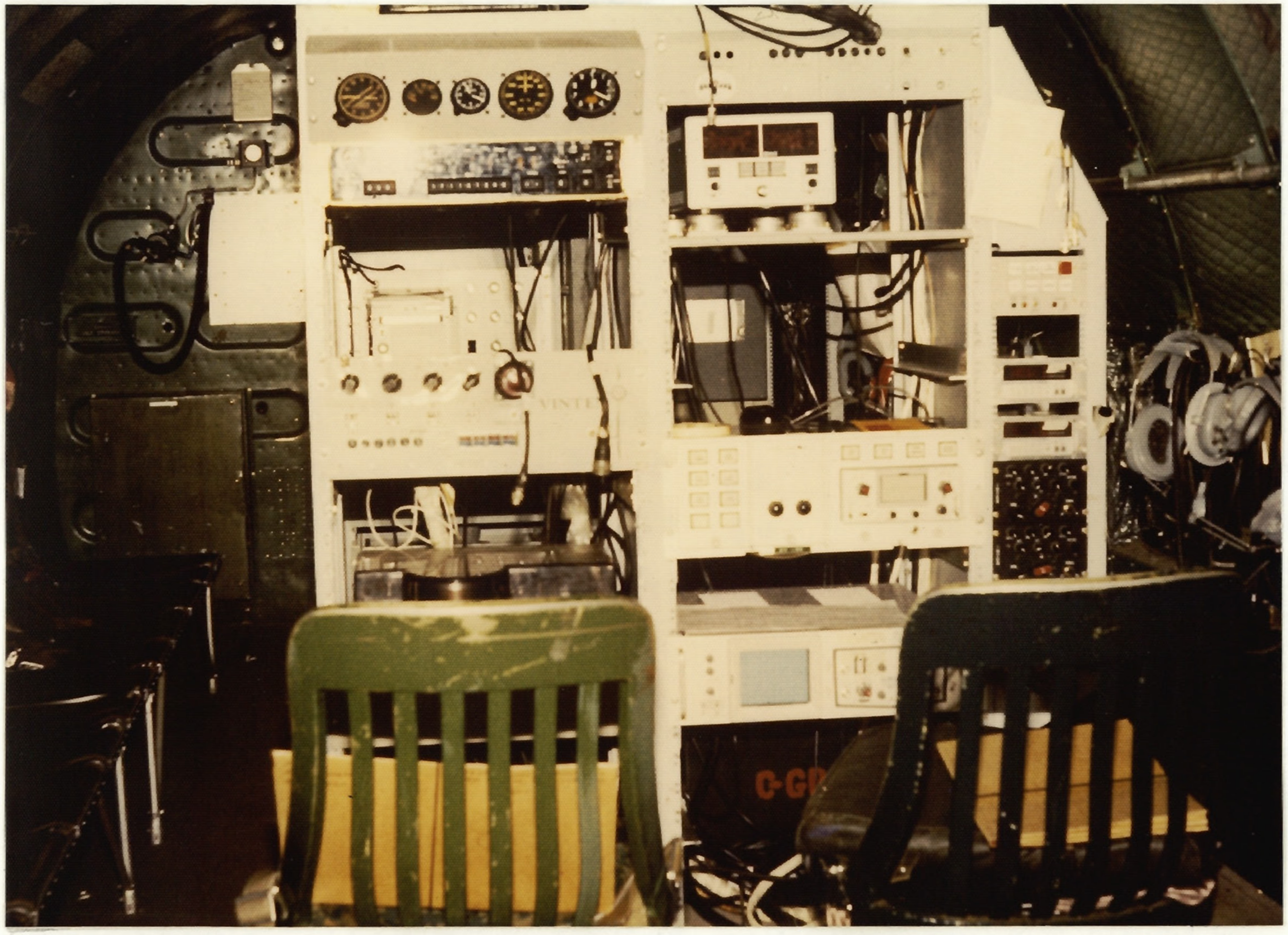

Fig. 7.6 -- Inside the Airplane Used by Doctor Thomson for Remote Sensing

14. No project

Two students, although they showed no particular animosity toward this assignment,did not do it. In fact, it was difficult getting most assignments or laboratory write-ups from them all year.

In a nutshell, these are the reports from the "individual field trips" submitted in late November. With a degree of restraint I have attempted to present them objectively. But the students had me participate in so many of them on an advisory basis that subjectivity may have emerged.

## THE MAXIS - TITLES

The above activity was to be a preparation for the more typical field trip to be conducted in a large group in March. The locales of these were to be:

1. The Beauharnois Hydro Power Plant in Beauharnois
2. The McGill Synchrocyclotron at McGill University in Montreal

## THE MAXIS - RÉSUMÉS

1. The Beauharnois Hydro Power Plant

In late February all students matching the normal PSI pace had covered the basic theory of induced EMF. Demonstrations on induced currents, Lenz's Law and the AC - DC generator were conducted. An excellent film "The Fundamentals of AC - DC Generation" [3] was viewed. The students by this time were ripe to see the theory in action. Arrangements were made with the administration, a bus was rented and on the overcast afternoon of March 22, the students left for Beauharnois about 40 kilometres south-west of Montreal.

[3] This film was produced by General Electric.

On our arrival the guide divided us into two groups and the tour began. It consisted of the following program:

1. A film was shown outlining the geography and history of the Beauharnois region. It specified what made the area an ideal power outlet, and described the three stages of construction undertaken to utilize the facilities to the maximum. A little of the industrial use and the economics of the hyrdo power was also mentioned.

2. This was followed by another film on other Hydro developments. In fact, throughout the tour we were reminded of other Hydro Quebec spectaculars from the Manic development to the huge James Bay project.

3. Then came the tour through the power plant. The tour is more geared to public relations than it is to demonstrating to high school physics students how an induced current is produced. Hence, impressive sights and wowie statistics are the order of the day. For example, first seen is the control room. The students found this large and impressive but it did little for their physics. Nevertheless, the relevancy of other scenes could readily be appreciated by the prepared student - the rushing water, the huge dam holding back a tremendous reserve, the top-to-bottom crack in the wall where the service building is attached to the dam.[4] The shafts connecting the

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[4] Water pressure against the dam had caused this crack; hydro engineers had literally sawed the building from roof to foundation to separate the dam proper from the other facilities. Then they filled the saw cut with a rubber caulking. Now after a year (1977) the dam shows further displacement - about the width of the saw cut.

A B

Fig. 7.7 -- View from the Top of the Beauharnois Dam
A) The Water Reservoir Build Up from Lake St. Francis, marking the end of the Beauharnois Canal (25 kilometers)
B) The Churning Water Resulting from the 25 meter Drop through the Dam into Lake St. Louis

turbines to the generators could be seen turning. The generator room contains 36 massive generators, moving with deafening sound, while throwing off almost unbearable heat.[5] To all this, the students could relate. They also appreciated that this generating process goes on in all weather. When we went into the building it was mild but overcast; when we walked out onto the roof overlooking the dam, semi-blizzard conditions prevailed. The method of transporting the electricity was spoken of while pointing out the huge transformers, 60Hz governors were seen. Dramatic statistics were hurled at us - power capacity, industry served, costs, quantity of water to run the turbines - all in all, it was a fine learning experience.

Most of the projects submitted followed a pattern similar to that of the guided tour. A description (essay or tape) was given of the Beauharnois project and tour accompanied by basic theory of induced EMF, AC - DC generation, and transmission by transformer to the consumer. Slides, pictures and diagrams complemented the papers. Many related topics were included such as: other Hydro-Quebec projects (both hydro and nuclear), the economics of hydro power, industrial use, relation to geography, and the history of electrical development. A number discussed turbines - the types, uses and efficiencies of each. Different types of alternators were also explained. A fairly exhaustive treatment of hydro power and aligned topics was handled in varying degrees of sophistication.

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[5] This is the only source of heat for the building.

2. <u>The McGill Synchrocyclotron</u>

After this topic was mentioned at the beginning of the year, seven students made a definite decision toward doing the synchrocyclotron project. They considered it more of a challenge than the Beauharnois project.

In preparation a film on the topic of the synchrotron was shown.[6] Although the synchrocyclotron is different, the basic principles are the same. The students had already studied the concepts of magnetic and electric fields and had experimented with magnetic and electric forces. They also had seen the effect of a magnetic field on a beam of charged particles in a Crookes' fluorescent tube. The PSSC experiment to determine the mass of an electron was performed (Haber-Schaim, 1975:86).

Two of the students had made a survey of the library reading available on the subject and this was at the disposal of those interested. It was at this time in late February that the aid of Dr. Robert Moore of the McGill University Foster Radiation Laboratory was enlisted. We asked if a graduate student could be made available to brief the students and then conduct a tour through the synchrocyclotron. Dr. Moore was very receptive to the idea and suggested Kenneth Oxorn, a doctoral candidate in nuclear physics. Mr. Oxorn was contacted and a briefing session was arranged for March 28 at LCCHS after school. He outlined the history of nuclear physics. He then spoke of some of his own research on spectra from nuclear particles with reference to wave-particle duality. The

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[6]"The Synchrotron" is a film produced for Harvard Project Physics. It shows a conducted tour through the Cambridge Electron Accelerator.

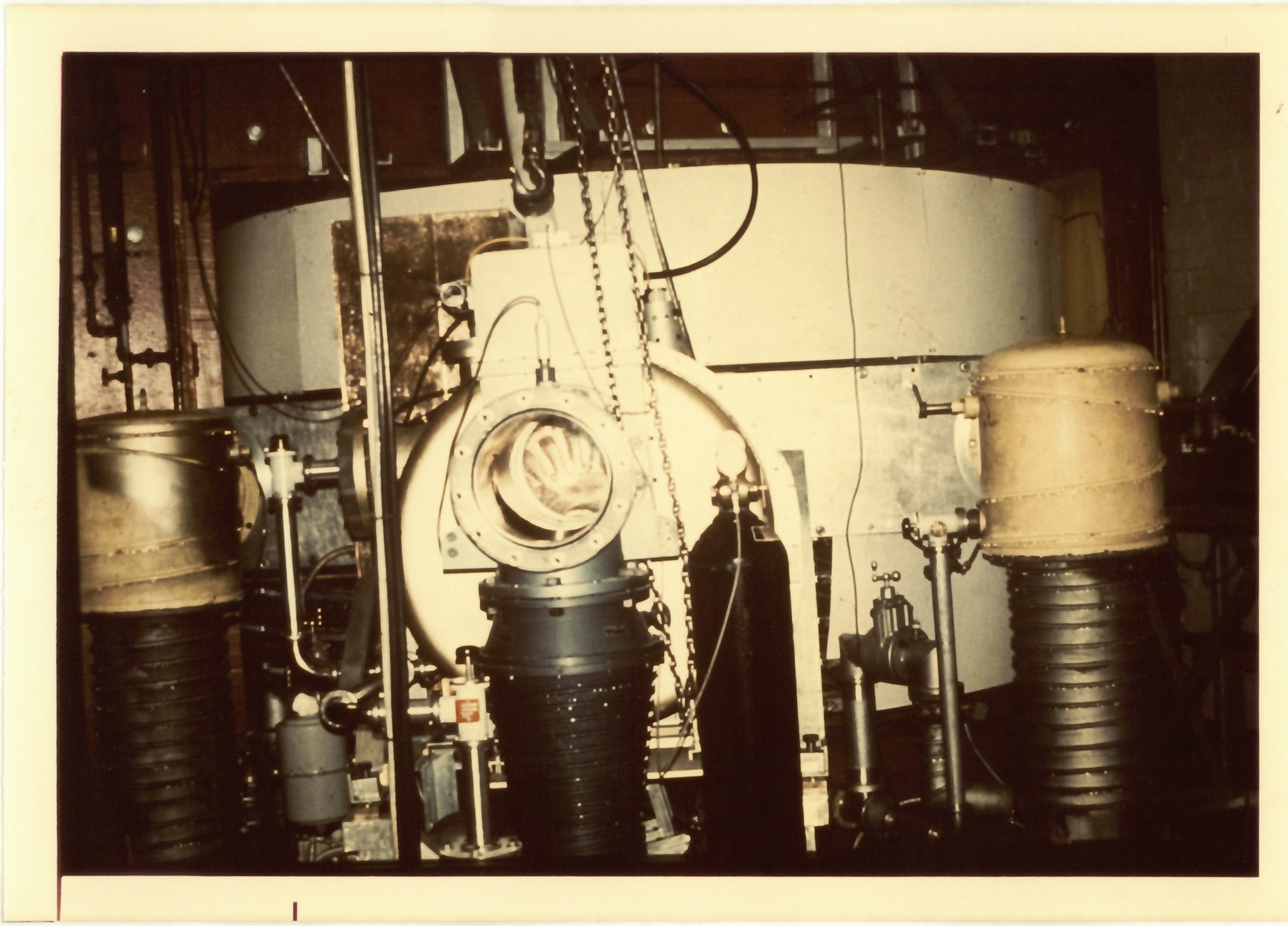

Fig. 7.8 -- The McGill Synchrocyclotron with the Oscillator in the Foreground (circular object in the centre of the picture)

students could relate to this through their study of line spectra and through their study of diffraction patterns produced by both electromagnetic waves and electrons (Haber-Schaim, 1976:604,614). The last half of Mr. Oxorn's talk involved mention of particle accelerators and the principles involved therein. Incorporated in this was something of the history, the structure, and the uses of the McGill synchrocyclotron. All the while, he was handling questions knowledgeably and clearly. Everyone profited from this introduction.

Then, on Wednesday, March 30, a pedagogical day (student holiday), seven students and two teachers visited the McGill synchrocyclotron. Mr. Oxorn conducted the tour; ample time for questions ensued; many pictures were taken and notes were copiously taken down.

A brief summary of what was seen is herein formed by putting a concise caption to consecutive snapshots included in the assignment of one of the groups (see Appendix B). These show: (1) the cyclotron proper (magnets, dees, and the three probes), (2) the oscillator, (3) power supply for the oscillator, (4) focussing magnets for external beam, (5) bending magnets for the beam, (6) one target area for the beam, (7) mass spectrograph, (8) computer with television screen displaying data and magnetic tapes storing data, (9-10) graphical data re the "number of particles of particular masses" displayed on a screen, (11-12-13-14) central control panel indicating current (beam intensity), vacuum control system and shut down controls, (15) super cooling tanks, (16) data collecting apparatus, (17-18) short half-life target.

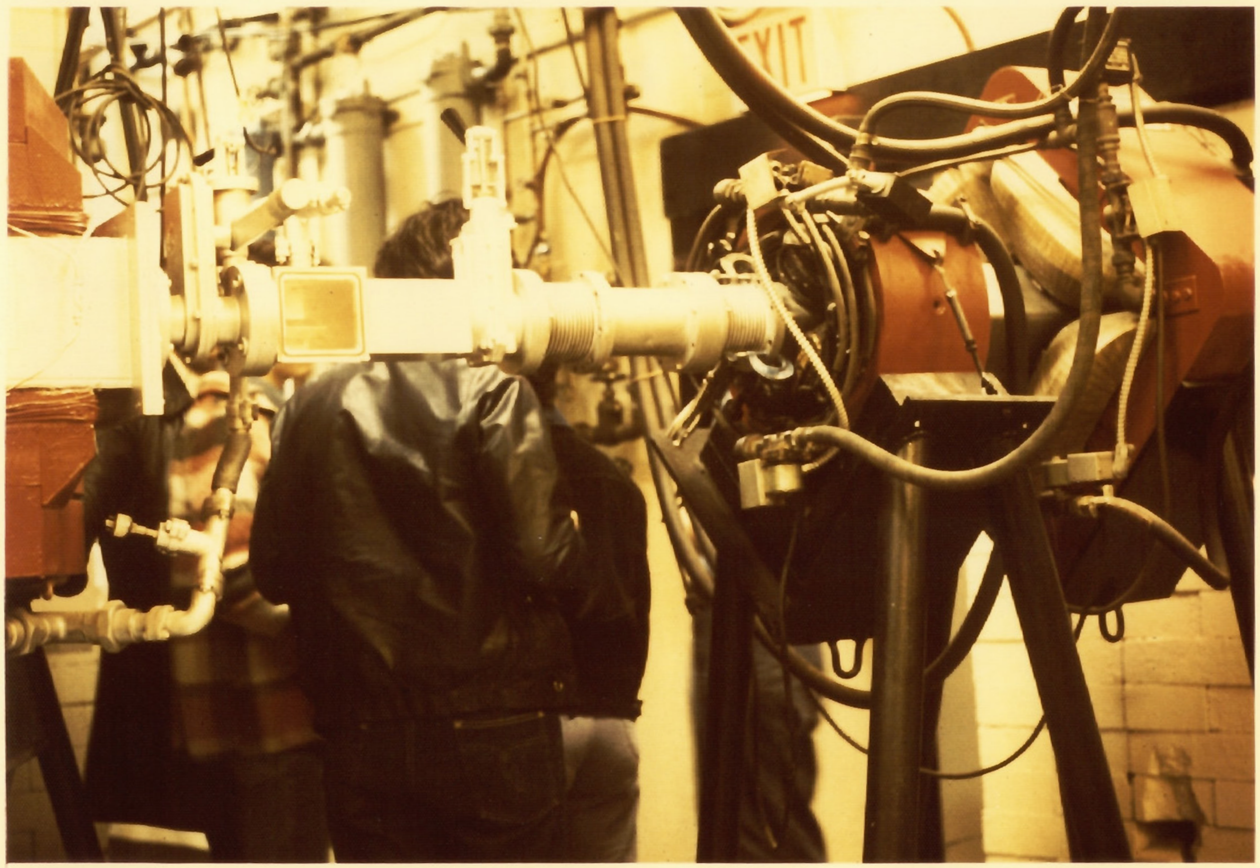

Fig. 7.9 -- A Huge Electromagnet Used to Bend the Accelerated Particles Toward an External Target. LCCHS students Are Seen in the Background

The format of the material handed in by these seven students was roughly similar. This included essays describing: (1) the tour, (2) instruction given by the guide who came to the school, (3) physics principles and apparatus as shown in the operation of the McGill synchrocyclotron (magnetic fields, electric fields, beam intensity, half-life, mass spectrograph, oscillator, and relativistic phenomena), (4) related topics such as other famous accelerators and their operation. The essays were often accompanied by slides, tapes, photographs, and illustrations, etc.

This culminates a description of the "field trips" undertaken by the students of LCCHS in Physics 552 for the year 1976-77.

# CHAPTER 8

## EVALUATION

No attempt has been made in this paper to present a formula guaranteed to dissipate all problems in high school physics teaching. Rather, it is an effort to: (1) underscore some shortcomings present in a specific physics program, (2) specify the obligation of any teacher to aid in effecting the intellectual development of the student, (3) describe an activity which was performed to treat the shortcomings and help answer the obligation. The question must now be posed: Was the exercise performed by these physics students effective in meeting the objectives proposed? That is:

1. Did it satisfy the criteria for development of scientifically literate and personally concerned individuals?

2. Was the exercise suited to enhancing the mental development of the students?

3. Did the students really learn physics and did it become more relevant?

4. Did it foster creativity and individuality?

It must be appreciated that the author cannot pronounce definitively on the achievement of the proposed objectives. He must necessarily depend on passing a judgment based on direct observation of performance and appraisal of submitted reports. Subjective though it may be, it is the most relied-upon method used by teachers in evaluation of their students. Bear this in mind, as each of the four questions just posed is briefly dealt with in turn.

Since all of the students did a maxi project on either Beauharnois (19 students) or the synchrocyclotron (7 students), it is understandable that more references should appear from these two topics.

1. Scientific literacy

Recall from Chapter 2 that the development of scientific literacy was the essence of the NSTA's major goal of science education. Consider the Beauharnois Hydro project in the light of this goal. The proper understanding of the Beauharnois hydro power station demanded reviewing, rethinking and organizing the basic laws of force, pressure, energy transformations, and electromagnetic induction. Apparent is the technological application of physics theory for the benefit of people both in industry and in homes. The completed papers with their written descriptions, explanations, diagrams, photographs, graphs, tapes, etc., showed an obvious appreciation of the "use", "recognition" and "understanding" outlined in the NSTA paper.

Here is one student's view:

> At the main entrance of the Beauharnois plant, at 2:30 P.M., I saw constantly changing numbers electronically flashing on a colorful backdrop. These gave the immediate kilowatt consumption from the plant. It was fluctuating between 1 197 000 kW and 1 332 000 kW. At the end of the tour a quite similar range of numbers flashed. But now I felt a firmer understanding of the energy transfer process. An inclined penstock sent 240 000 cu. ft. of water per sec. down an 85 foot drop. Potential energy was changing to kinetic. The turbines picked up the K.E. and caused the magnets in the generators to revolve past conductors. Electrons in the conductors picked up this energy from the magnetic field. Here was the potential electrical energy. The electronic

> readout was the end product verifying that the potential energy had turned kinetic and was doing its work.

It was also interesting to read an observation of two students who reported on the cyclotron. They were alert enough to observe that the "scientific community" was equally an important part of our society. They realized that here it had a relevance that could easily be lost to most.

> The visit [to the cyclotron] was very enlightening because it allowed us to see many of the concepts learned in our PSSC course being applied for research. It was very interesting to observe present theory applied, even if it was merely for the benefit of future theory.

According to NSTA (1971:12) again:

> Scientific literacy must contain a balance among concepts and conceptual schemes, science processes including rational thought processes, and special aspects of science to enable scientifically literate persons to use the achievements of science and technology for the benefit of mankind.

The implementation of the field trip provided an impetus toward achieving such a balance. Induced EMF was no longer an effect produced in a lab by moving a conductor in a magnetic field. It was the effect produced by the force of water on huge magnets which caused them to rotate past miles of conductors. This effect produces electricity which is sold to industry and households as useful energy - the balance between pure abstract concept and its concrete manifestation and application.

The groups dealing with remote sensing came to realize that the electromagnetic spectrum was no longer just a physics concept but a usable reality. Included in their presentation were reproductions of some thermographs taken by infra-red radiation. They showed the use of this radiation in: (1) detecting cancer, (2) analyzing effluent pouring into rivers, (3) discovering fertile terrain.

The students who used and explained the Doppler Effect demonstrated a solid comprehension of how this concept was related to the electromagnetic spectrum. This insight permitted them to appreciate how the Doppler Effect and the electromagnetic spectrum enabled astronomers to theorize on the very birth and death of the universe.

The scientifically literate person is one who is well-rounded and integrated with the other disciplines such as mathematics, economics and the social sciences.

The material submitted gave proof indeed of research in areas other than physics. The geography of Beauharnois and vicinity, gleaned from the tour, movie, guide, and pamphlets, was presented in many papers. Some of the economics surrounding Hydro Quebec surfaced also. Students noted that Quebec was to take full fiscal advantage of this resource in 1977. Until then, forty percent of Beauharnois power was sold to Ontario who used part and sold the balance to the United States at generous profit.

In a project on the electromagnetic spectrum it was noted how physicists became geographers and environmentalists. Students reported how radiation was used to determine the depths of lakes and rivers and to show the contours of mountain country. Microwaves were used to take pictures of the North Pole. Infra-red rays through thermographs were used to monitor the effluent of the Pickering nuclear plant to ensure safe radiation levels.

Other issues were not lost to the observant and concerned student. Hydro Quebec's James Bay project was portrayed as "an inflationary spark plug". Enumerated were certain dramatic statistics, viz., the cost of a single truck being one quarter of a million dollars - the tires alone going for \$8 000 each; salaries ranging from an average of \$900 up to \$1 600 per week. One socially concerned student deplored the

> ... depressingly high cost of this project - up to thirty billion dollars so far. However, human suffering is also significant. Not only has labor strife been rampant but often the basic rights of native people have been ignored.

A legitimate pride in province and country was markedly demonstrated. It was this which prompted one student to write of the Hydro Quebec Research Institute:

> This is the most complete research institute of its kind in North America. Its highly qualified staff from all over the world has led the way in research and is an asset for all mankind.

The McGill synchrocyclotron was hailed as "the first of its kind in Canada". And, on tape, another spoke of "the McGill Foster Radiation Lab [which] houses one of the most expensive and elaborate apparatus of modern times."

These foregoing are just brief excerpts but they demonstrate participation in an activity well suited to developing those qualities attributed to scientific literacy.

2. Mental development

In the plan to supplement the curriculum we wished to doctor a two-fold deficiency. First, it should be able to bridge the concrete-formal gap of which Renner speaks. Second, it should be flexible enough to stimulate and promote the mental development of all students.

To accomplish the first, it would be necessary to become engaged with concrete objects, events or situations. The second would be achieved if the student were forced to think about abstractions, analyze variables, or make conclusions from hypotheses. There was no problem forseeing that the students would be fully involved with concrete objects, events, personalities, etc. What I anticipated was more than realized in the completed product. Consider that from a single project, for example the one on radioactivity: they worked with dry ice; they made a cloud chamber; they observed the tracks and took pictures of them; they utilized geiger counters; they interviewed authorities; and they employed tape recorders. In the many other projects accomplished, this "concrete interaction" was multiplied many times over. Students used blow torches, drove cars, measured heights, fired a rifle, took movies, developed film, experimented with air pucks, used a stroboscope, made models, visited museums, pedalled a generator bicycle, etc., etc., etc.

"Concrete interaction" was not only with objects, apparatus, and places. Most projects portrayed "active interaction" with people whether in interviews, guided tours or just in information sessions with teachers, librarians, or friends.

There was abundant opportunity, for those who could, to progress further into formal thinking. Consider the groups who worked on the synchrocyclotron. Their product reflects the constant mental calisthenics involved in flipping from one formal concept and its mathematical relationship to another. They explained: (1) the purpose of different probe lengths, (2) the electric field operating in the dees, (3) the magnetic force of the focussing and bending magnets, (4) the synchronizing effect necessary to adjust to the relativistic mass.

Likewise, finding the circumference of the earth, students formulated hypotheses, experimented, and made conclusions based on their hypotheses.

In some instances, some students delved into concepts which their mental structures could not then fully handle. Yet this hardly retarded their further development. For one thing, there was no predetermined answer they were obliged to arrive at. And if, on the other hand, the student used genuine inquiry to think out a problem and could not cope with the complexities involved, hopefully he was left in a state of healthy disturbance. This would leave him receptive to further events and experiences which could help him resolve the problem in the future.

> Inquiry does not always result in a solution to the problem. But inquiry, seldom if ever, proves fruitless in the sense that one would have been better off had one not inquired. In fact, the really lasting educational benefit of the inquiry is the search itself, since it is during the search that the thinking ability of the investigator is being developed (Renner, 1972:123).

Hopefully, the above are convincing indications of the validity of these projects as instruments to aid the development of logical thinking.

To say that the projects provided opportunity for experience, social transmission, and maturation would be an understatement. Just to run down the list of topics would be to confront all three factors.

But where in these experiences would equilibration take place? This should be considered, since the equilibration process is a basic tenet of Piaget's theory on mental development. Renner and Lawson (1973:168) explain this process in physics students using the relationship V = IR.

> Our first contact with V = IR was a rather traumatic experience. We vaguely understood that it involved conservation of energy, but they concentrated upon memorizing what the symbols were and how to juggle the formula - an advanced state of disequilibrium. When meter readings were substituted for the very abstract terms of potential difference and current the symbols seemed to have meaning, and after a good deal of thinking, equilibrium was achieved.

In many of the projects the students went through the process outlined in the above quote. The pupils' first contact with their many invented relationships, such as,

$$F = ma, \qquad F = \frac{mv^2}{R}, \qquad \mathcal{E} = -\frac{\Delta\phi_B}{\Delta t},$$

caused disequilibrium, perhaps "traumatic" because the concepts were difficult and only partially assimilated. Some "concentrated upon memorizing what the symbols were and how to juggle the formula." Analysis of laboratory data and thinking about teacher directives provided partial restoration. But further equilibration ensued when the relationship was viewed in surroundings more natural to the concept illustrated. The cyclotron was not built to illustrate

$$F = \frac{mv^2}{R} = QvB.$$

These relationships were merely a part of understanding the operation of the cyclotron. Similarly the formula equation

$$E_p = mgh = \tfrac{1}{2}mv^2 = QV = VI\,\Delta t$$

was just a part of understanding the operation of the Beauharnois power plant. Piaget, who said: "teaching means creating situations where structures can be discovered" would, I feel, have been in accord with these "created situations" (Duckworth, 1964:174).

3. Has the student learnt any physics?

Evaluation, thus far, has dealt with the academic and theoretical goals and objectives outlined in Chapters 2 and 3. Hopefully, the reader has become aware that much physics was assimilated in the process of completing the projects. This author still maintains that the down-to-earth duty of the physics teacher is to ensure that the students learn physics. He would have considered the project without merit in a physics program if such learning had not ensued. Many opportunities to learn physics have already been documented herein. Nevertheless, one area that deserves special mention is the topic of efficiency. Already we have alluded to the constant references by physics texts to ideal set-ups as a negative factor in making physics relevant. But, during some of the trips it was impossible to ignore such factors as friction and heat loss. While on the tour of Beauharnois the "waste" heat from the generators was almost unbearable and the "noise" was practically painful. Not one group missed this obvious energy loss. One student who was curious to find the efficiency of the system presented, the next day, the following calculations. He started with an end product (taken from the hand-out literature) of $1{,}6 \times 10^9$ watts (maximum) and a water head of 25 metres. He reasoned that:

$$\text{POWER} = \frac{\text{FORCE X DISTANCE}}{\text{TIME}}$$

$$1,6 \times 10^9 \text{ watts} = \frac{F\,(N) \times 25(m)}{1(s)}$$

$$F = 6,4 \times 10^7 N = 6,5 \times 10^6 \text{ kg}$$

$$6,5 \times 10^6 \text{ kg} = 14,3 \times 10^6 \text{ lb. or } 229\ 000 \text{ ft}^3.$$

This, he informed us, was 11 000 $ft^3$ / sec less than its 240 000 $ft^3$ / sec rating, or about a five percent loss. In actual fact the loss is close to fifteen percent.

The group working on conservation of energy were quite upset about their experimental results until they "put a drop of oil on the turning parts" of their self-made models.

It would be presumptuous to point out definite concepts that the student had surely learned. However, during a brief re-reading of the project resumés, it would not tax the imagination of the experienced teacher to conclude that a great deal of physics was confronted in very relevant situations.

4. Student need for individuality and creativity

It would be well to remind ourselves that creativity is the essence of the learning process in Piaget's theory of cognitive development. Each new structure formed is a creation which, in turn, forms the seed for a newer creation. Because the manner in which these creations are effected is unique to each person, they are an essential mark of individuality. This aspect of creativity and individuality has been treated elsewhere.

The following pages will concentrate on incidents and aspects which illustrate some of the more discernable characteristics of creative individuals. Some of these traits are: (1) curiosity - "probably one of the easiest signs by which a science teacher can discover creative individuals"(Sund, 1973:350), (2) resourcefulness, (3) preference for difficult tasks, (4) use of innovative techniques[1], (5) drive and assiduity in pursuing a task, (6) reads extensively.

The variety found in the list of topics for the minis is in itself an obvious indication of individuality and creativity. Then, too, although the backbone of most final products was an essay, the complementary material was refreshingly varied. The manner in which substantial audio-visual material was employed was quite exceptional. Altogether, thirteen audio tapes were presented. These tapes included: (1) introductory or background music, (2) interviews (actual or simulated), (3) comment to run parallel to the visual presentations, (4) actual demonstrations (as with the car horn in the Doppler Effect). As well, one group recorded their commentary on the right channel of a stereo tape and a pulse on the left channel. When the tape recorder was hooked to a slide projector by a synchronizer, the taped pulse triggered the slide machine to advance automatically. Considerable time was obviously needed for such imaginative techniques.

The camera also played an important role for many. Seventeen groups handed in slides or photographs they took themselves. Some even developed their own film. One group, not satisfied with merely learning how to use a SLR 35 mm camera, became increasingly concerned about the composition and quality of their pictures. Unsatisfied with the pictures taken during the class tour of Beauharnois, they returned on a Saturday to get better results.

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[1] These innovations can be new to the individual without being new to mankind (Sund, 1973:349).

Another group produced an 8 mm silent film which was technically quite poor but in terms of content was excellent. It showed succinctly how the project on the ballistic pendulum was performed. Each trial (firing of the rifle) was introduced by the partner who flashed a card indicating the number of the trial and the distance to the target. The height increase of the pendulum after the bullet hit was taken from a measuring device placed near the pendulum.

In the circumference-of-the-earth experiment, the students waited many days for good weather, but had to settle for a sunny day with cloudy periods. At the critical time, twelve noon, there was no sun for shadow measurements. At 12:58 P.M. the sun did appear and they measured the length of the shadow of a plumb line. They then calculated the value of the angle through which Montreal had travelled from the noon position, when shadows would be cast in a due north direction. Next, a right-angled triangle was set up with the shadow length scaled down to form the hypotenuse. They projected the shadow length back onto the true N - S line. Although there were a few erroneous assumptions along the way, resourcefulness was demonstrated in their improvisations.

To conclude these references to individuality and creativity, let us recall the car-horn experiment which was used to illustrate the Doppler Effect. A clever feature was that they reproduced very closely the "musical" notes of the horn on a quitar. They specified quantitatively three frequencies: (1) that of the oncoming car at a distance, (2) that of the horn while passing the recorder, (3) that of the ongoing car at a distance. The apparent frequency change caused by the Doppler Effect was quite obvious.

The field trips provided the students with a learning environment conducive to developing their individual creative potential. Many of the pupils responded well to these opportunities.

In this section on evaluation, there are several other aspects which should not be overlooked because they reinforce the value of the assignment as an overall educational tool.

Social Skills

Most students had good opportunity to increase their social skills. Frequently the field trip necessitated preliminary contact by phone or mail. Such communication was often part of a follow-up exercise as well. Precise and proper use of the English language was a must in making appointments and in forwarding thank-you notes.

It appears that the students conducted themselves rather well and good rapport was established with the resource persons. Some of these persons showed a more-than-passing interest; they wanted the student to do well. Feed-back on how the project was received by the teacher was requested in a few instances. Dr. Terroux of McGill University's Rutherford Museum was kind enough to express in a letter to the boys who visited him that "since my retirement I have greatly missed this contact, and so I need hardly say that the opportunity to meet such a keen and intelligent group as yours was for me a great pleasure."

The contacts already mentioned became especially valuable to the students in another way. The meetings and association with staff from post-secondary institutions contributed to easing the feelings of uncertainty experienced by many high school students about to enter CEGEP or College.

## Library

The use of the library is another aspect worthy of particular attention. A survey of library cards revealed this information: for the year 1976-77, the year of the projects, the twenty-six PSSC students withdrew forty-six books from the physics section, whereas the twenty-six PSSC students of the previous year's class made only seven withdrawals. Hence, it appears that the projects definitely stimulated reading in this area.

## Conclusion

An evaluation is first and foremost a judgment on the effectiveness of what has been done. In this chapter such a judgment has taken place, based on many facets of the educational process. The overall conclusion leans much in favor of field trips as a creditable supplement to the physics program.

# CHAPTER 9

# THE AFTERMATH

The value of the assignment in 1976-77 called for its continuation in 1977-78. It would be remiss to terminate this monograph without a brief reference to this added experience. The fact that the assignment was repeated and can be an ongoing feature of the physics program renders it more acceptable to the teacher contemplating such an exercise. Further, the quality of the second year's projects lends weight to the arguments supporting their introduction in 1976-77. A slight innovation over the previous year also merits mention.

The procedure used the previous year was followed fairly closely. However, this time there was more insistence that the students determine their own topic and make the arrangements for their pursuit and realization. The manner in which they responded to the new conditions makes one even more aware of the tremendous resourcefulness of the senior high school student.

Here are a few brief notes on a half dozen of this year's (1977-78) projects. Aside from the variety, it is interesting to note the relative ease with which they found contacts to initiate proceedings.

Two students "walked in off the street" to the Montreal Children's Hospital, and were able to arrange a project on electrocardiographs (ECG's). They underwent an ECG. Their completed report included an analysis of their own ECG's and excellent photographs of one of them in the process of undergoing the ECG.

Four other students (2 separate groups) did projects on quite different aspects relating to X-rays. This was the result of a trip to the X-ray department at the Montreal Children's Hospital where a parent of one of the group worked.

Another two students, through a contact on the secretarial staff at McGill University, were given the name of Dr. Robert Moore who obliged them with a two-hour session on a Saturday morning. He gave them a conducted tour of Foster Radiation Laboratory with its synchrocyclotron.

Two other groups arranged sessions by telephone with Professor B.G. Newman of McGill University's Faculty of Engineering. Two separate interviews produced papers on aerodynamics.

Another duo were given a guided tour through the electronics department of a local CEGEP. The outcome was a paper which listed specific high school physics concepts and laws (Coulomb's Law, Ohm's Law, electromagnetic spectrum, etc.) with references as to how these were demonstrated by specific electronic equipment. An older brother of one of the group was the guide.

A father of one student arranged a tour through the CN Railway diesel repair shop. This group submitted a project that explained the principle of induced EMF and the physics of the external combustion engine.

A trip to Dorval Airport was undertaken by another group. Their contact came via an uncle of one of them. They were guided through the cooling system of the plant. The physics of the air conditioner was their topic.

The results from these were all very satisfactory. Certainly, the general calibre of the work compared favorably with that of the previous year.

There was no doubt that in both years the authors of good projects viewed their final product with genuine pride. Many considered that their work was a real accomplishment such as they had not before attempted. When I asked for their papers for the writing of this monograph, they were often reluctant to relinguish them. One student respectfully quoted the old aphorism that "education is what is left over after all my lessons have been forgotten". She said that her project would be part of that residue for her.

Finally, those teachers wary of making adjustments to their PSSC physics program (or any physics program) should feel reassured that they have the blessing of the authors of PSSC.

> The most important element of a successful PSSC course is the teacher. The teacher provides the indispensible services of interpretation and clarification of the substance of the course. His presentation can be tailored to the needs and abilities of his individual students (PSSC Teacher's Guide, 1966:iii).

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# APPENDIX

This section contains two reports from the students' work. These are the originals. The corrector's comments have been eliminated. The photographs in the project in Appendix B were developed by the students themselves.

Many reports involved the complication of synchronizing essay reports with slides and audio tapes. The inconvenience this would have imposed upon the reader (viewer, listener) did not warrant their inclusion here.

These, however, are quite representative of the project work. They are presented to lend a clearer, more concrete, and perhaps, more objective view for the interested reader.

# APPENDIX A

# B E A U H A R N O I S

Produced by; Randy Hosek

Ted Kopytowski

Prepared for; Mr. Sullivan

Date Due; April 18, 1977

# INTRODUCTION

Since the time of the early settlers, rivers have always been harnessed to provide energy, be it mechanical or electrical. The early settlers used river water to drive their machinery, and this trend continued through the years, until the era of technology had arrived, that is, the coming of electricity. The coming of electricity brought a more efficient means of tapping the power of the river, which could now be transformed into electrical energy and transmitted over long distances on electric wire. This could serve users miles away from the energy sources, as well as the surrounding area.

The ability of Beauharnois to provide clean, economical energy attracts many. As soon as it is generated, the energy from Beauharnois flows to its market. The flow of power is channeled towards other networks and the substations which apportion it according to needs. The Beauharnois generating station is, at present, the largest of Hydro-Québec's generating plants. The total installed capacity of the station is now 1,574,260 kilowatts, with an average annual production of 11.2 billion kilowatt hours. The Beauharnois plant, which is located 40 kilometers west of Montreal, supplies Montreal, as well as the rest of the Hydro-Québec system and Ontario, with clean, economical energy.

## HISTORY

The flowing of the waters of the St. Lawrence River, as of any river, has great potential to produce energy. But the problem lies in tapping this great potential. Such was the case some 50 years ago. The entire 240,000 cubic feet of water of the St. Lawrence near Beauharnois had to be put to work.

A few engineers tackled the problem and came up with only one solution: to divide the flow of the St. Lawrence. A canal would have to be built. The new canal would be 24 kilometers long, and nearly 1 kilometer wide. A series of small dams would hold the river in check. The powerhouse would be built in three stages

Work began on this huge undertaking on October 12, 1929. Every possible means of excavation was used to dig out the canal: steam dredges, shovels, and dynamite. By August, 1933, the first 2 turbines were in operation. There was room for 12 more turbines, but these were added as required, until by 1948 all the space was occupied. A total combined capacity of 538,400 kilowatts was obtained with the addition of the fourteenth turbine, by Hydro-Québec.

The first portion of the powerhouse was constructed for the Beauharnois Light, Heat and Power Company. In 1944, the electricity sector was nationalized, and the provincial government created the Québec Hydro Electric Commission, granting it the right to produce electricity. Known as "Hydro-Québec", its first acquisition was Beauharnois.

At first, the principal markets for Beauharnois power were the two largest cities in the country, Montreal and Toronto. From then on, however, the power attracted industry to Beauharnois, and industries continued to expand.

On June 9, 1948, Hydro-Québec awarded the contract for the construction of the second portion of the powerhouse. The demand for electricity in the province had already out-stripped the production from the first stage. Stage Two called for enlargement of the Beauharnois canal, and this required removal of more than 191 million cubic meters of earth and rock. This is 15% more than the Panama Canal, or a little less than Mount Royal.

Just beside the first stage of the powerhouse, the same operation was repeated. The work was finished at the end of 1953. Twelve generators, with a capacity of 40,000 kilowatts each, were added to the other 14 units. This doubled the generating capacity of Beauharnois powerhouse. With a capacity of more than one million kilowatts, Beauharnois became one of the largest power stations in North America.

Montreal and Toronto were receiving power from Beauharnois. Around Beauharnois, the market for electrical energy multiplied. The modern home, with its myriad of electrical appliances, added its demand to those of industry and science. Again the demand out-stripped the supply of power as more industries, laboratories, offices and homes were added to the list of consumers. By 1956, Beauharnois was too small. Once again, it had to be expanded and brought up to date.

For the third time in thirty years, Beauharnois became a construction site. Ten units were added to the existing 26, a more modern and powerful propeller turbine type. They added nearly 600,000 kilowatts, bringing the capacity of the powerhouse to more than 1 and ½ million kilowatts.

From the control room, located in the highest part of the powerhouse, one man can control the entire million and a half kilowatts. This was a dream 235 years in the making and a combination of 30 years of work.

Beauharnois has now reached its ultimate size.

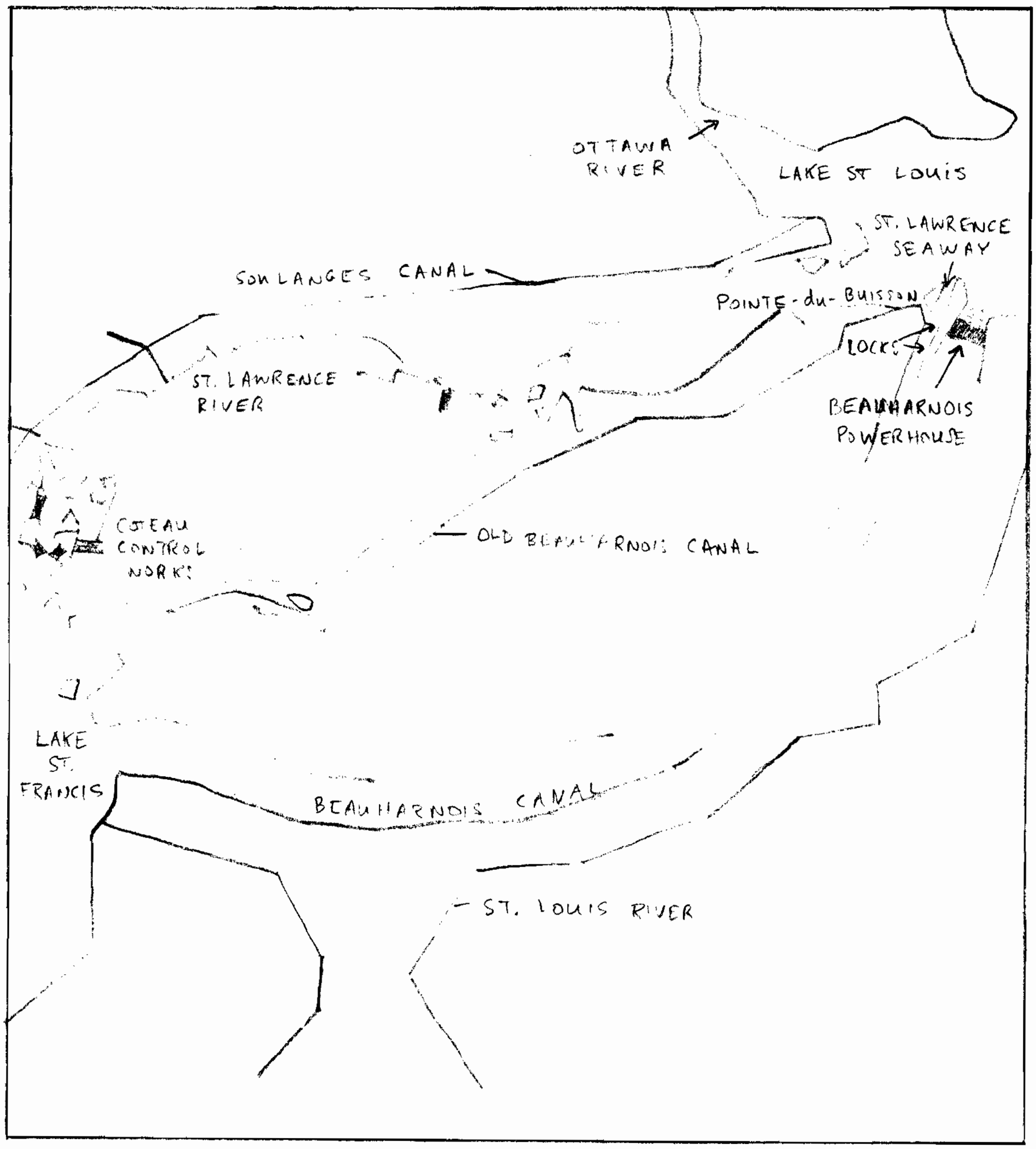
In the lobby at Beauharnois, reminiscence of its past.

# TRANSPORTATION AND LOCATION

Beauharnois Power Station is located 40 kilometers west of Montreal. It is near Lake St. Louis, at the mouth of the Beauharnois Canal. As it is not in a remote region, it is easily accessible.

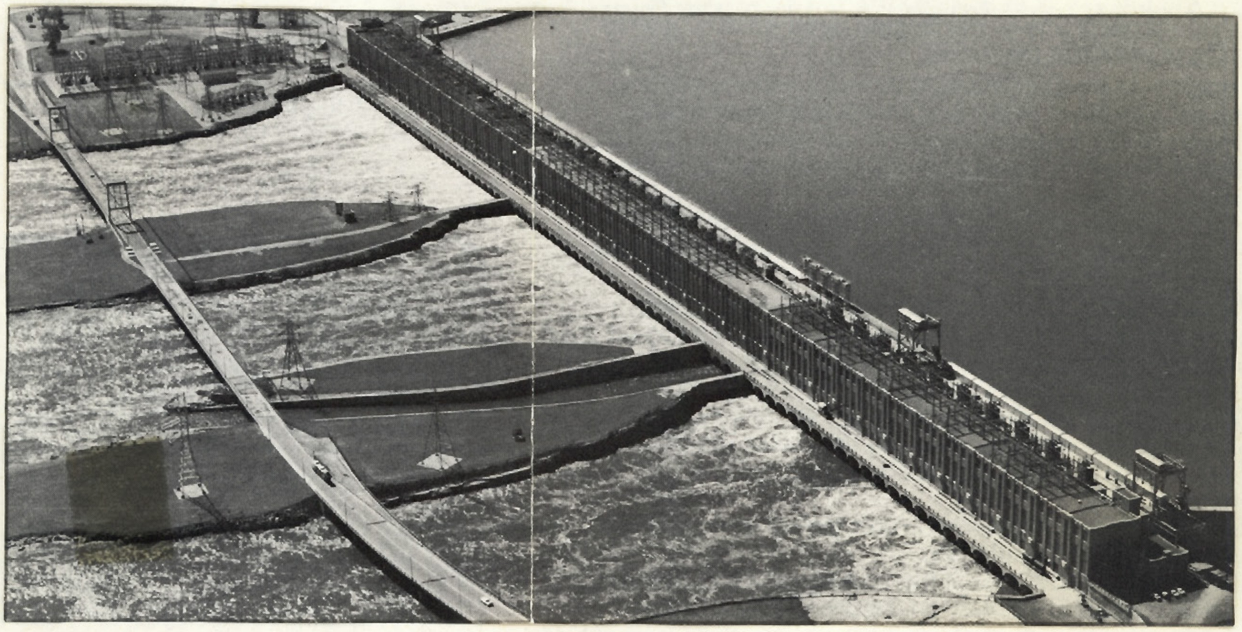
In the map below one can see that the waterway makes Beauharnois. The combination of the canal and the smaller Coteau dams re-direct the river flow.

The land in this area is plain-like so no great accumulation of water is possible and river flow must be utlized immediately.



## OUTER DESCRIPTION

Beauharnois is a large plant, approximately 1 kilometer in width. It consists of three main sections which were all built at different parts of the century. At the dam there is a 25 meter drop from one side to the other. The canal is



approximately 25 kilometers long and starts at Lake St. Francis, ending at the powerhouse at Beauharnois. The average depth of the canal is a minimum of 9 meters. The navigation channel has a width of 182 meters, a depth of 10 meters above the lock sill and has two locks. There is a highway (Highway 132) along the side of the dam which passes under the locks through a tunnel. Going through this tunnel leads to a bridge across the canal on the lower water level end of the dam.

Built on the top of the powerhouse are a series of transformers for stepping up the voltage. The number of transformers on the rooftop is 38, one for each generator. The transformers go to the substations which are located at each end of the powerhouse. The two transformer substations are for raising the voltage. The first, located on the east side of the powerhouse, receives the electricity produced by 22 generating units and sends it to Montreal on eight 120,000 volt lines. The second substation, on the west side, feeds six lines connected to the province's power grid, and

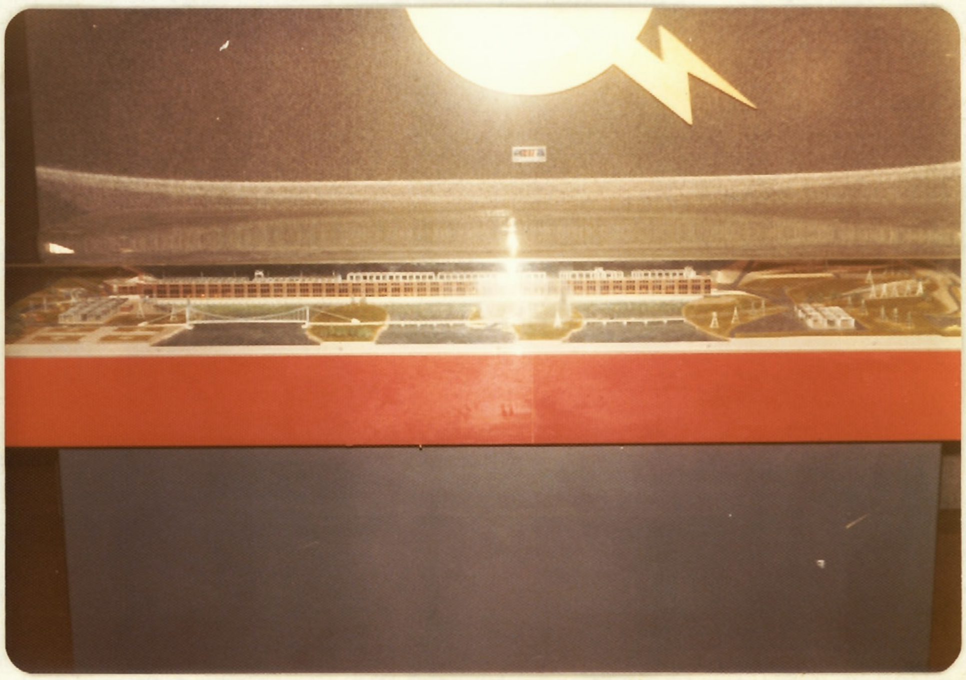
two lines deliver electricity to Ontario. These substations also supply power to installations on the St. Lawrence Sea-way, and to several industries in the region.

A view from the roof of the power station where the water drop can be seen. The bridge is in the back-ground.

The main entrance at Beauharnois.

INNER DESCRIPTION

Inside the powerhouse there are various areas. Directly inside when entering Beauharnois one comes to a lobby. In



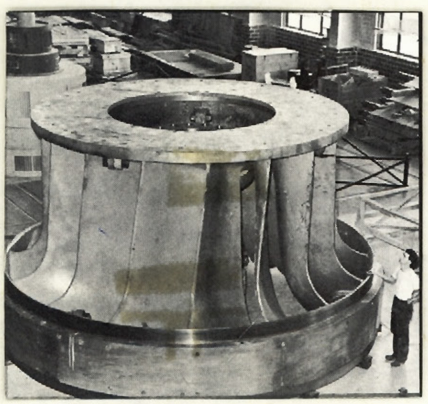
the lobby there are general information areas about the plant. They show the location of the plant and there is also a scale model of the Powerhouse. There is an elevator which goes up a few floors to offices and the like. On the same floor level as the lobby are the generators, a total of 38, of which two are auxilaries, powering the plant. The generators stretch

out for almost 1 kilometer.

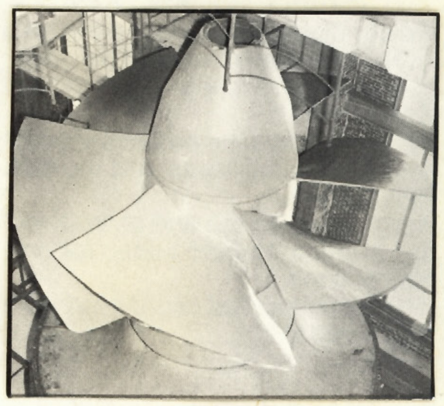
The first 14 generators turn at 75 rpm and produce 53,000 horsepower. These are air-cooled. The second section is water-cooled. They turn at 94.7 rpm and produce 73,000 horsepower.

The auxilaries turn at 180 rpm, produce 8000 horsepower, and are used to supply electricity to the plant. The heat all the generators give off is the heating system of the plant and there is no other heating system. In the summer the temperature can reach 102 or 103 degrees on the generator floor.

A view from underneath the generator.



A Francis Turbine.



A Kaplan Turbine.

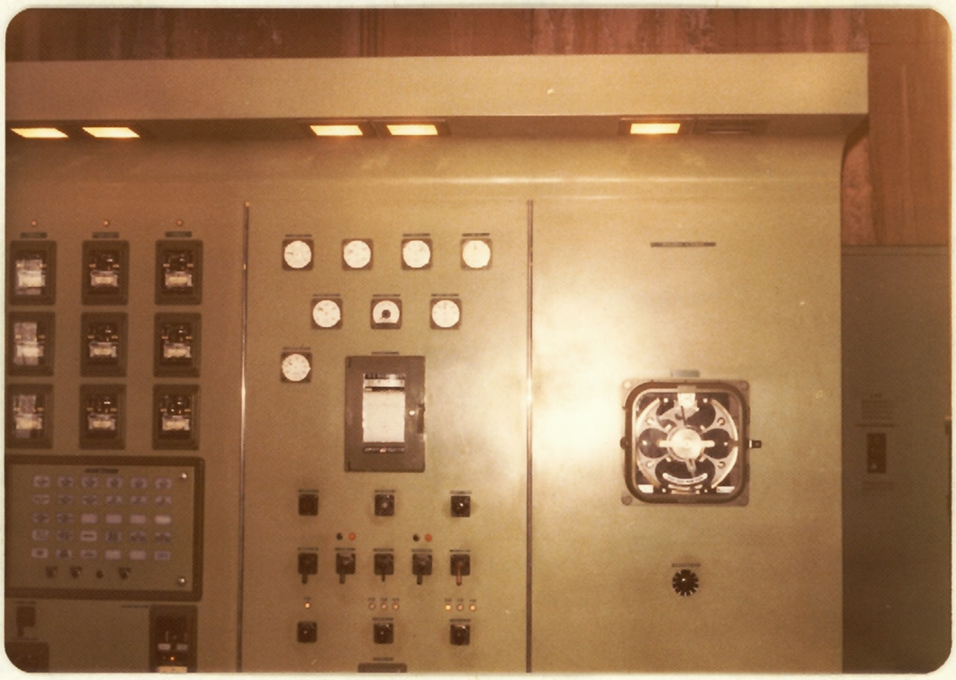
The power plant has its own machine where the majority of repairs are done.. There are overhead cranes in the generator room which travel on rails near the ceiling. There are two hooks, each weighing 25 tons, that together can lift 200 tons. If anything had to be repaired, it could be transported by the cranes that would bring it to one end of the plant, where the machine shop is located. Doors in the floor could


A plaque above the machine shop door.

be opened and anything that needs repair could be lowered to the machine shop, one floor below.

In the plant there is also a control room. Operators

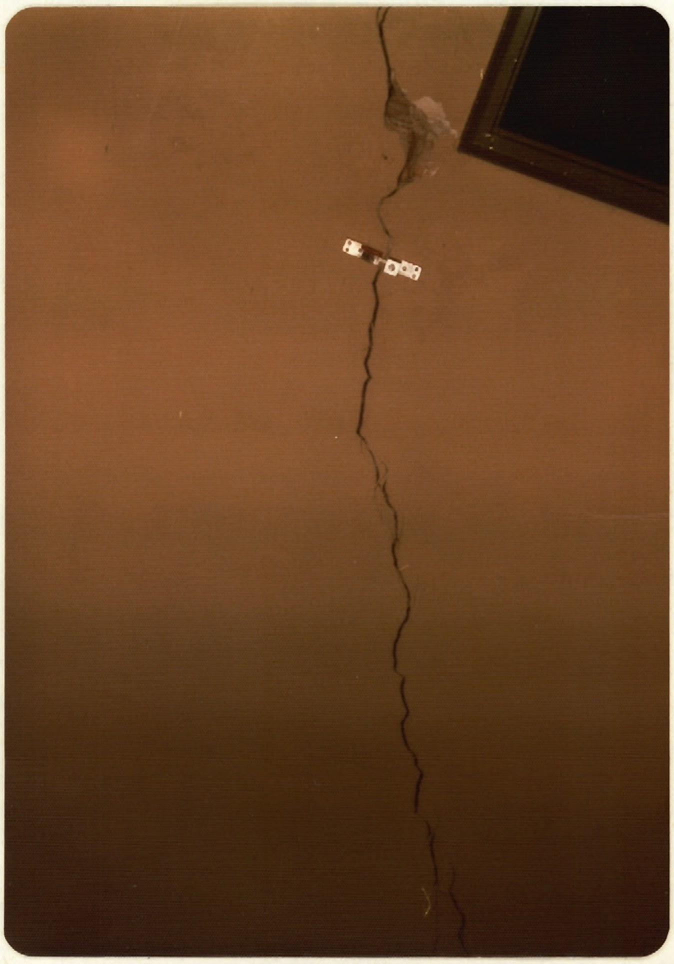
work here 24 hours a day, but one man could control the entire system as the operation of all equipment is automatic. Every



generator has its own switchboard with the same clocks on the generator floor as in the control room. The operators on the generator floor take the same readings as the operators in the control room every hour.

The power leaves the plant on lines of 13,200 volts and it goes to transformers where it is stepped up to 120,000 volts. There are a lot of plants closeby using the power produced by Beauharnois. Among them are Standard Chemical and Chromium Mining. They get the power direct from Beauharnois on lines of 44,000 volts. About 60% of what is produced here is sold to Ontario Hydro. They in turn sell it to the United States, but in 1978 it will be sold directly from the power plant at Beauharnois.

There has been a cut made through the entire structure at Beauharnois, near the main entrance side. Engineers took readings, after noticing cracks in the walls, and discovered that the water pressure on the dam has moved the entire powerhouse ½ an inch. A cut has been made in hope of lessening this pressure and it has been filled with a flexible rubber-like substance.



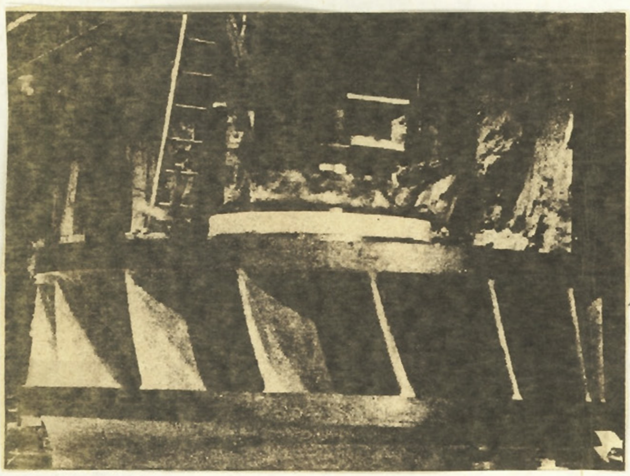
## THEORY

### Basic Principles

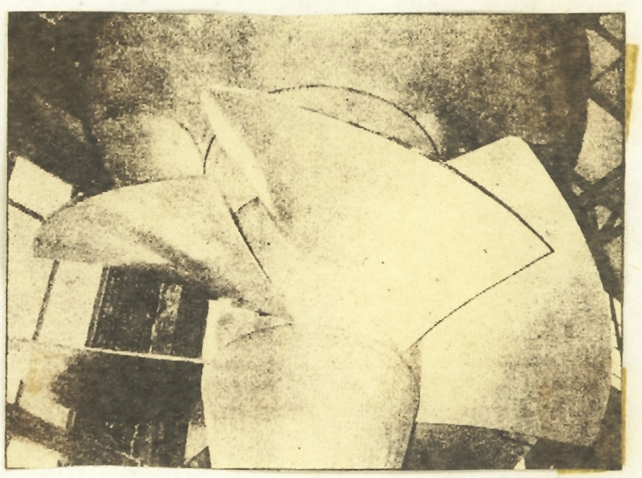
The dam of Beauharnois builds up a large reservoir of water which can enter the tunnel-like channels that lead to the turbines. Hatches, control the flow of water. The opening of the hatches is controlled by an automatically controlled machanical system. The two devices, which are identical operate on a rotating basis. One operates for 24 hours then, precisely, as one shuts off, the other one takes over. These can be checked manually or by the control room and are constantly monitered. Care is taken to ensure adiquate lubrication.

Water flowing through the tunnel-like channels strike the turbines, causing them to spin. They spin at various speeds, depending upon the design of the turbine. At Beauharnois the 24 turbines in stages One and Two are of the

Francis type.  In this type, water comes in and hits the blades of the turbine, which are parallel to the shaft, and spins it counterclockwise.



Francis



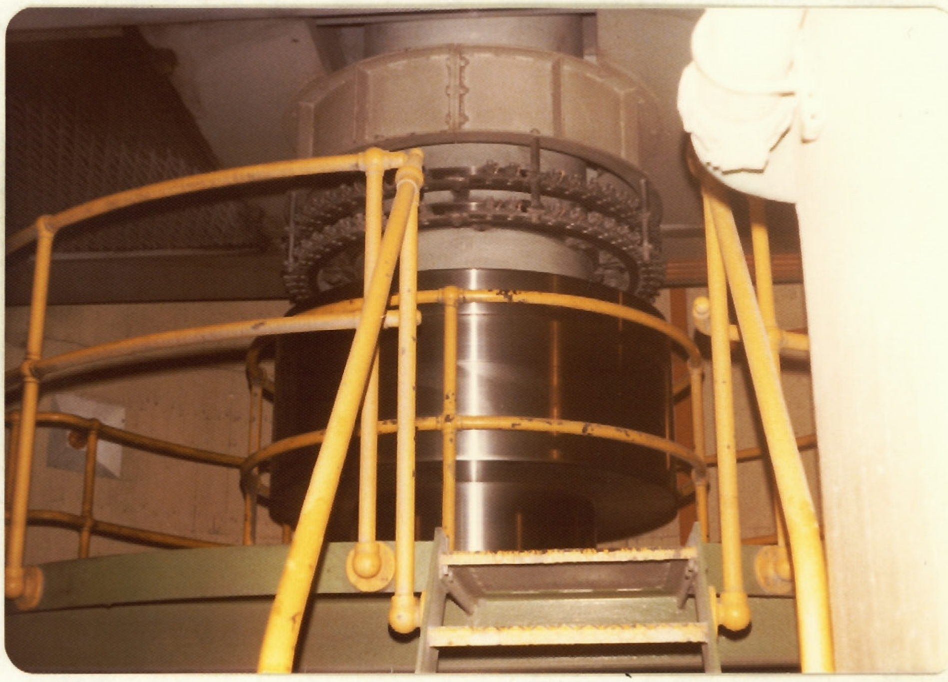
Kaplan

The ten turbines in stage three were changed from the Francis to the more modern and powerful Kaplan propeller type.

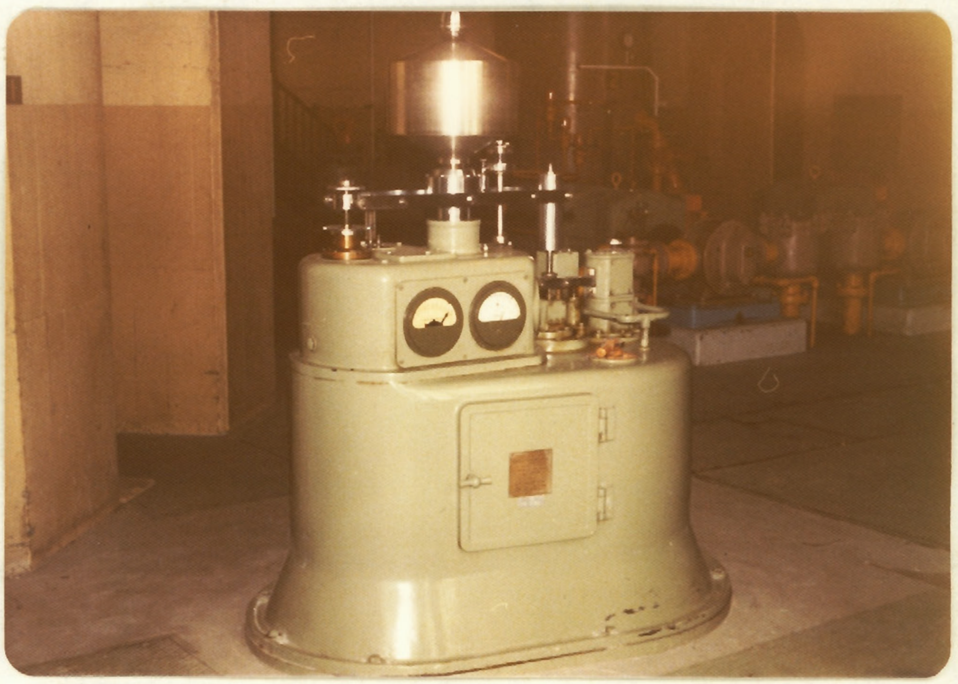
Due to the design they can achieve high speeds and require less water pressure in the tunnel-like channels.

As the water strikes one side of the turbine, it circulates in a semi-lunar opening directly behind the turbine, and strikes the other side of the turbine. It then flows out another tunnel-like channel which leads out to the other side of the dam.

The shafts on which the turbines spin rise to the level of the generator floor, some 15 meters up. Each shaft is built of stainless steel and is one piece; this gives one an idea of the weight. These shafts run day and night and therefore are being looked after constantly. They are well lubricated for minimum friction, therefore no heat build-up.



Outside each shaft, one floor below the generators, is a device for each shaft known as the governor. This device is precise-



synchronized with the speed of the shaft and indicates the shaft's speed. Therefore each shaft can be easily monitered.

At the end of the shaft is the generator, which is located on the ground floor. The generator converts the mechanical energy of the shaft to electrical energy.

In the generator you must have a magnetic field and a conductor. There must be relative motion between the field and the conductor; either the field must move or the conductor must move. In generators of the size of those in a generating plant, the magnetic field is produced by electromagnets and the conductors are moving coils.

Induced Current

As the conductor first enters the field a little current starts to flow. The current increases as the conductor moves toward the halfway point or to the center, where the magnetic field is the strongest. Then as the conductor moves away from the center, the current decreases until it becomes zero when the conductor has passed precisely out of the field on the other side. In order to create a continuous motion of a conductor through a field, it is convinient to have a coil rotate in the field. In Fig.1 a single loop of wire is arranged to rotate in the field. The curved arrows show the

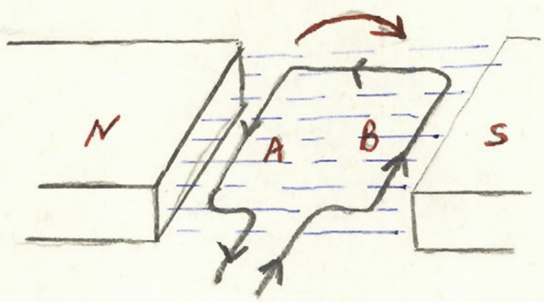



Fig. 1

direction of rotation. As side A of the coil passes up through the field, accordingly a current flows in the direction indicated by the arrows. Also, at the same time, side B is moving down through the field. Current flows into side B and out of side A. As the coil turns one quarter turn, the sides of the loop coil are parallel to the lines of the field and are not cutting through them. At this point the current is zero, this is shown in Fig. 2.

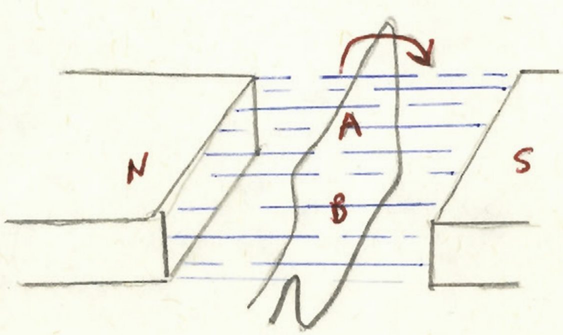



Fig 2

As the coil continues its rotation, side A cuts down through the field and side B cuts up through the field. A current flows, but in the opposite direction. It flows out of side B and into side A, this is seen in Fig. 3.

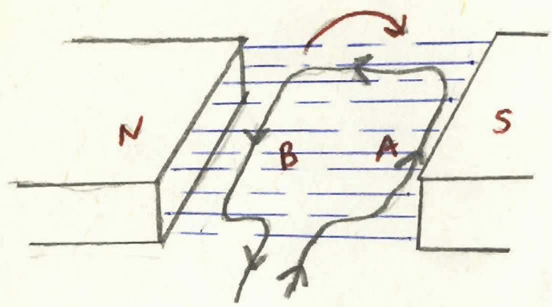



Fig. 3

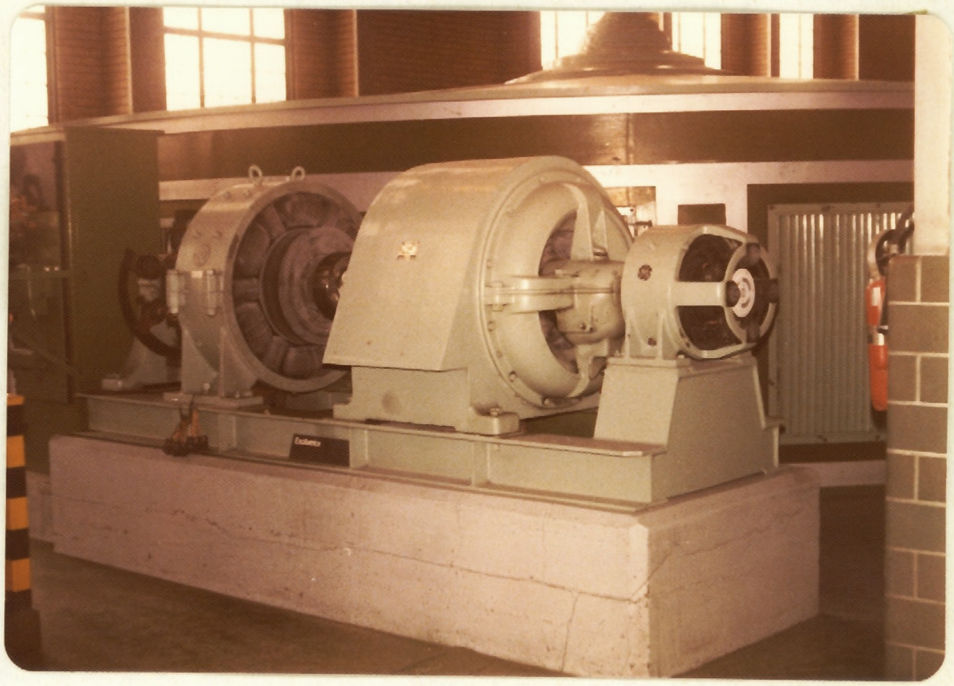
Continuous rotation produces a current in the armature coil, which is reversing its direction every half revolution of the coil. A current which changes its direction periodically is known as an alternating current, or a.c. The continuous change in magnetic flux gives you an induced current and from that current you have an induced E.M.F., or voltage.

Generator Output

The simple generator which has been described, uses only a single loop of wire rotating in the field. The currents generated are weak. To improve the output, the rotating coil can be may of many turns of wire. Such is the case in the armature of a practical generator. Likewise the magnetic field in which the armature rotates can be made a great deal stronger by the use of field windings and electromagnets.

Field Excitation

In order for the generator to operate, it must have a magnetic field. In the case of the permanent field magnet, of course, the field is there. But this field was weak and we have introduced electromagnets to replace them. An electromagnet requires electricity for its magnetic field.

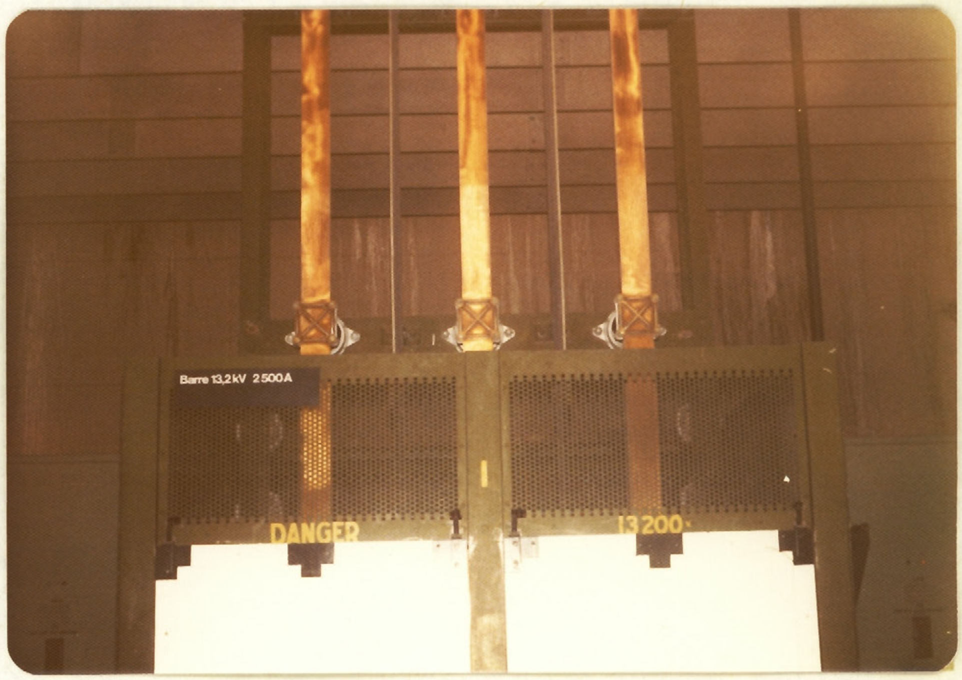


Generator Loses

All of the current produced by the generator does not serve a useful purpose. There are losses within the generator itself, which take the form of dissipated heat. The losses resulting from this source are known as copper losses. A second important loss in the generator is known as Hysteresis loss. Hysteresis sometimes is defined as molecular friction. Due to the rotation of the armature, the groups of molecules in the core of the armature are constantly changing polarity. This internal changing polarity creates a heat within the core which is a loss. Special alloy steels and heat treating processes have been discovered, which will reduce the hysteresis loss of the armature core. A third loss in the armature is known as the eddy-current loss. This loss can be understood when one realizes that not only a current being generated in thewindings of the armature, but also currents circulate back and forth in the core. Eddy-current losses are overcome by laminating the core of the armature. This means that the core is made up of layers of metal, rather than one solid piece of steel.

## Generator Power Flow

The current produced by the generator goes to a common junction before entering the transformer. Each generator has

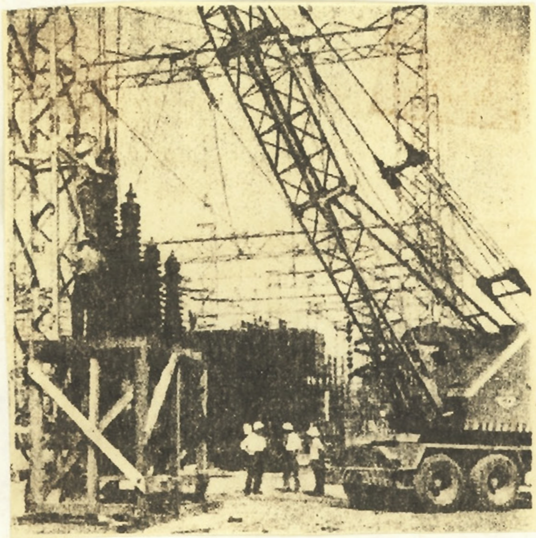


one of these junction boxes, where there is, at this point, a total of 13,200 volts. The output supply at Beauharnois is a three phase supply. This type of supply gives you the greatest output possible for the type of generator installed there.

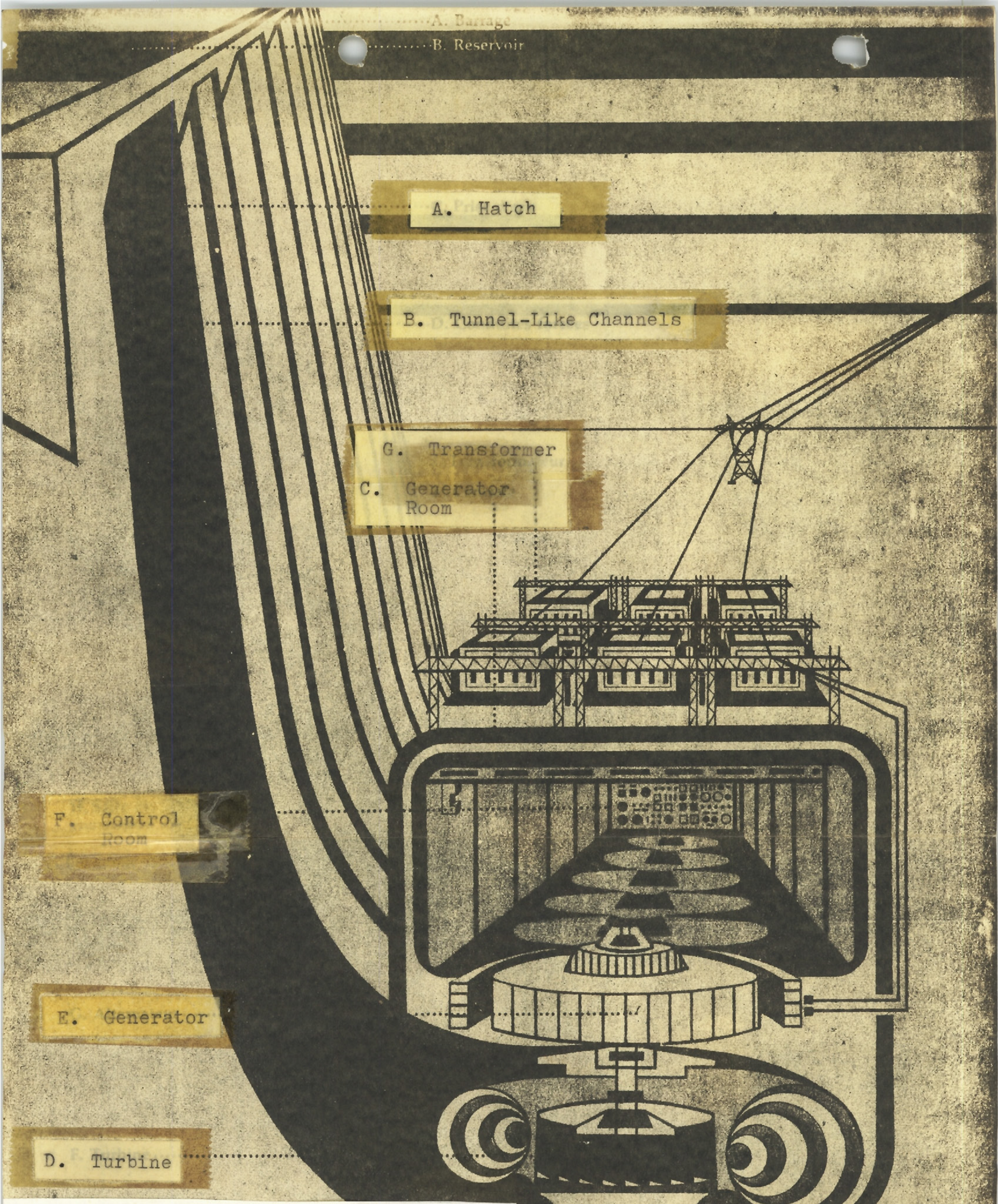
From the junction boxes, voltage flows to the transformers located on the powerhouse rooftop. A transformer consists of

coil windings which step up the voltage. There is one transformer per every generator in the plant which steps up the 13,200 volts produced by it. From the transformers, electricity flows to two substations, one on each side of the powerhouse.

Twenty-two units are connected to the east side substation and fourteen units to the west side substation. From the



substation, power is directed by transmission lines to the suppliers. Well this gives a complete run down of how the electricity is being made. After that it is a question of who needs it.




Water enters through the hatch and flows through a tunnel-like channel, hitting the turbine, and then flows out.

## ELECTRIC POWER

Exploitation of resources dates back to the end of the last century. As early as the nineteenth century, water was used to drive factory mills, sawmills, and the first manufacturing plants in the country. Saint-Hyacinth, Valleyfield, Beauharnois and Joliette originated with the growth of small factories on the falls of rivers. In 1889, the Chaudiéres Falls, thirty foot falls on the Ottawa River, sent the first power to Québec. From then on, generating stations multiplied, being built by paper manufacturers such as the Canada Paper Co. in 1902 at Windsor Falls on the Saint-Francois. They were also built by various companies, among them Québec Power and Gatineau Power; and by several municipalities: Sherbrooke in 1908 and 1914 on the Magog River and Coaticook in 1910. However, the power stations up to this time were all small. In 1920, the installed power reached one million horsepower. From then on, a steady increased followed, almost doubling every 10 years. A substantial contribution to this increase was made by the Beauharnois Generating Station.

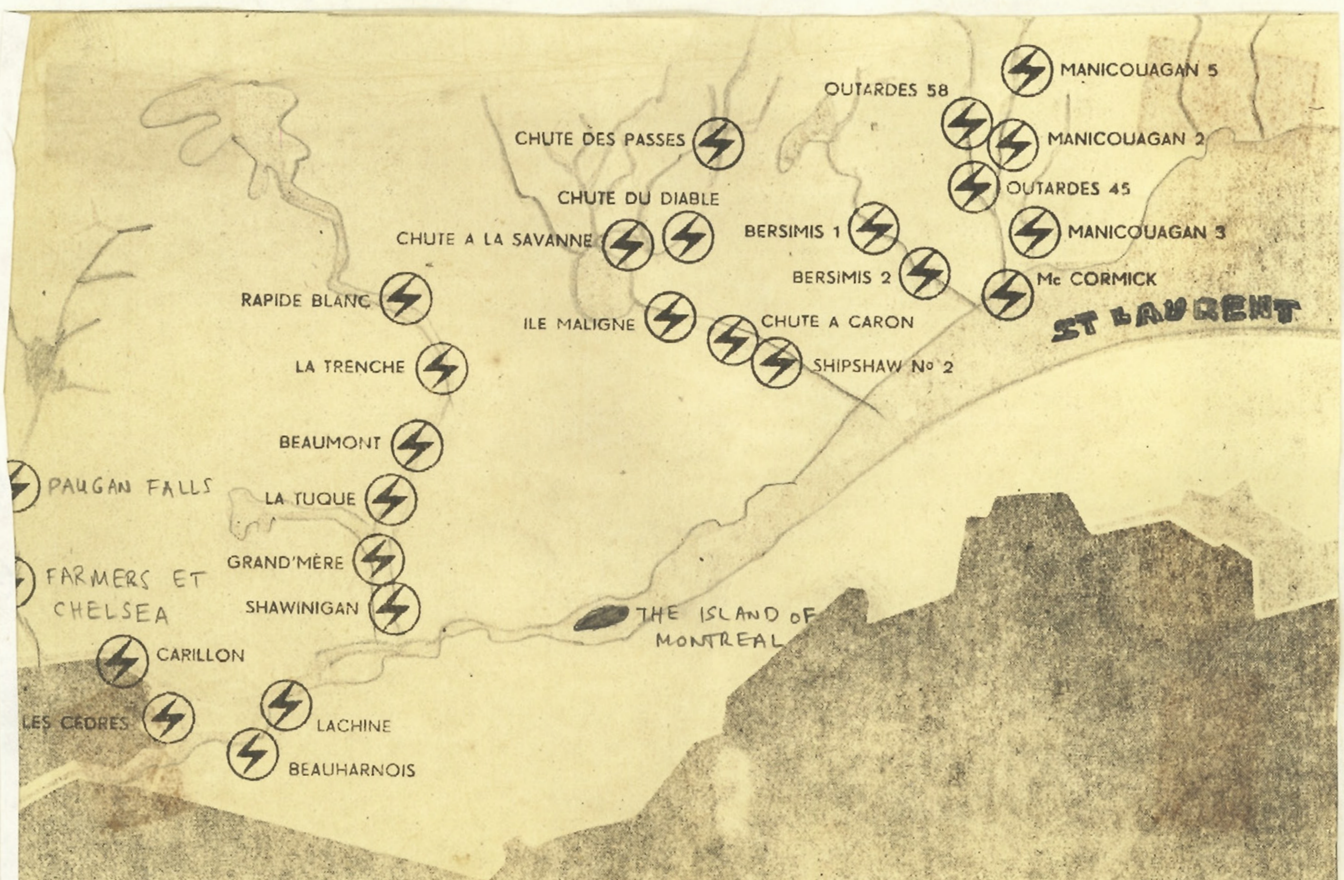
INSTALLED POWER

| Year | Million H.P. |
|---|---|
| 1920 | 1.0 |
| 1930 | 2.7 |
| 1940 | 4.3 |
| 1950 | 6.4 |
| 1960 | 12.4 |
| 1964 | 13.5 |

QUEBEC

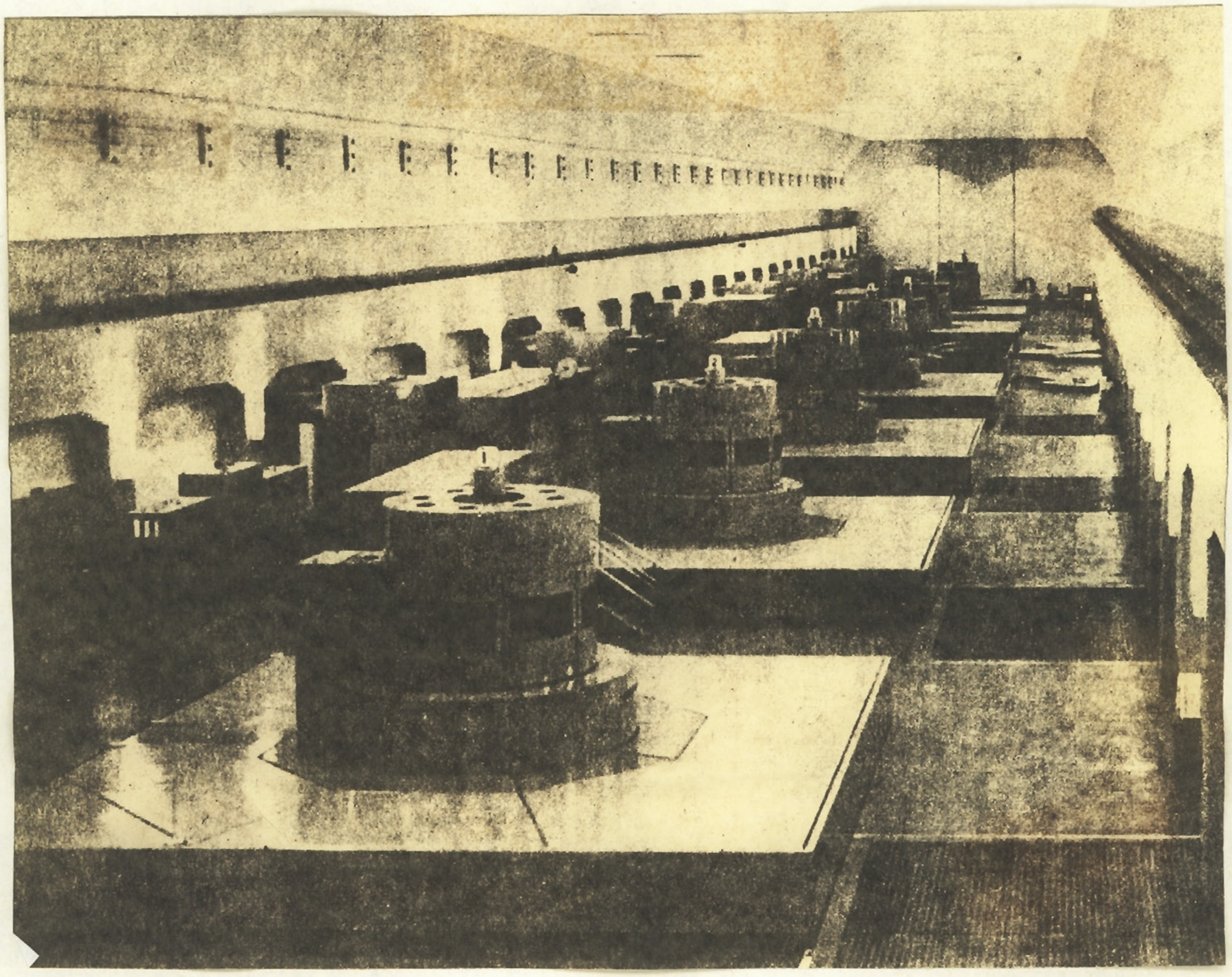
Québec takes first place in the world for production of electric power per capita with 9,000 kilowatt hours. Electric power in Québec is the cheapest in the world, costing less than 1 cent on the average per kilowatt hour. Québec possesses half of the total hydro-electric resources in the country, putting Canada in third place after Africa and Russia in countries possessing the largest hydro-electric resources.

Main Hydro-Electric Installations.



Betsiamites

The two Hydro-Québec dams on the Betsiamites River, supplying turbines of over 2 million horsepower, were completed in 1956 and 1958. Parallel to the Saguenay, the Betsiamites

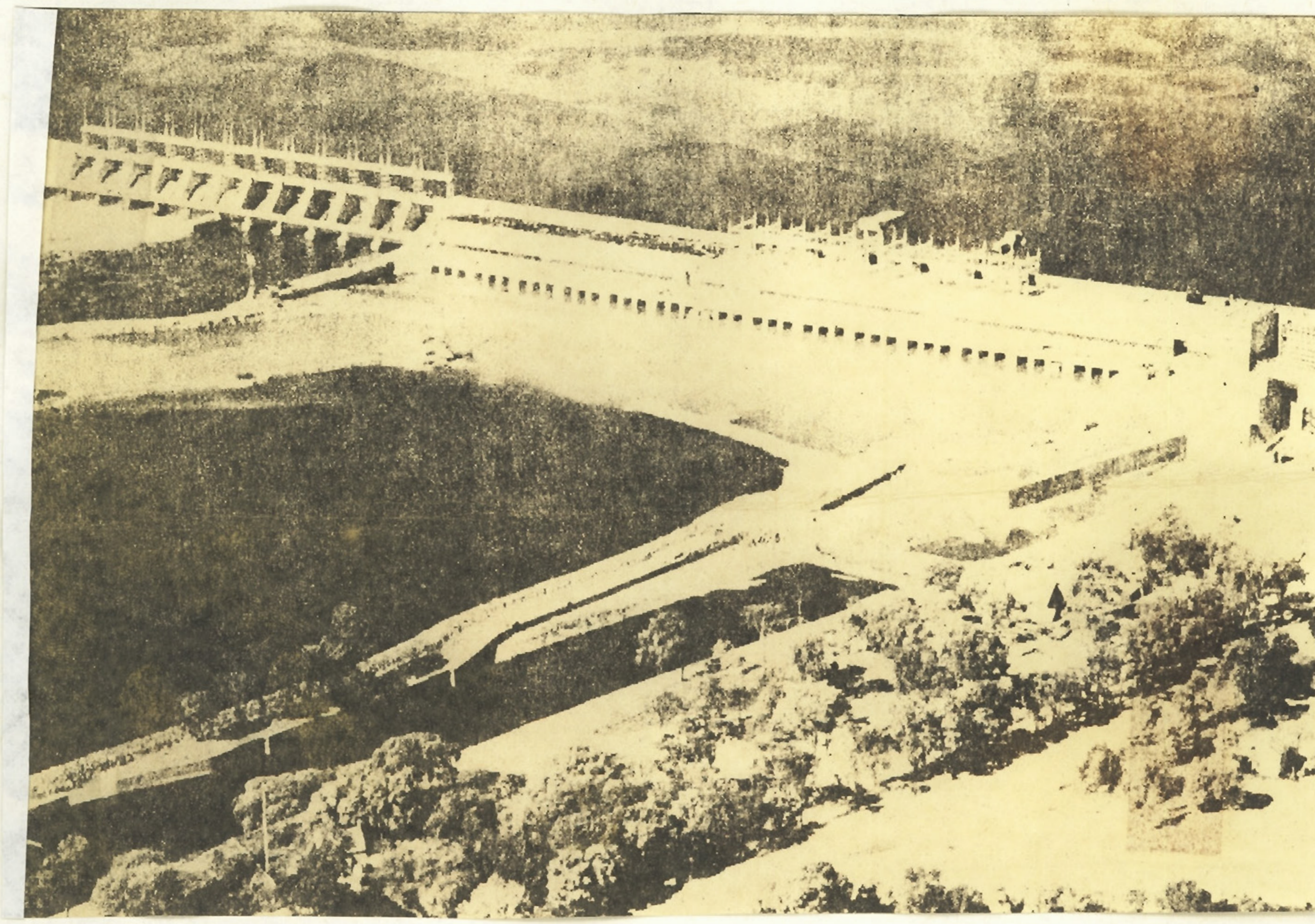


The eight, huge 150,000 H.P. generators buried in the heart of a mountain at Bersimis.

River empties into the St. Lawrence, about 200 miles northeast of Québec City. Over a length of 100 miles, it collects the waters of the Canadian Shield. Bersimis I, the main dam, is 200 feet high, 2,300 feet long and 925 feet thick at the base. Bersimis II is very similar. The two installations together produce 7,400 million kilowatt hours per year. This power is transported to Montreal by high voltage lines of 300,000 volts.

Carillon

Carillon, a combined powerhouse and dam on the Ottawa River, is 64 kilometers west of Montreal. It is similar to



The Carillon Dam and its 840,000 H.P. power station.

Beauharnois, but owing to its reservoir it could operate as a heating plant in winter, when the river is closed to navigation.

Manicougan

The Manicougan is the largest power station and dam of its kind. The dam is 745 feet high and has a length of 4000 feet. The width at the base is 660 feet, rising to a width of 20 feet at the crest. There are 2.5 cubic yards of concrete in this dam which builds up a reservoir of 800 square miles. The combined turbine horsepower is 1.8 million.

The Dam

# CONCLUSION

A hydro-electric power station like Beauharnois does not cause pollution and does not contribute to the depletion of non-renewable resources. The electricity it creates from the riverflow is clean power and among the most inexpensive in the world.

In Québec, the need for electrical energy is increasing rapidly. In fact, the demand doubles every 10 years. By 1985, 32 million kilowatts will be required, which is three times the present capacity of the Hydro-Québec system. To satisfy this demand, Québec must add some 15 million kilowatts to its power system between 1977 and 1983. This is equivalent to all the generating power built in Québec since the advent of electric power, some 100 years ago. Solutions have been analyzed with some use of nuclear power, but mainly a reliance on hydro-electric power.

# B I B L I O G R A P H Y

All of the imformation used in this project was obtained by:


Own Physics book

Beauharnois

Book known as " The Silent Electricity "

# APPENDIX B

# A C C E L E R A T O R S

by

Lawrence Marcoux and John Miller

C O N T E N T S

# ACCELERATORS

A Report by Lawrence Marcoux and John Miller

## THE ATOM:

Once believed to be an indivisible particle, the atom is now the subject of much research.

In order to have a more complete understanding of accelerators, it is useful to have a bit of background into the nature of the atom.

At its most elementary level, the atom can be considered as a solar system, with the electrons behaving like planets orbiting around a central mass, the nucleus. The electrons are tiny particles of mass approximately $9.1 \times 10^{-31}$ kilograms, possessing a charge of -1 elementary units and rotating about their axis. The nucleons (particles that make up the nucleus) can be either neutrons or protons. The latter differs from the first in that it possesses a charge of +1 elementary units whereas the neutron is neutral as its name implies. They both have a mass of about $1.6 \times 10^{-27}$ kilograms.

However, research has shown that the atom is not this simple. Particle Accelerators have aided greatly in the search for new knowledge about the atom and its constituents.

ACCELERATORS:

The main principle of all accelerators is that electric and magnetic forces can be used to increase the speed of charged particles. The method by which this is done can be more easily understood if we consider an electron current flowing through a wire. The difference in potential between two points on the wire will cause the electrons to move towards the point of lower potential. The force that causes them to move in this direction is an electric force and the force per elementary particle is known as your electric field.

If instead of being in a wire, the electrons are in a vacuum between two charged plates, the same general effect will be observed. The magnitude of the difference in charge on the two plates will determine the strenth of the electric field. The relationship will be that of a direct proportion.

By the Newtonian equation: $F = ma$

one can see that the stronger the field, and subsequently the force, the greater the acceleration. (This is true until the particles reach a speed near that of light, where relativity will play a part in increasing the mass of the particle, hence the acceleration will not increase uniformly.) The increase in speed also increases the energy of the particles, thus allowing them to do more work. This is what accelerators try to do; impart as much energy as possible to a stream of particles.

However, when examining moving charged particles, we observe a new phenomenum. A moving charged particle will virtually "induce" a magnetic field perpendicular to the direction of its motion. This magnetic field is capable of interacting with an external magnetic field to produce a new field. This magnetic field will then exert a force on the particles which is perpendicular to both the direction of the motion of the charges and that of the external magnetic field. This concept is used in such accelerators as the cyclotron, synchro-cyclotron, and synchrotron as will be discussed later.

DEVELOPMENT OF THE VARIOUS TYPES OF ACCELERATORS:

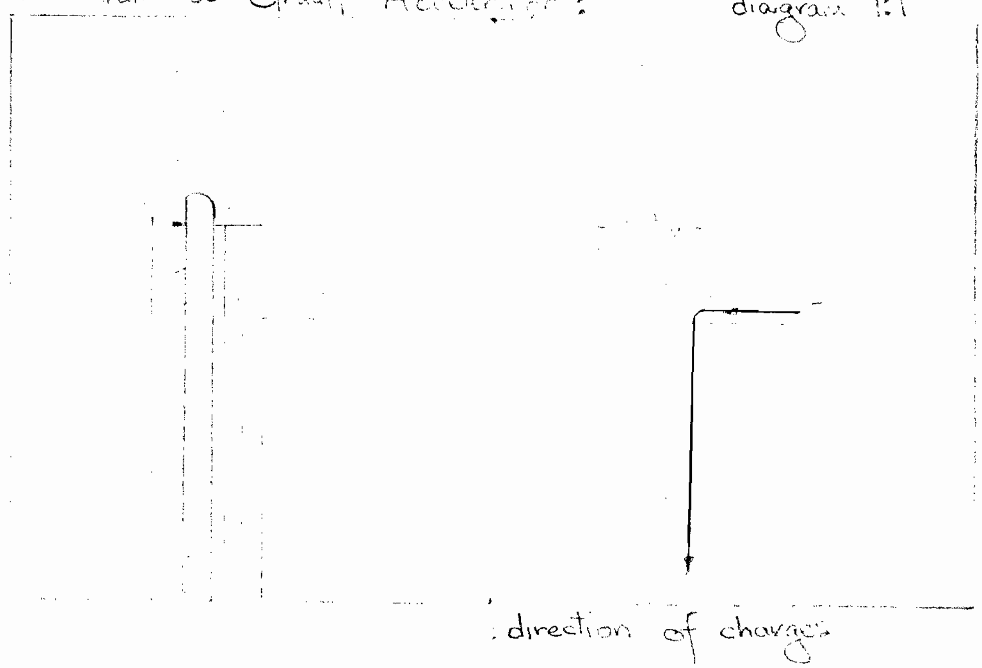
In 1928, John D. Cockcroft and Ernest T.S. Walton constructed a device similar in concept to the parallel plates discussed previously. They used such a large potential difference (voltage) that the accelerated ions had enough energy to split a target nucleus. This was accomplished by accelerating protons ($H^+$ ions) to 400,000 electron volts. (1 electron volt equals the energy gained by an electron or a singly charged positive ion accelerated through a 1 volt potential difference). Ultimately, an energy of 800,000 electron volts was reached by their machine. One of the problems encountered by the Cockcroft-Walton accelerator is that the voltage can not exceed 1,500,000 volts. At this point, insulation breakdown occurs.

VAN DE GRAAFF:

The next accelerator to come along was the familiar Van de Graaff accelerator in 1931. It was a more powerful instrument, being able to give particles up to 10 Mev (million electron-volts) of energy. It is limited from going beyond the stated amount by insulation difficulties.

A Van de Graaff electrostatic generator is based on the principle of accumulating a large charge on a hollow metal sphere, using a rubber belt that serves as a carrier for charges. Ions are sent in through the side and accelerated by the charge on the sphere (see diagram 1:1). It then goes through the indicated tube and strikes the desired target causing a reaction to possibly occur altering the molecular strucure of the target. The physicist can then study the results to obtain insight into the structure of the atom.

The Van de Graaff Accelerator: diagram 1:1



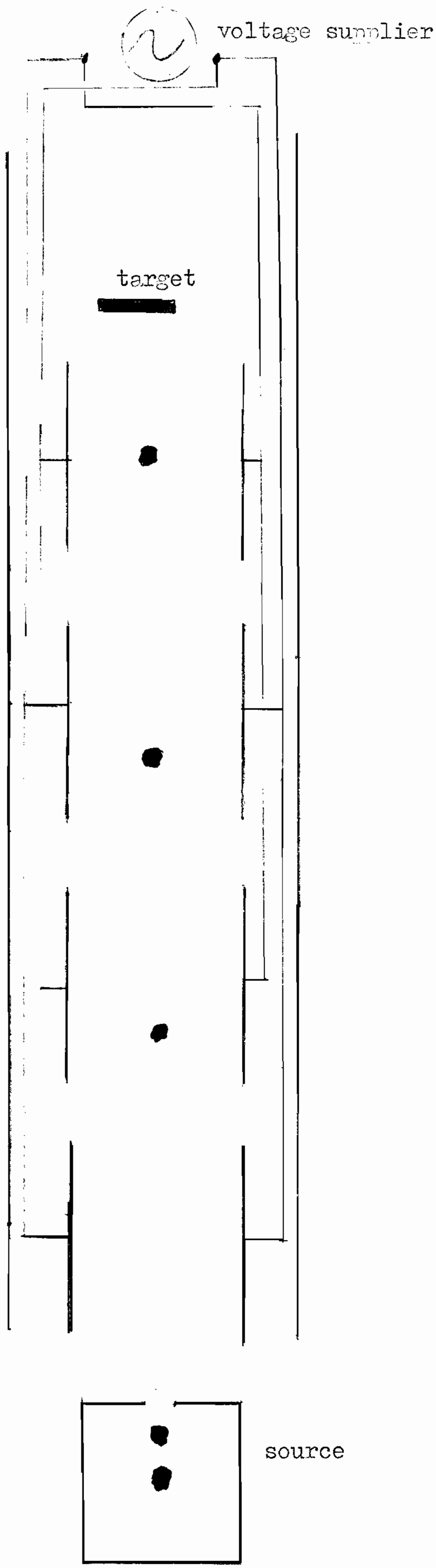
THE LINEAR ACCELERATOR:

A linear accelerator (also known as a linac) does exactly that: it accelerates charged particles in a straight line with the use of electric and magnetic fields.

The obvious question at this point is how do linacs differ from the two previous accelerators we have already mentioned. After all, both of those also accelerate particles in a straight line. In a way, these could be viewed as linacs. However, while the Cockcroft-Walton and the Van de Graaff machines utilize only one stage of acceleration, a linac is a multistage device. In linear accelerators, the size of which range from a few feet to 10,000 feet, electrons are introduced into one end of the accelerator whereupon they are acted upon by electric forces. There are two major types of linacs: standing wave, and travelling wave.

In a standing wave linac, a series of opposite parallel plates are set up as shown in figure 2:1. The opposite plates are equally charged, and succesive plates are opposite in charge. After the electron travels the distance between the plates, all of them (the plates) reverse sign. Hence, what would have been a decelerating plate ~~is~~ now ~~and~~ acts like an accelerating plate. The picture obtained looks like this:

An electron flowing freely in a tube approaches a positive set of plates. Since opposite charges attract, it is slowly




Standing Wave Linear Accelerator

accelerated towards the positive plates. After it has passed the half-way point in the plate, the charge on the plate becomes negative. This is important, for if this were not the case, all the energy spent in speeding up the electron would be lost as the electron would continue to be attracted twoards the positive plate and thus the net result would be no gain in energy. At the same time, the next plate becomes positive. Therefore, not only is the electron repelled away from the first plate but it is also attracted towards the second. In the normal linac's, the first plates are shorter than the subsequent plates. This is because the speed of the electrons is greater and the time to travel the same distance is smaller. This way, the electrons reach half-way point of each plate in exactly the same interval of time though the distance travelled might be different.

This is the method of eliminating this factor used in most cases. However, there is another way, less obvious, more difficult perhaps, that can be used. It would be known as a sort of synchro-linear accelerater (synchro meaning synchronized). The idea here is that an increase in velocity can have two reasons for being: an increase in distance (time remains constant), or a decrease in time (distance remains constant). This is more obvious when you see the equation $v = \frac{d}{t}$. In other words, rather than making the plates longer, the frequency of charge alternation is increased. The problem here is that the increase is not necessarily linear in slope, meaning the oscilator used in regulating the frequency must increase or decrease its period of osscilation according to the presented situation. To see one reason why this might be true, we must enter the relatively new world of relativity. Einstein predicted that as a mass gains velocity, its mass will increase (see figure 2:2) The problem arises not in low speeds, which is why Newtonian Classical Physics was accepted and parts of it still are today. For instance, an object of rest mass 1.0 kilograms accelerated to a velocity of 300 m/s will show a gain of mass of $(1 - \sqrt{((1 - 10^{-14})^{-1})})$, a neglible amount. In this case then, a more realistic or rather everyday applicable circumstance, Classical Physics and Relativity will both yeild the same results. However, when dealing with speeds of 98 to 99.999 % the speed of light, which an electron being accelerated in a linac can attain, relativity becomes a very important factor. Whereas classical physics would have told you to keep the osscilating frequency constant, relativity tells you to prepare for an increase in mass of (in the case of 99% the speed of light) 7.088 times your original mass! (It should be mentioned that allowances for this phenomenon have been made in the traditional linac's.) Now perhaps

figure 2:2

$$m_p = \frac{m_r}{\sqrt{1 - v^2/c^2}}$$

$m_p$ = mass at present
$m_r$ = mass at rest
$v$ = present velocity
$c$ = speed of light

it is more obvious that velocity is not the only factor regulating osscilating frequency. What usually happens is that all of the required data is inputted into a computer, which will control these parts of the experiment when it actually is under way.

The two-mile electron accelerator at Stanford differs from most linac's in many respects: the particles it accelerates, its length, its purpose. Though electrons can attain higher speeds than protons, their small size and low mass make them a relatively uninteresting particle to bombard nucleii with. It is much more interesting to see the effects of a nucleus which has been split by a high enerty proton, almost 2000 times the mass of the electron. The reactions are more outstanding and reveal much more about atomic nucleii (as will be discussed later). Most linac's today are usually no more than, say, 10 feet long. This is because they are not the only accelerators dealt with. They serve as "pre-accelerators" for the main accelerators: synchrotrons. (See figure 2:3) The compactness of these linac's is something to marvel, since we know that they can accelerate some particles up to 98% the speed of light before the particles are sent into the main stream.

However, the purpose of the Stanford two-mile long electron accelerator is to investigate new reactions caused by super-high acceleration of electrons (Stage One: 25 Bev; Stage Two: 40 Bev)

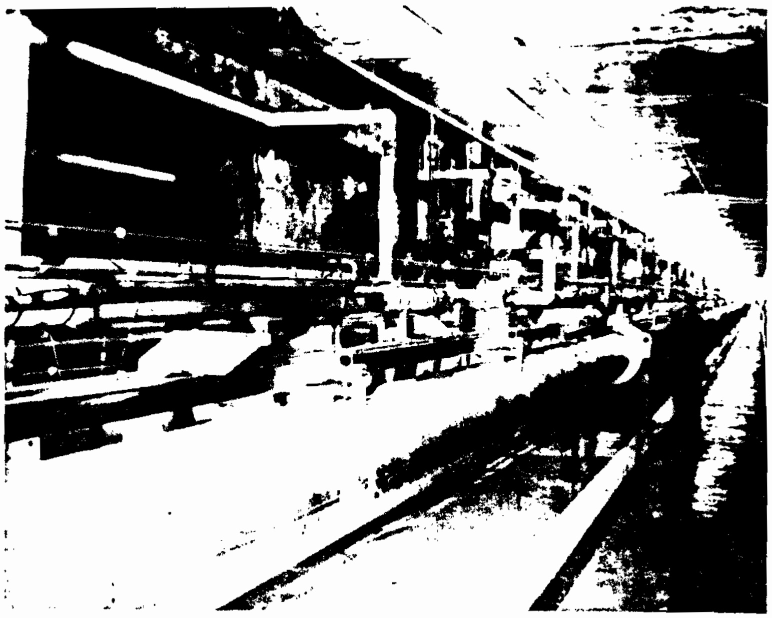


FIGURE 5–1 A view inside the two-mile long accelerator housing of the Stanford Linear accelerator which accelerates electrons to 20 billion electron volts. This enables the internal structure of elementary particles to be observed down to $10^{-15}$ cms.

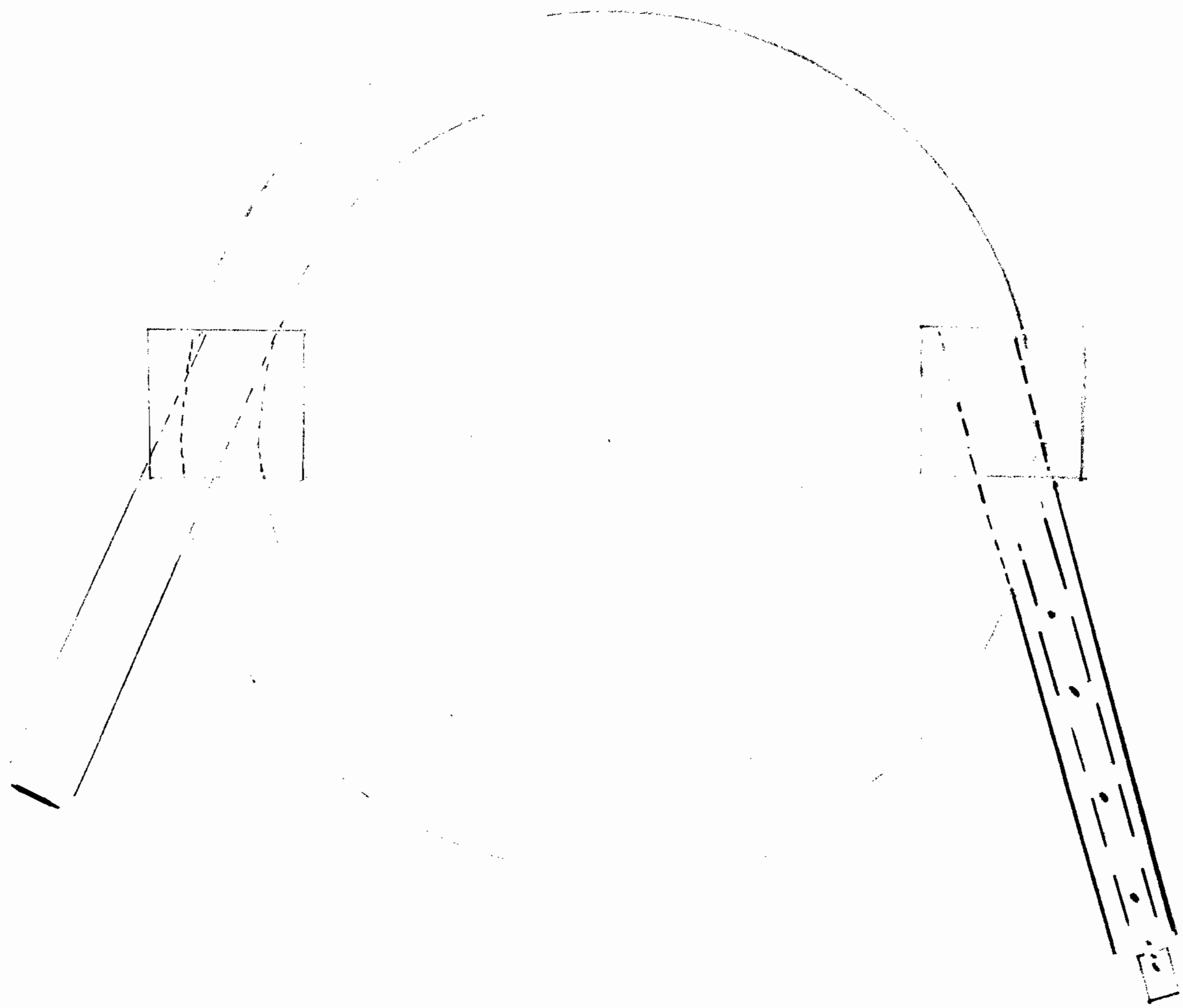


Diagram of synchrotron with added linac (on the right). The ions are produced at the ion source and sent through the linac and the synchrotron, after which it is deflected out through the accelerated beam tube. Synchrotrons will be discussed in more detail later.

and hence protons can't be used. Also, electrons are good for defining the shape or outlines of objects which protons are too big to do.

There is another type of linac which does not work on plates; at least not the same kind as the standing wave. It uses a completely different principle: the acceleration of particles with the use of electromagnetic radiation. Before explaining it technically, it is better to examine a relatively good analogue. If you could imagine the electromagnetic 'wave' as a wave of water, the particles being accelerated would be the surfer riding at the top of the wave. Any lagging electrons would be picked up at the crest of the wave. If you were to give the water more energy, thus increasing the frequency, the surfers would be travelling at a faster speed.* Returning to the actual linac, electrons are picked up by the crest and accelerated using the maximum capacity or energy of the radiation. The radiation is supplied by special generators called "klystron tubes" which also serve to regulate the speed of the waves. At first the waves must travel a bit slower than the speed of light, since theoretically particles can never reach the speed of light (see diagram 2:4). Otherwise the particles would be continuously accelerated and decelerated as they felt the effects of the crests and troughs which would be moving too fast for them to keep up. The particles must be kept on the 'crest' or maximum accelerating point of the field as the

* see page 6

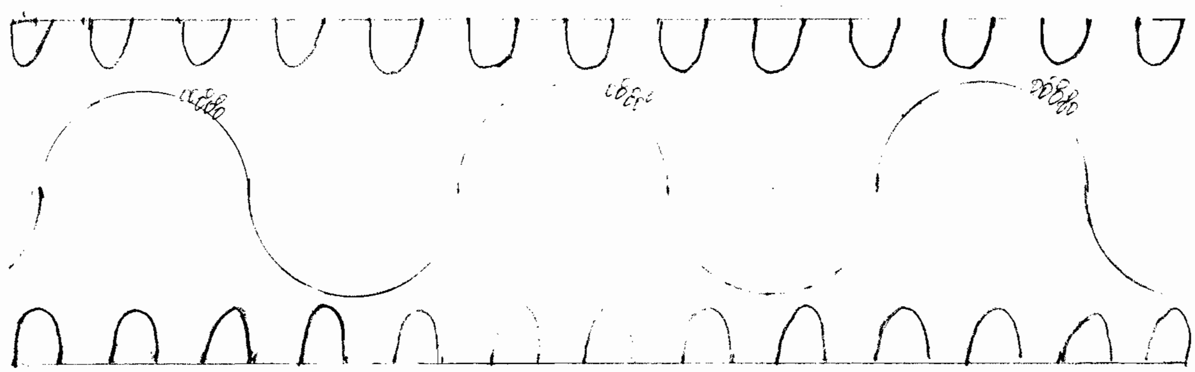


Diagram 2:3

Travelling Wave Linear Accelerator

$$v^2 = c^2 \left( 1 - \left( mc^2 / E \right)^2 \right)$$

v = velocity

c = speed of light

m = mass

E = energy

Einstein's equation predicts the behaviour of moving particles as a result of an increase in energy. Note that for $v^2$ to equal $c^2$, hence the particle to travel at the speed of light, E would have to be zero. Since light is assumed to have rest mass zero, it is the only thing which can travel at this speed.

wave speeds up. All this is regulated by computers and klystron tubes.

* This is not exactly how it is done in real accelerators. Usually the frequency is kept constant but the distance between the crests of the waves is reduced. Since frequency times width gives you speed, a decreased width reduces your speed.*

The difficulty one encounters with linear accelerators is that it is easier to accelerate particles up to, say, 98% the speed of light than to get them from 98% to 99% the speed of light (for reasons previously mentioned). Though this is true for all accelerators, it is a major drawback in dealing with linac's, because as the name implies, the process is linear, and irreversible. In other words, the particles will never feel the effect of one set of plates more than once. Therefore, to increase the speed of your particles above 99% that of light requires that you make your accelerator longer. It is for this reason that most high-energy (by this we mean energies ranging in the billions of electron-volts) accelerators are not linac's.

The next question might be: "If linac's are so terrible, why do they exist at all?" The question is a good one and its answer even better. The main advantage to the linac is that almost all the forces that the particles feel accelerate them in the desired motion. For example, with the standing wave linac's, the proton has no reason to stray away from the center (vertically) since this would mean being acted upon by a greater force by the plates. So, you might say that the linac has an 'automatic focusing' principle which other accelerators lack. However, magnets are often introduced to the system to increase the beam concentration. Another advantage is that less radiation is given off by the charged particles (when a charged particle is accelerated, it gives off a certain amount of electromagnetic radiation itself). However, in some cases, the radiation given off by linac's and other accelerators is great enough so that precautionary measures must be taken so that the harmful radiation does not escape freely into our atmosphere. Still another advantage might be that in the standing wave model for the linac, you can feed current at any time, since the field acting on one set of particles at one speed is not different than the one needed to accelerate newly entered slow moving ions. This is not true for most accelerators including the 'synchro'-linac, the traveling wave linac, and other assorted accelerators which will be discussed later along with the reason for this.

Considering the positive and negative aspects of the technological breakthrough, the LINEAR ACCELERATOR, one can say that though it may not replace the other accelerators, it will most probably never be phased out.

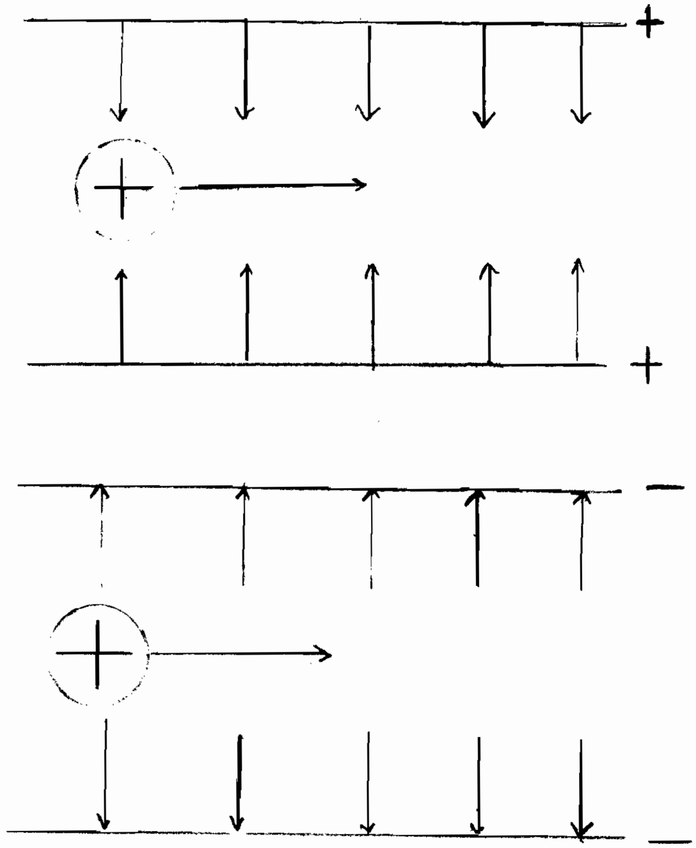



Diagram of "automatic focusing". Since the forces felt by the charges are equal, it tends to remain centered.

CYCLOTRON:

The major problem with linacs is that in order to bring particles up to high energy levels an apparatus of considerable length and cost would be needed. This seemed to put a damper on future progress in nuclear physics. However, E.O. Lawrence came up with the solution: why not make the particles go in a circle and thus cross the same gap repeatedly? This would allow scientists to reach much higher energies in a relatively small space. This machine became known as the cyclotron.

The basic principle of the cycltron is the same as all other accelerators: an electric force accelerates the particles. However the cyclotron has an added feature: there is a strong electromagnet that forces the particles to move in a spiral path. This is illustrated in the diagram. It works out that the faster the particles move the wider thay move in their orbit around the cyclotron. This makes it so they take the same amount of time to go around the circle each time. Therefore, the frequency at which the voltage to the accelerator is reversed can be calculated to allow for voltage reversal everytime a particle crosses the gap between the "dees"(so called because the ~~because the~~ electrodes are shaped like D's). The oscillator controlling the voltage

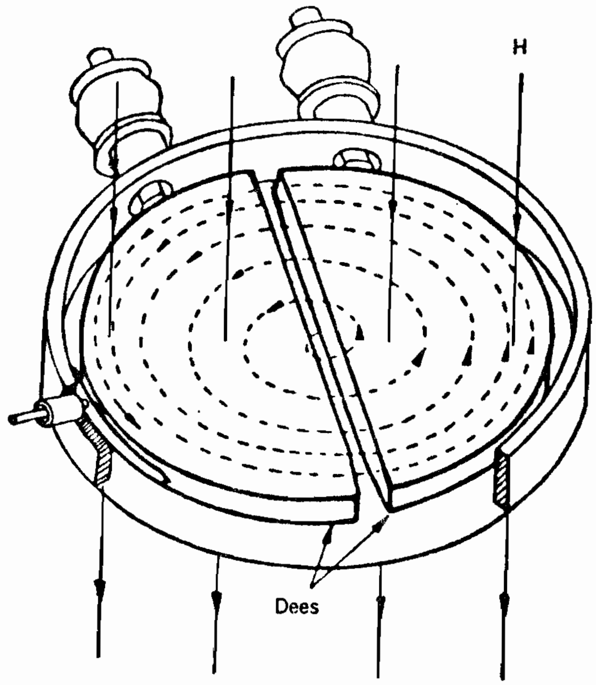



Diagram of a Cyclotron: The space enclosed by the ring (shown partly cut away) and by magnetic poles above and below (not shown) is evacuated. The magnetic field is vertical as shown by the arrows (h). Protons are produced at the center and accelerated by the alternating voltage between the "dees".

to the electrodes can then be set to this frequency. Because the momentum of the particle and thus the radius of the spiral keeps the time per revoulution constant even though the speed is increasing, the frequency of this oscillator can be kept constant as well.

The particle enter the cyclotron at its center. They are emitted by either an ion source (as is the case in prot on cyclotrons such as the one at McGill which uses a hydrogen ion source) or an electron source (as is the case in, you guessed it, electron cyclotrons). They are then acted upon by the electric and magnetic forces, gaining energy as they spiral outwards. It is easily seen that the amount of energy a particle would have depends on how far out it had spiraled. Thus, if you wanted to bombard a target with particles of a particular energy, you would simply have to use a rod which could be placed as close to the center of the machine as you wanted and which would have the target on the end that is inserted into the machine. You could easily calculate the radius for the energy you recquired and then insert the rod to that radius. After bombarding the target, the rod would then be removed, either manually or automatically, and all necessary tests could be preformed on the target sample. However, in some cases where the experimental testing must be done simultaneous to the bombardment of the target, an external beam is used.

When this happens, a electrode at the outer edge of the cyclotron deflects the beam of charged particles into a evacuated pipe outside the accelerator. The beam can then be "steered" by magnets to the experimental area.

The cyclotron allows a continous beam of charged particles to be delivered to the target as compared with linacs which deliver their particles in spurts. It should be noted, of course, that these spurts of the linacs are occuring hundreds of times a second.

SYNCHRO-CYCLOTRON:

The cyclotron works fine at low energylevels. However, because of the fact that the speed of the particles are nearing the speed of light, relativity starts to take effect once a particle reaches a level that is dependent on factors that will be discussed below. The particular problem that plagues cyclotrons is the formula of Einstein that states that the mass of an object increases with its speed. At velocities with which we are accostumed this increase is negligible but at ten Mev a prot on is moving at 1/7 the speed of light. Therefore, its mass has increased ( by slightly more than 1%) along with its speed and it is now taking longer to go around the cyclotron. This puts the particles out of step with the frequency of accelerating electrodes. After several revoulutions, the particles are so out of step that the electrodes, alternating at their fixed frequency, can no longer accelerate the particles. In order to reach higher energies we must have a greater voltage between the electrodes so that the particles receive large amounts of energy before completing enough turns to lose the electrodes accelerating ability. For example, to acquire ten Mev would require 50,000 volts across the gap; higher energies would need higher voltages. How high an energy can be given to a prot on before relativity steps in depends on the voltage between the electrodes but the cyclotron is limited to approxiametely 10 Mev for prot ons.

Although it posed a major problem, E.O Lawrence, whom the reader will remember as the scientist who came up with the cyclotron idea in the first place, was not to be defeated by the " relativistic barrier ". His lab at the Universty of California found a way around the difficulty in 1945. They modulated the frequency of the oscillator to match the time it would take a charged particle to go one revoulution. As the particle gained energy, the oscillator's frequency would be lowered slightly to allow for the extra time needed to make one revoulution. It would keep pace with one batch of particles until they hit the target and then start over with a new batch. Be- the oscillator can not be synchronized to both particles at the beginning of the spiral and those which have reached a higher energy, the synchro-cyclotron accelerates only one batch of particles at a time. The prot ons (or elec- trons) hit the target in spurts. However, these spurts follow rapidly; in the McGill machine there are 400 "spurts" per second. Physicists were quite happy to give up beam intensity in order to obtain the higher energies possible with a synchro-cyclotron.

The synchro-cyclotron did not solve all the problems of the cyclotron design. There was still the problem of the electromagnets. These magnets had to be the diameter of the machine and were very costly. The 600 Mev synchro-cyclotron in Geneva has magnets that cost $1,000,000 in 1960. In order to reach 1200 Mev would take a magnet that would cost four times as much. This is also completely ignoring the inflation of these costs in the past 15 years. When scientists starting dreaming of machines with ratings in Bev's, costs were prohibitively high. The problem of expense was partially solved by the synchrotron. The synchrotron is discussed in our next section.

The McGill accelerator is a synchro-cyclotron.

SYNCHROTRON:

A new idea came along in 1945, published independently by E.M. McMillan (in the U.S.) and V. Veksler (in the U.S.S.R.). They proposed that instead of letting the particles spiral outwards, as is done in cyclotrons and synchro-cyclotrons, it would to keep the particles in an orbit of constant radius. Rather than the fixed magnetic field which causes the spiral effect, a magnet of increasing strength would compensate for the increased speed of the particles, making the idea of a constant radius pratical. The magnetic field would not have to extend over the entire area within the ring; it would only have to cover the small doughnut shaped path that the particle would follow. Because it synchronizes the magnetic field strength with the speed of the particles this type of machine is known as a "synchrotron".

At first, synchrotrons were used mainly for the acceleration of electrons. However, a proton synchrotron had been proposed in 1943 by M.L. Oliphant (in the U.K.) and construction started on it at the end of the Second World War. After numerous setbacks, it was finally completed in 1953 at which time it had already been passed in energy. The "Cosmotron" at Brookhaven National Laboratory passed one Bev in 1952 reaching its designed energy of 3 Bev in 1954. The "Bevatron" at Berkely soon pulled ahead with a 6 Bev instrument. The Soviets were not to be outdone: a ten Bev machine was built near Moscow in 1959. It was followed in 1960 by a 30 Bev unit at Brookhaven and, in Geneva, a 28 Bev acclerator built by the Centre Européen de la Recherche Nucléaire (CERN) which has 13 countries as members. The preceeding examples serve to illustrate the big push for more powerful instruments with which to probe the atom.

It should be noted that despite the similarity in the names, a synchrotron and synchro-cyclotron work on two different principles. The "synchro" in synchro-cyclotron refers to decreasing the frequency of the accelerating field to keep pace with the particles; the magnetic field remains constant. In a synchrotron the magnetic field is increased to keep the particles in a fixed orbit. At the same time, because the particles are going around the circle at a constantly increasing speed, the frequency of the accelerating must also increase and it must do so in perfect step with the varying magnetic field. It should be remembered that the synchro-cyclotron is merely a modification of the cyclotron; the particles still spiral outwards from the center to the edge of the machine. Synchrotrons are an entire new design.

Before the particles even enter the synchrotron, they are first acclerated by a small linac. The particles thus enter at a speed closer to that of light than they would if they were just injected by an ion source directly into the synchrotron. This may not seem to matter but it is actually a considerable advantage. The difference between injection and ejection speeds is reduced. Therefore, the amount that the magnetic field and the accelerating field frequency must change is also reduced. This makes the design of the accelerator less complex.

Because of the large number of times the particle must go around the ring (in the Cosmotron, for instance, the protons go around 4,000,000 times— the equivalent of 100,000 miles.) it becomes crucial to keep the particles as close as possible to the ideal orbit. There are several methods of doing this. It can be accomplished if the magnetic field is a little weaker at the outer edges of the doughnut than it is at the center. This will tend to push the the particles back to their proper path. They will not be kept on this orbit exactly but will be pushed back and forth around this orbit. If a proton was following the ideal orbit (which isn't likely to happen) it would not be deflected. By knowing how far the particles can diverge, it is to design the tube for the particles to be the proper height and width. Before discussing the concepts of "weak focusing" and "strong focusing", we must introduce the idea of the magnet field index. The field index is defined as the percentage decrease of the field in a 1% increase of the radius from the center of the circle. A uniform field would have an index of zero. A particle in such a field would be guided horizontally but would be free to travel vertically. When the index is one, the particle would be guided vertically but would be free to travel horizontally. A compromise must be made between the two extremes. This compromise is known as "weak focusing".

An alternate system is to use "strong focusing" (high field index) but also alternate the gradient (direction of field decrease). One section would be towards the center; the next would be away from the center. The particles' path is constantly corrected, first away from the ideal orbit and then towards it. Even a particle following the ideal orbit would deflected slightly. An analysis of the forces involved shows that most particles will be pushed more towards the ideal orbit than away from it. This system of focusing is much more efficent than "weak focusing". A major problem develops with this system however. If any of the sections is out of place, particles will be greatly deflected at this point and the beam will lost after a few turns. To avoid this it is necessary to line up each of about 200 sections weighing 20 tons apiece within .01 of an inch. And this was only for the 3 Bev Cosmotron. Imagine the problems with the monsterous synchrotrons we have today!

An electron synchrotron is much simpler than a prot on synchrotron because electrons can be injected so close to the speed of light that it is not necessary to modulate the frequency of the accelerating field. Like all accelerators we have discussed, the electron synchrotron has its disadvantages. When electrons are accelerated to high energies they start to send out electromagnetic radiation. Almost all additional energy is lost to this radiation. This limits it to seven or eight Bev. In order to go higher, it is necessary to use a linac.

Like a synchro-cyclotron, a synchrotron delivers the particles in spurts. Because the magnetic field must rise from its minimum to its maximum value (which requires 10,000 kilowatts) in one second for each batch of particles, a way had to be found to supply this power. It was noted that most of the energy was recoverable if it could be reharnessed. The method employed in the Cosmotron and in all synchrotrons with modification is as follows: a large motor (1,750 H.P.) drives a 45 ton flywheel connected to a generator; when the flywheel is at maximum speed an electronic switch is closed giving power to the coil windings, causing the magnetic field to increase; about a second later the switching is reversed; the generator now acts as a motor to bring the flywheel back up to almost its original speed. The have then reached zero strength and are given a brief period with no current during which the motors brings the flywheel and generator back up to the original speed, compensating for the energy lost in the process.

Scientists would like to combine the lower cost of the synchrotron with the higher beam intensity of the cyclotron (N.B. not the synchro-cyclotron). Their name for this is "Fixed magnetic Field with Alternating Gradient" (FFAG). A way would have to be found that would allow particles of varying energies to be kept in the same orbit or in orbits that were close enough not to matter. Several scientists are currently working on this idea.

Another idea is to let two different beams collide with each other rather than with a fixed target. When a 28 Bev prot on hits a nucleus, 23 Bev are needed to break the nuclear bonds; only 5 Bev is available for creating new particles. But if two 28 Bev protrons hit each other all of the 56 Bev is available for the creation of new particles. Stanford's SPEAR is an example of this setup. It started operations a few years ago.

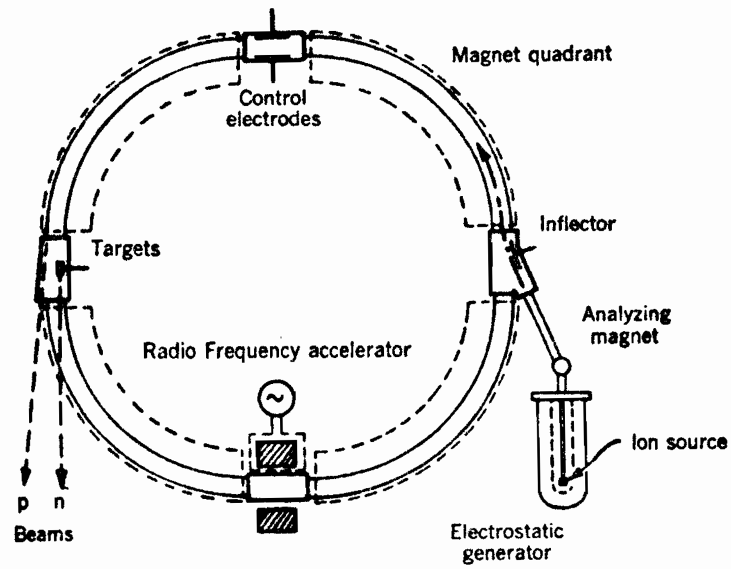
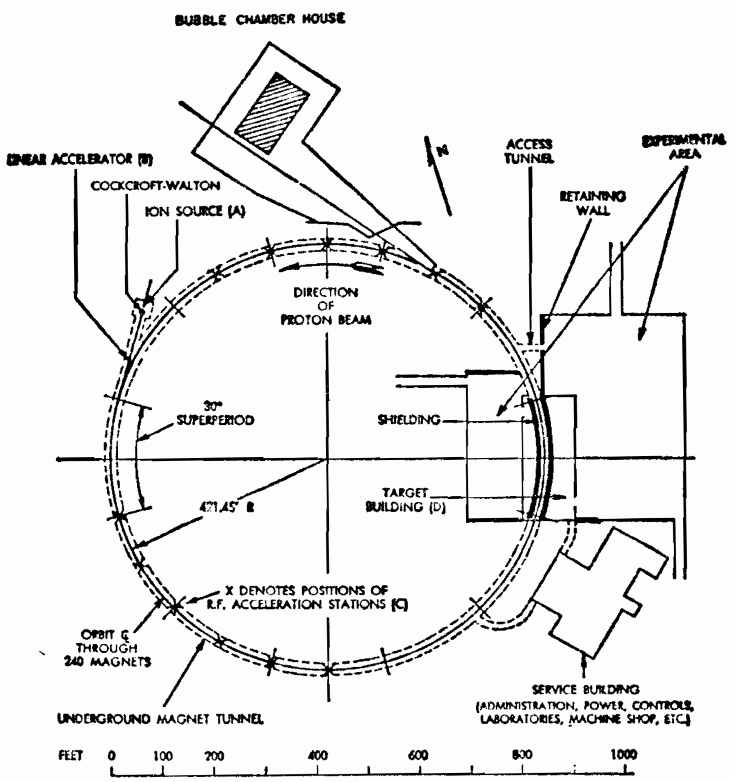



DIAGRAM OF THE COSMOTRON, the great proton accelerator at the Brookhaven National Laboratory.




PLAN OF BROOKHAVEN ALTERNATING GRADIENT SYNCHROTRON

THE NEW 30-BEV SYNCHROTRON at Brookhaven has a circular track about half a mile in circumference. The particles, given an initial speed of 50 Mev by a Cockcroft-Walton machine and a linear accelerator, are further accelerated to very high energy in many turns around the track and they are directed at the bubble-chamber target. (*Courtesy of Brookhaven National Laboratory*)

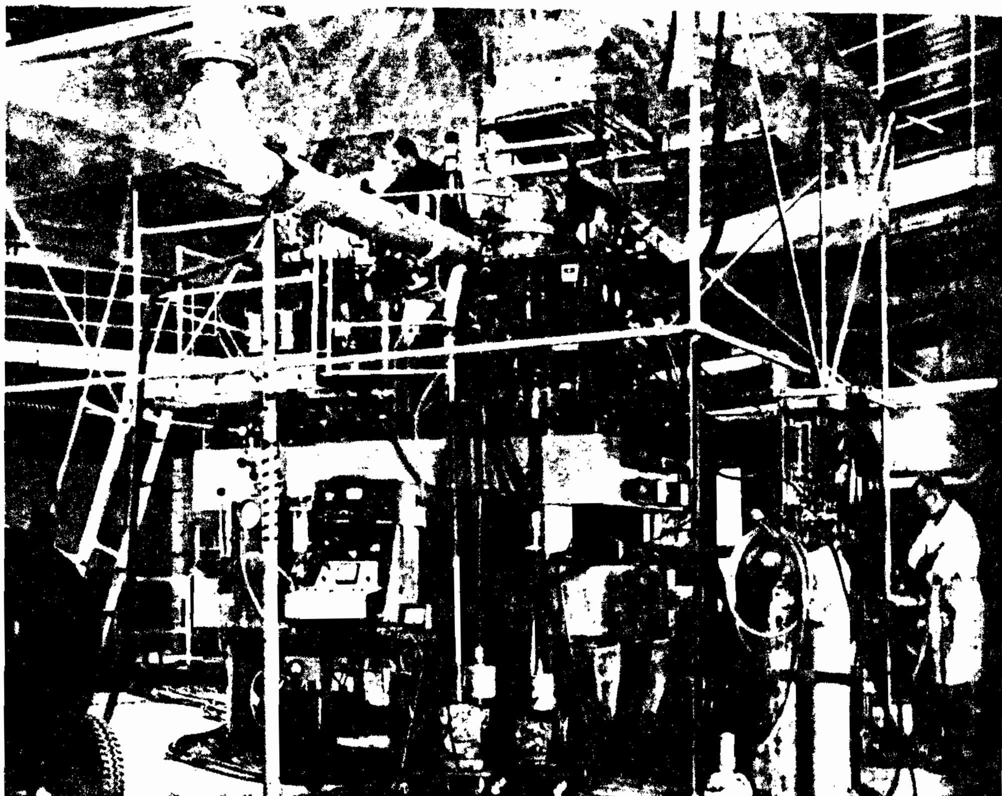


PLATE 8. A BUBBLE CHAMBER at Brookhaven. The 20-inch chamber itself, containing liquid hydrogen, is surrounded with a huge complex of apparatus which illustrates how complicated an affair this machine is. (*Photo Brookhaven National Laboratory*)

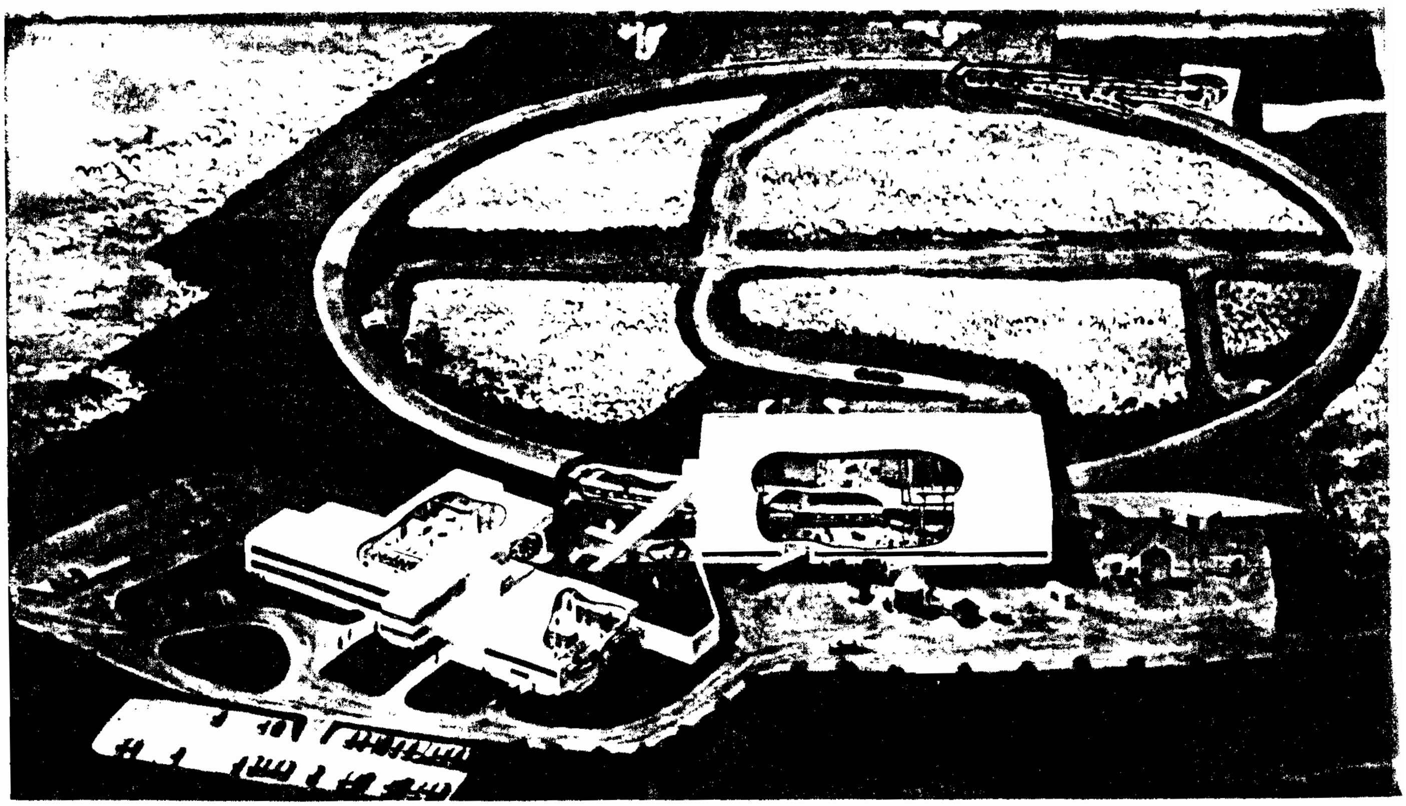


PLATE 7. THE BROOKHAVEN 30-BEV SYNCHROTRON, pictured in a drawing before its completion. Like the CERN acceler[illegible] is buried underground. It has 240 strong-focusing magnets and measures more than 800 feet in diameter. The recta[illegible] building in the center houses the target and instruments. (*Photo Brookhaven National Laboratory*)

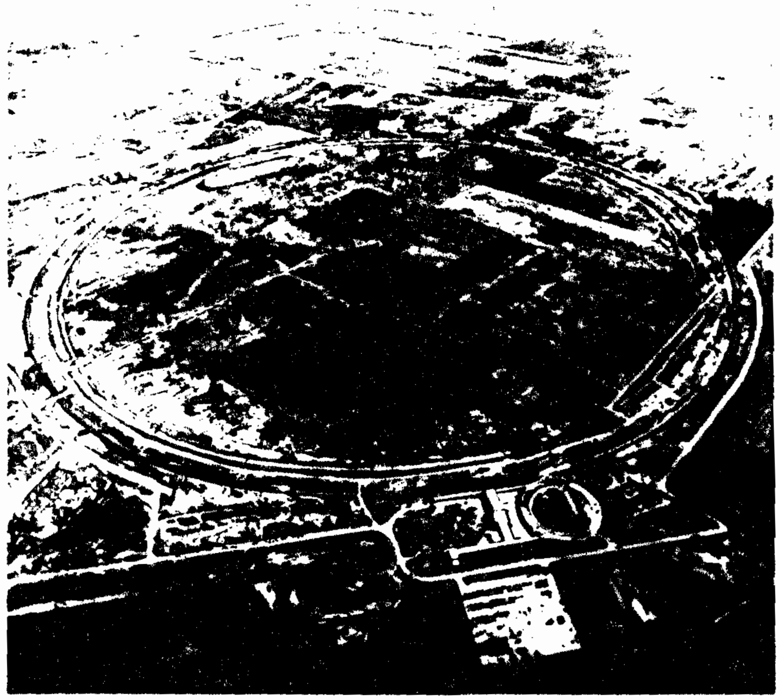


Figure 5-2 An aerial view of the 500 BeV accelerator at Batavia, Illinois. The machine is four miles in circumference and one and one quarter miles in diameter, and accelerates protons to 500 BeV, after these have been helped by a linear accelerator and booster ring shown in the foreground. (Photograph from NAL.)

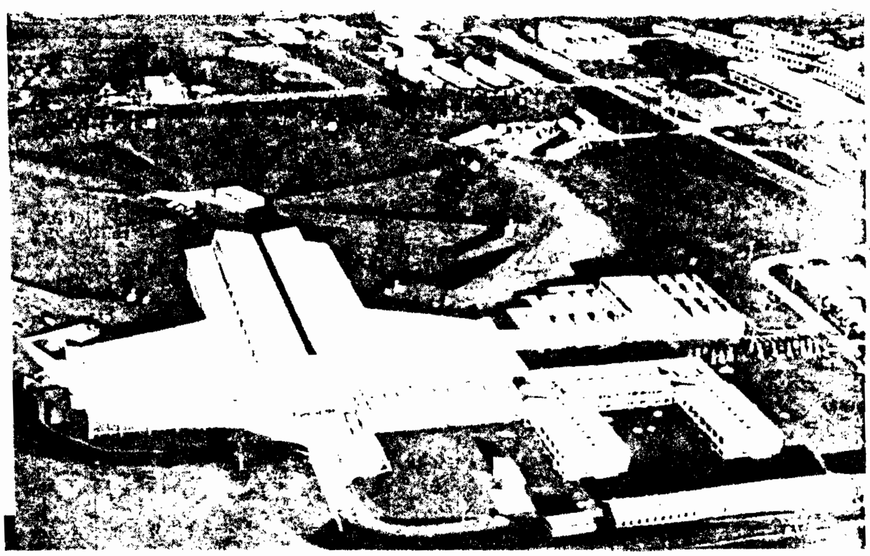


PLATE 5. THE CERN PROTON SYNCHROTRON at Geneva, shown in an aerial view. Its long circular track, enclosed in concrete and buried under earth, forms a wheel 700 feet in diameter. In the foreground is the big building in which experiments with the 28-Bev protons are carried out; in the upper right-hand corner are other laboratories and workshops.

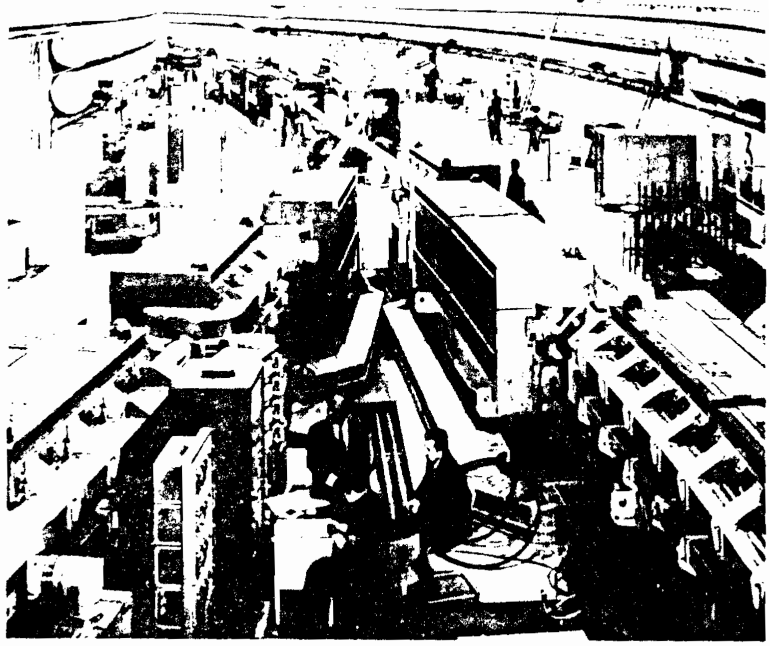
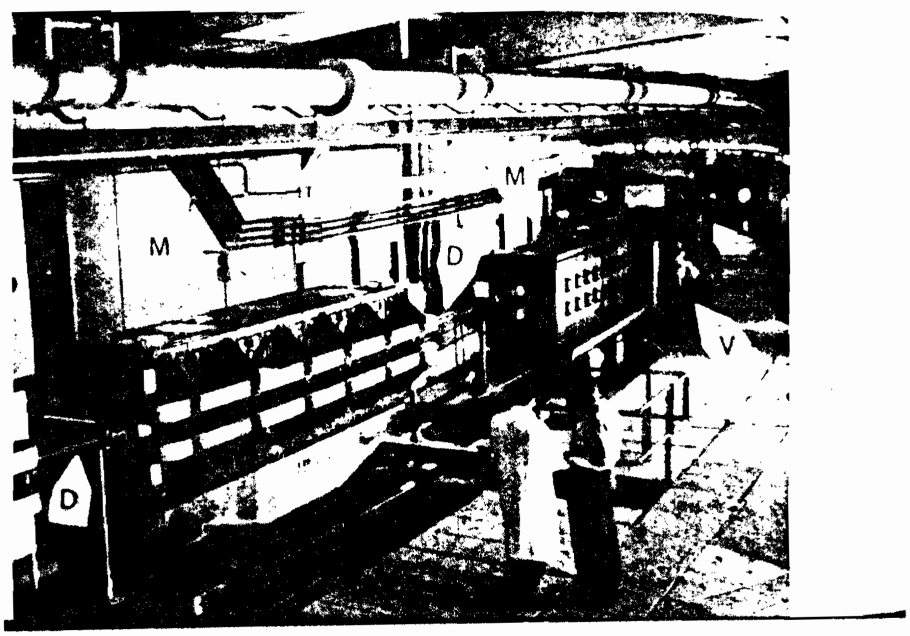


FIGURE 5-3 An intersection point of the intersecting storage rings at CERN. It is fitted out with vacuum chambers shaped in an X, inside which head-on collisions are produced between protons, each traveling with 28 billion electron volts of energy. (Photograph from CERN).

PLATE 6. DETAIL OF THE CERN SYNCHROTRON. *D* points to the narrow track, or doughnut, in which the particles travel; *M* designates magnet sections (there are 100 around the circuit); *V* is one of the vacuum pumps that keep the track evacuated. (*Photo Cern*)

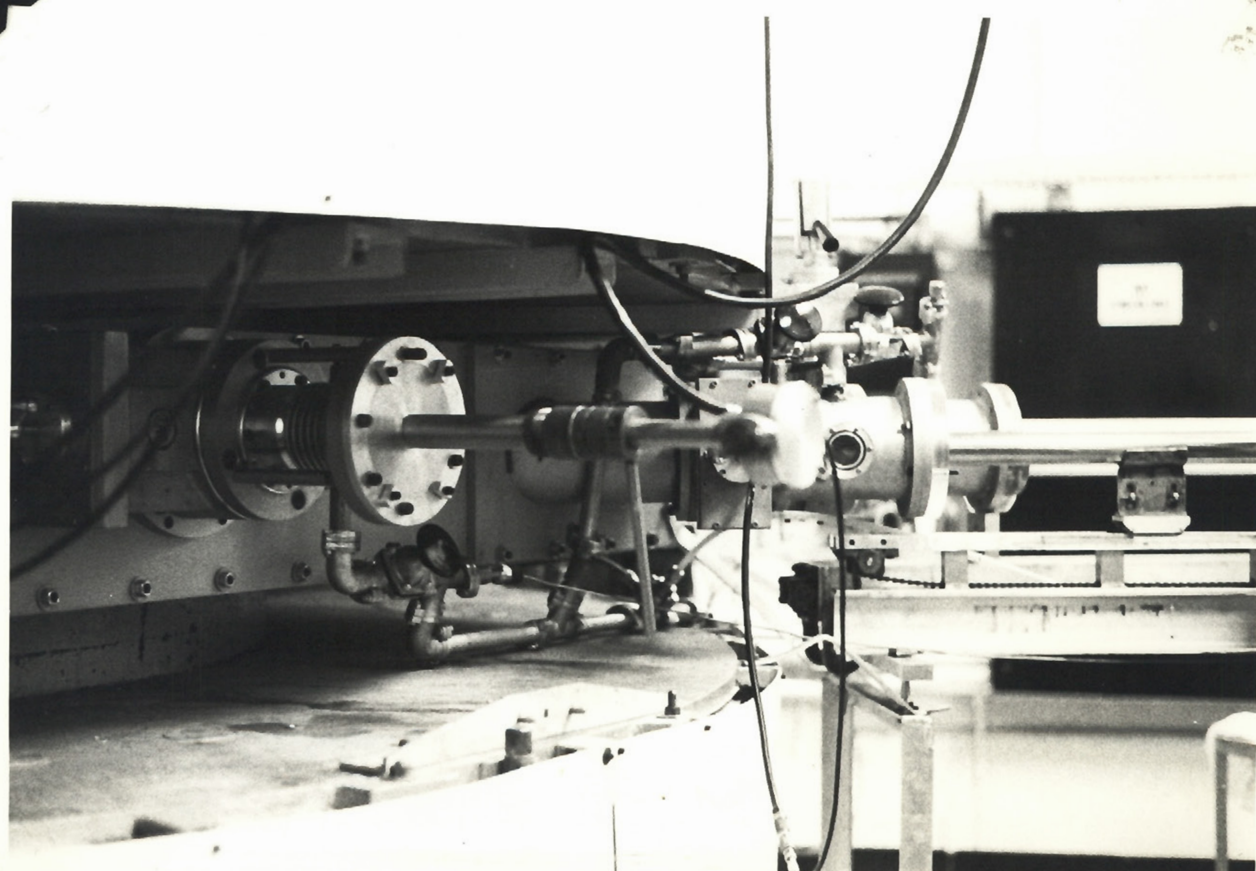


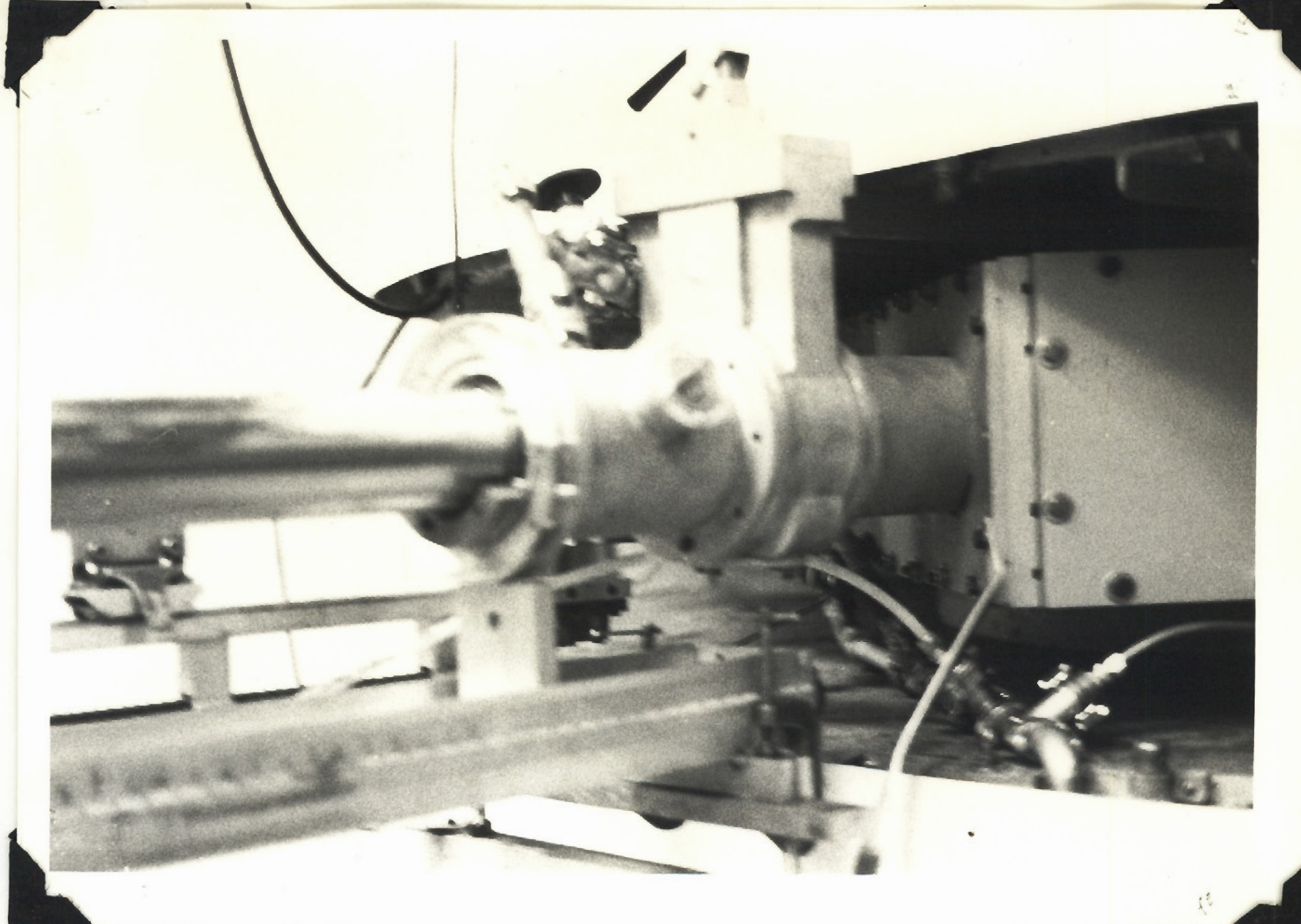
THE McGILL SYNCHRO-CYCLOTRON:

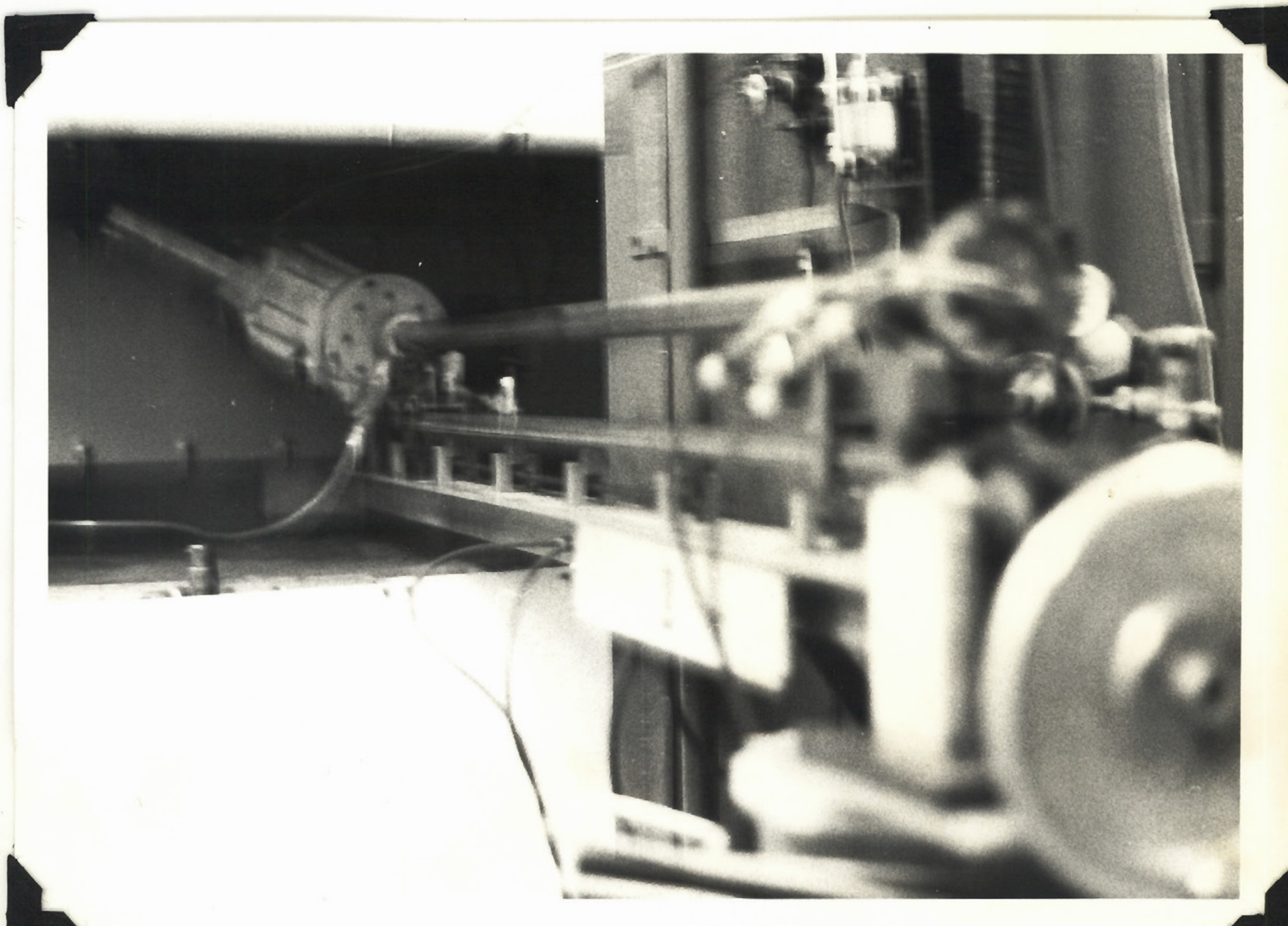
The accelerator at the Foster Radiation Laboratory at McGill University is a proton synchro-cyclotron (synclo). Built in 1949, it was the first synchrocyclotron in Canada. It can bring protons up to an energy of 100 Mev, which today is considered low-energy. While now it is only capable of accelerating protons, it is expected in the near future to accelerate deuterium ions, helium 3 ions, and alpha particles. This will greatly extend the capabilities of this machine. As has been mentioned, synchro-cyclotrons deliver ions in 'spurts'. In the McGill synclo, there is a rest time of two milliseconds and it operates for .5 milliseconds. It delivers $3.15 \times 10^9$ protons per 'spurt' giving an average current of .2 microamperes. The major part of the research done at the McGill synclo is on the half-lives of various isotopes. The visit was very enlightening because it allowed us to see many of the concepts learnt in the course being applied for research which may someday have some use to someone for some reason or other. It is disillusioning to find that the tables accumulated at the Laboratory will be rendered obsolete. However, it was very interesting to see present theory applied, even if it was merely for the benefit of future theory.

In the pages that follow, we shall have pictures and descriptions of some of the features of the McGill synchro-cyclotron.

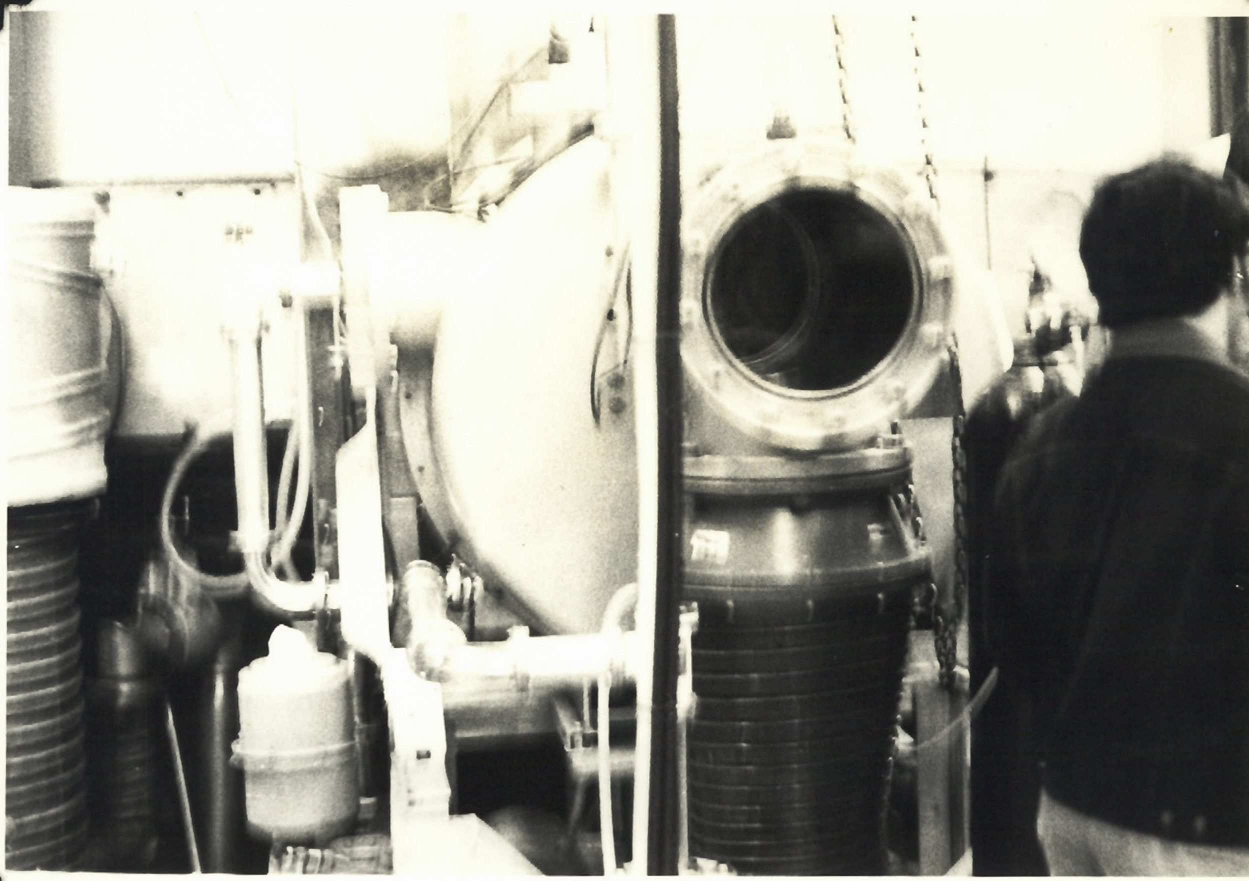
This picture shows the probes with which the target is inserted into the cyclotron. There are three probes: the probes for long, medium, and short half-lives. The probe for the long half-life is manually operated. The probe for the short half-life particles (about 100 milliseconds) is automatically controlled. The one for the medium half-life particles is semi-automatic: it is manually inserted and automatically sent back to the control area for testing. On the next page are two more views of the probes seen here.



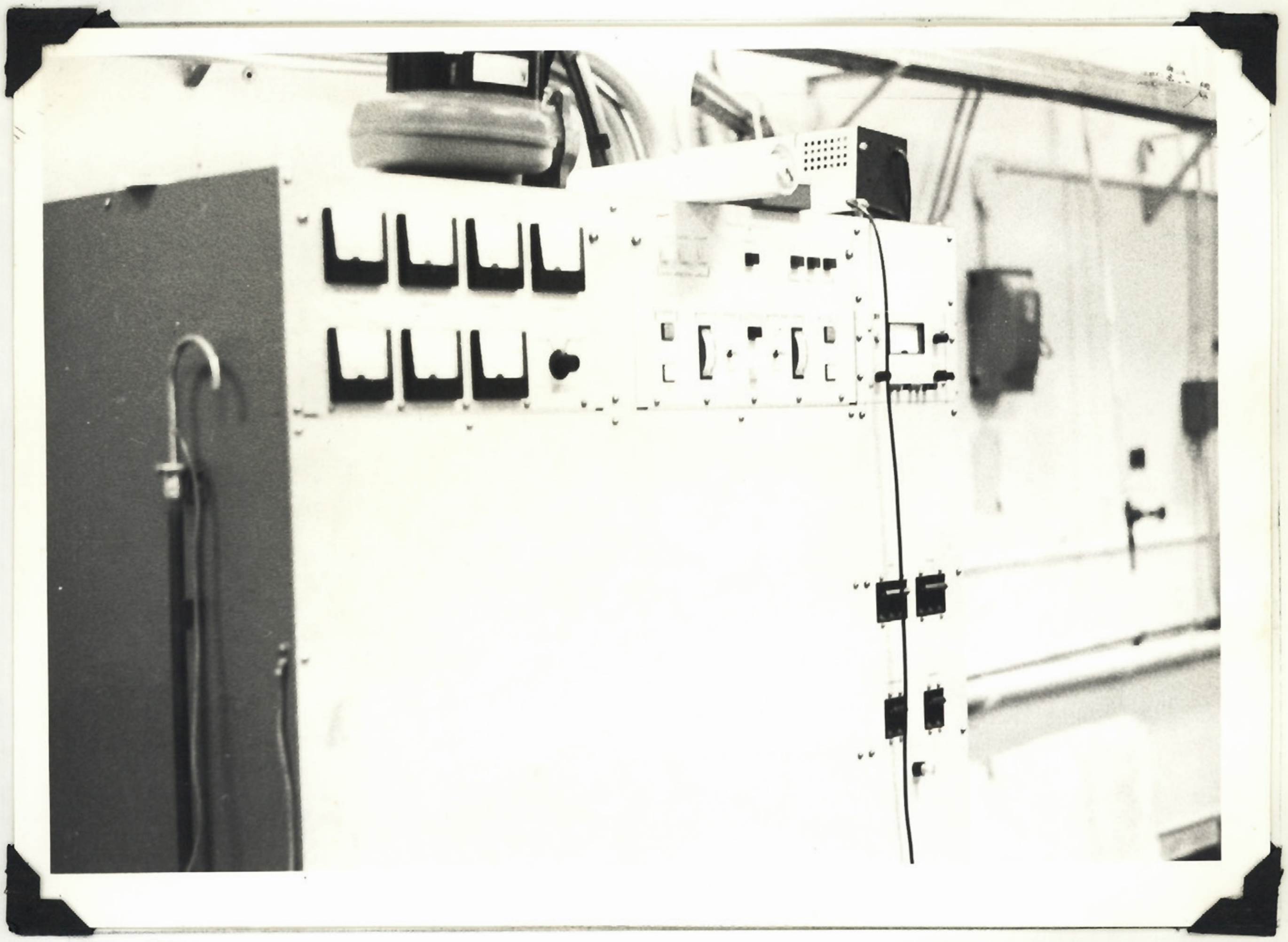




This is a picture of the oscillator which controls the frequency of the voltage to the accelerating dees.

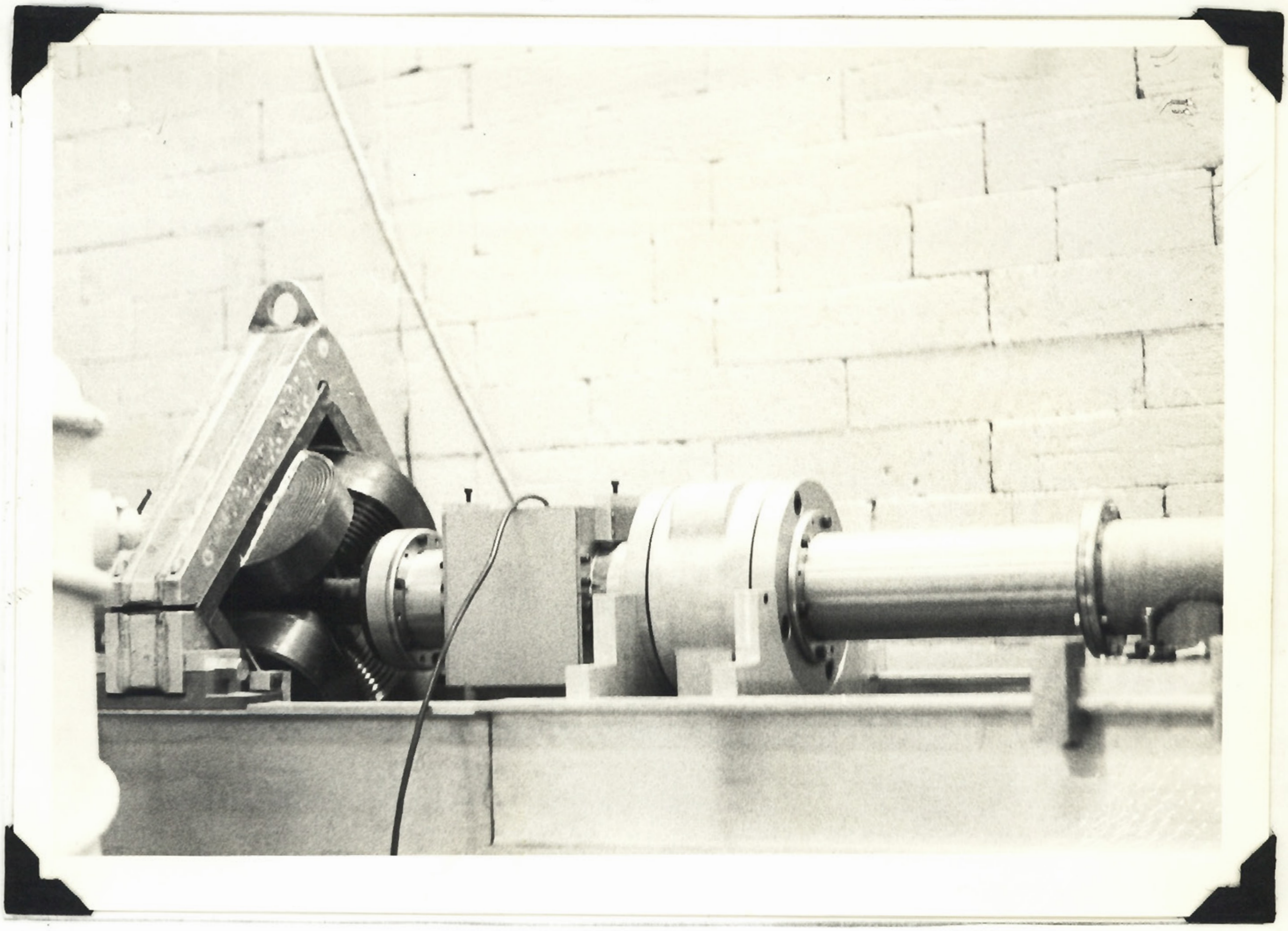


N.B. The blotch to the right is Paul Sebeh, a student, and not the oscillstor.



This is the power supply for the oscillator. It is but one of many power supplies needed to run this synclo and its size helps demonstrate the huge power requirements.

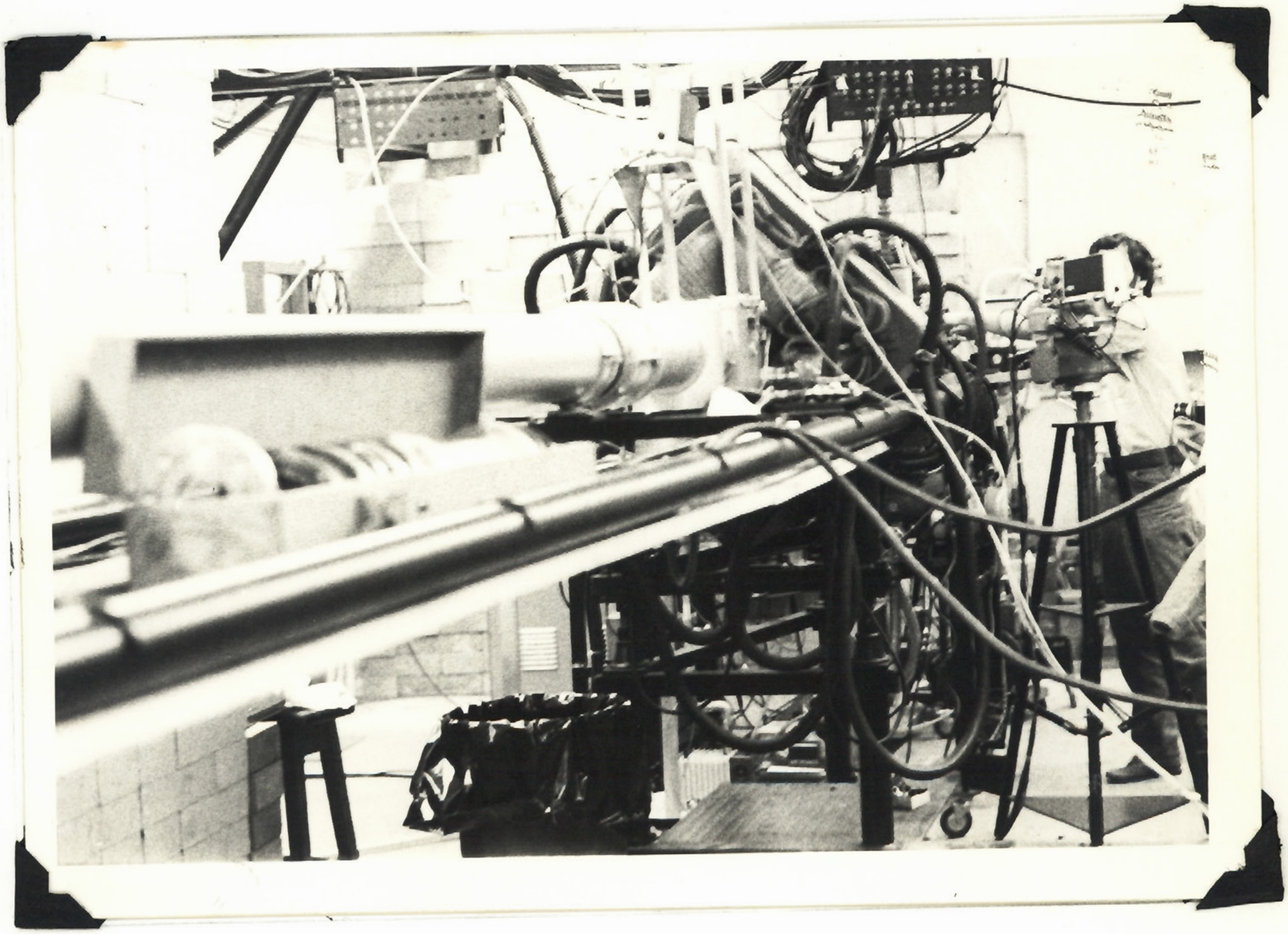
This picture shows the magnet that focuses the external beam from the synclo. Because the external beam can only be extracted from the outer edge of the dees, it is fixed at 100 Mev. Later on, it can be slowed down by an apparatus for this purpose.

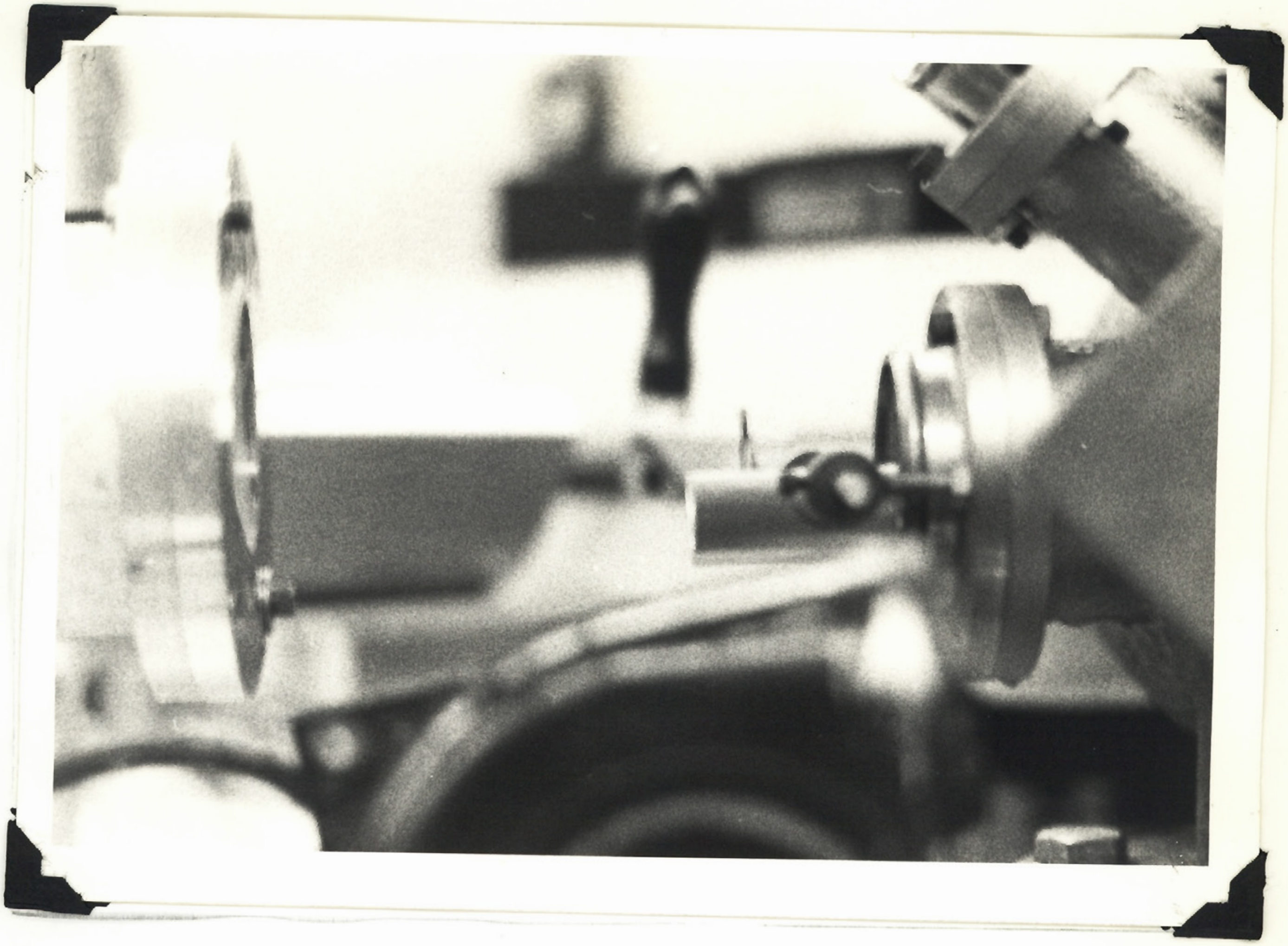


The configuration of the magnets is as such: $S\,{}^{N}_{N}\,S$

This is a bending magnet which steers the beam into the target area.

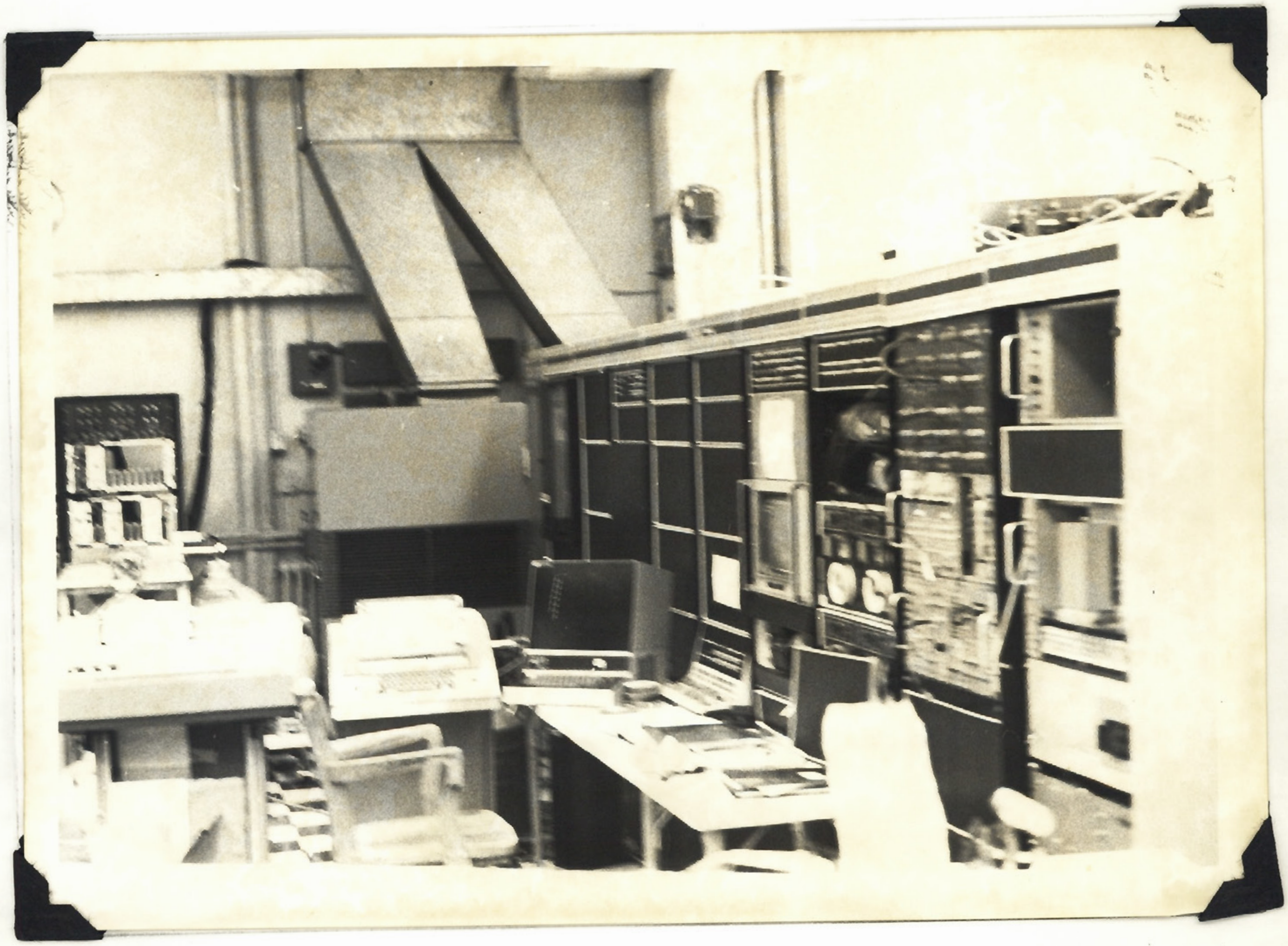
Here we see the beam as it enters the target area where the fission and scattering experiments are performed. Note in the background the "particle stopper" consisting of cement blocks and candy wrappers.



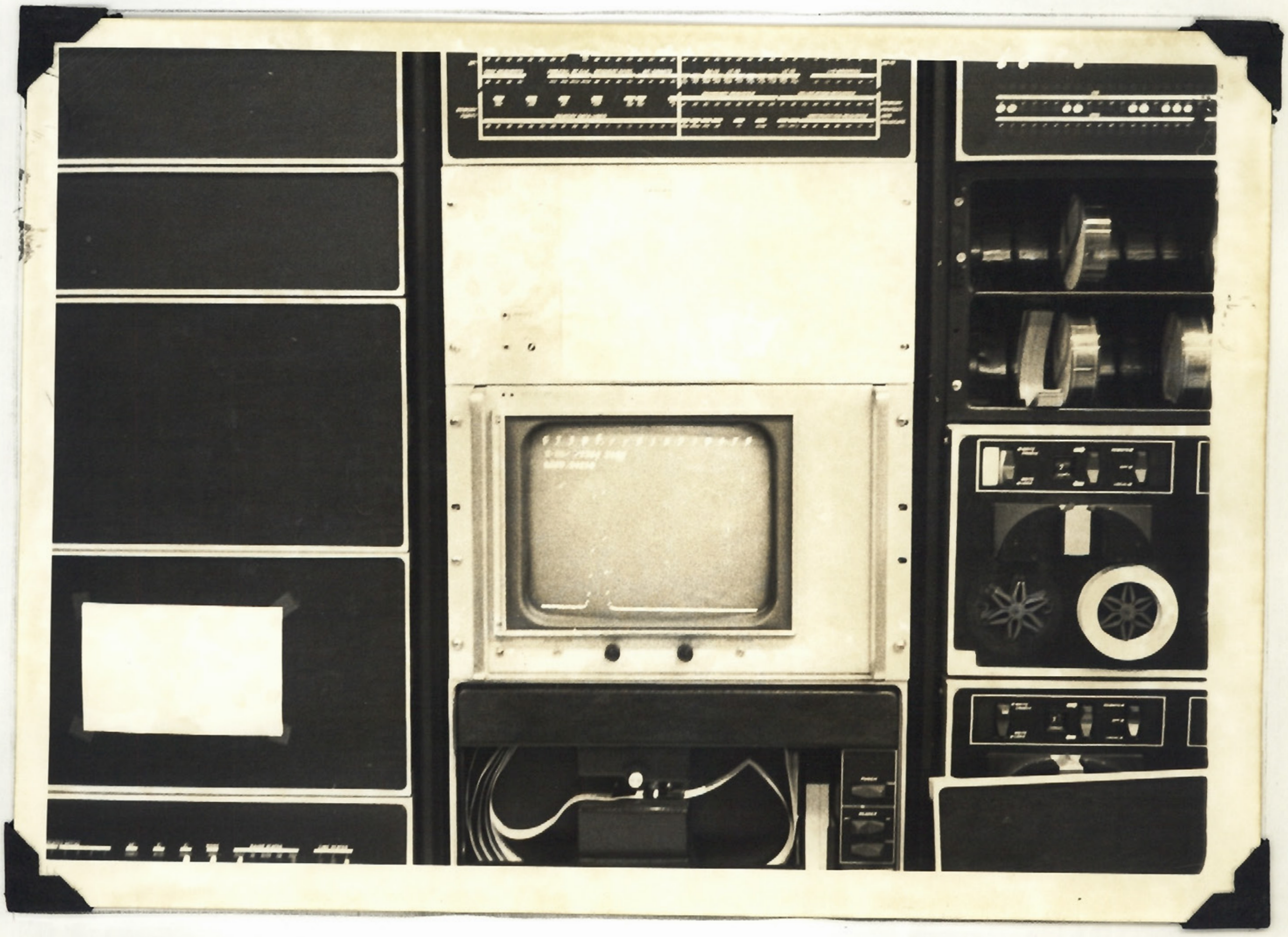


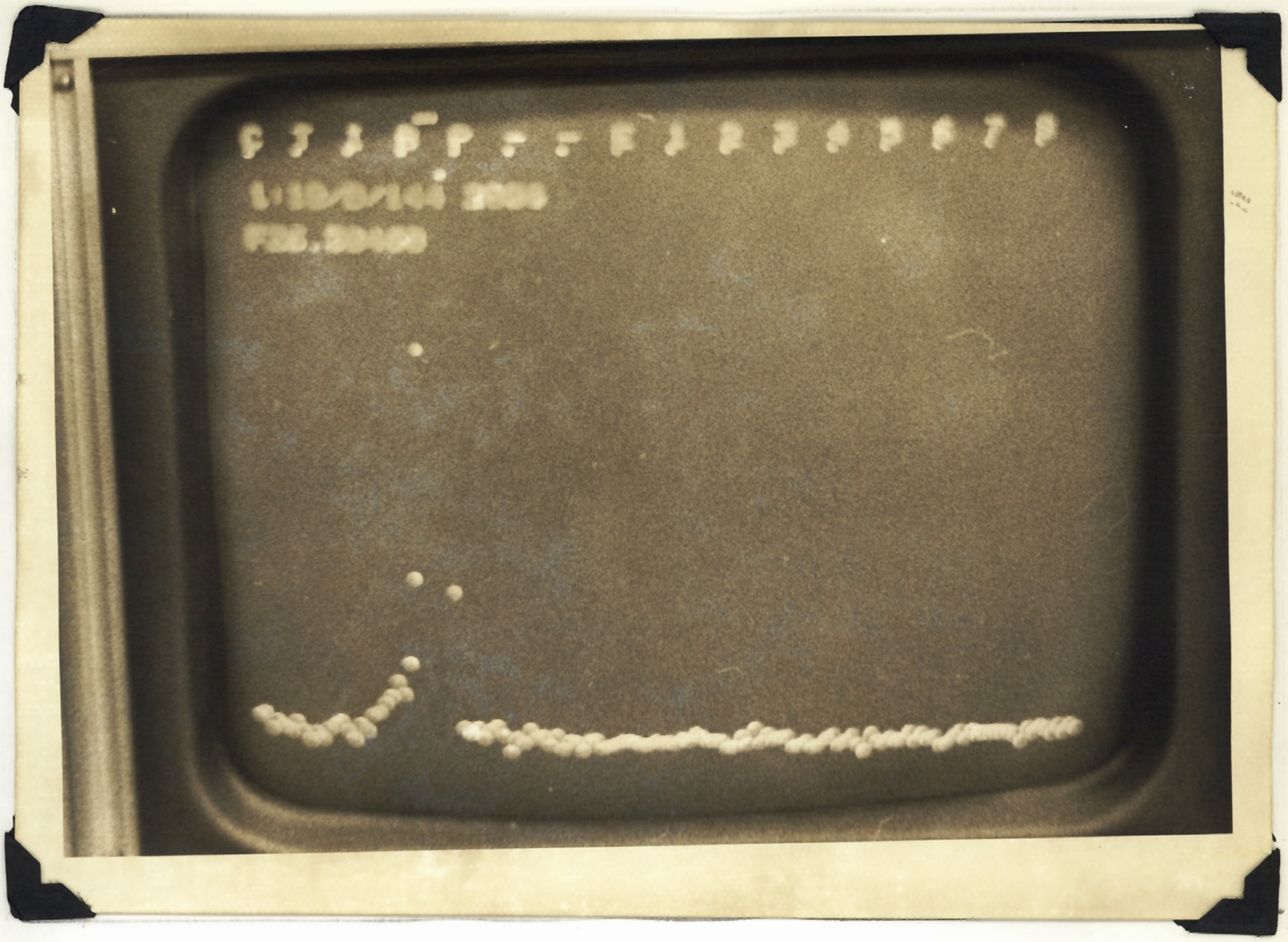
This is the actual external beam target. Behind this is the mass spectrograph that is used to measure the mass of the particles scattered by the proton beam. This gives the scientist informationabout the way fission occurs in the sample. It is interesting to note that with the enormous size of the cyclotron, this is the major point of interest in many experiments.

This is an overall view of the PDP 15 computer and peripherals which control the collection of data. Data from an experiment will usually be stored on magnetic tape for future analysis.



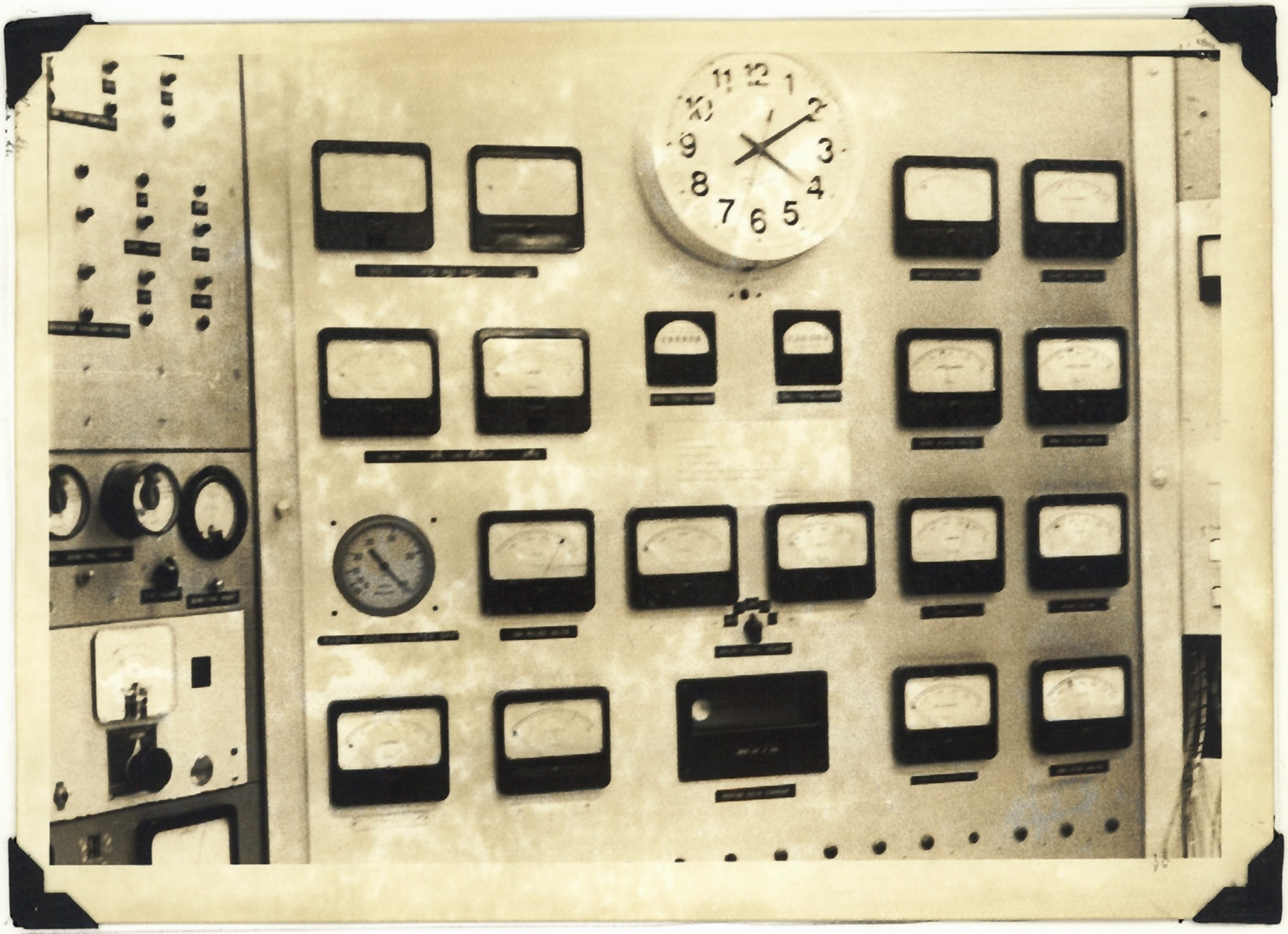
This screen is a graph of the number of particles having particular masses. Other data can also be displayed.



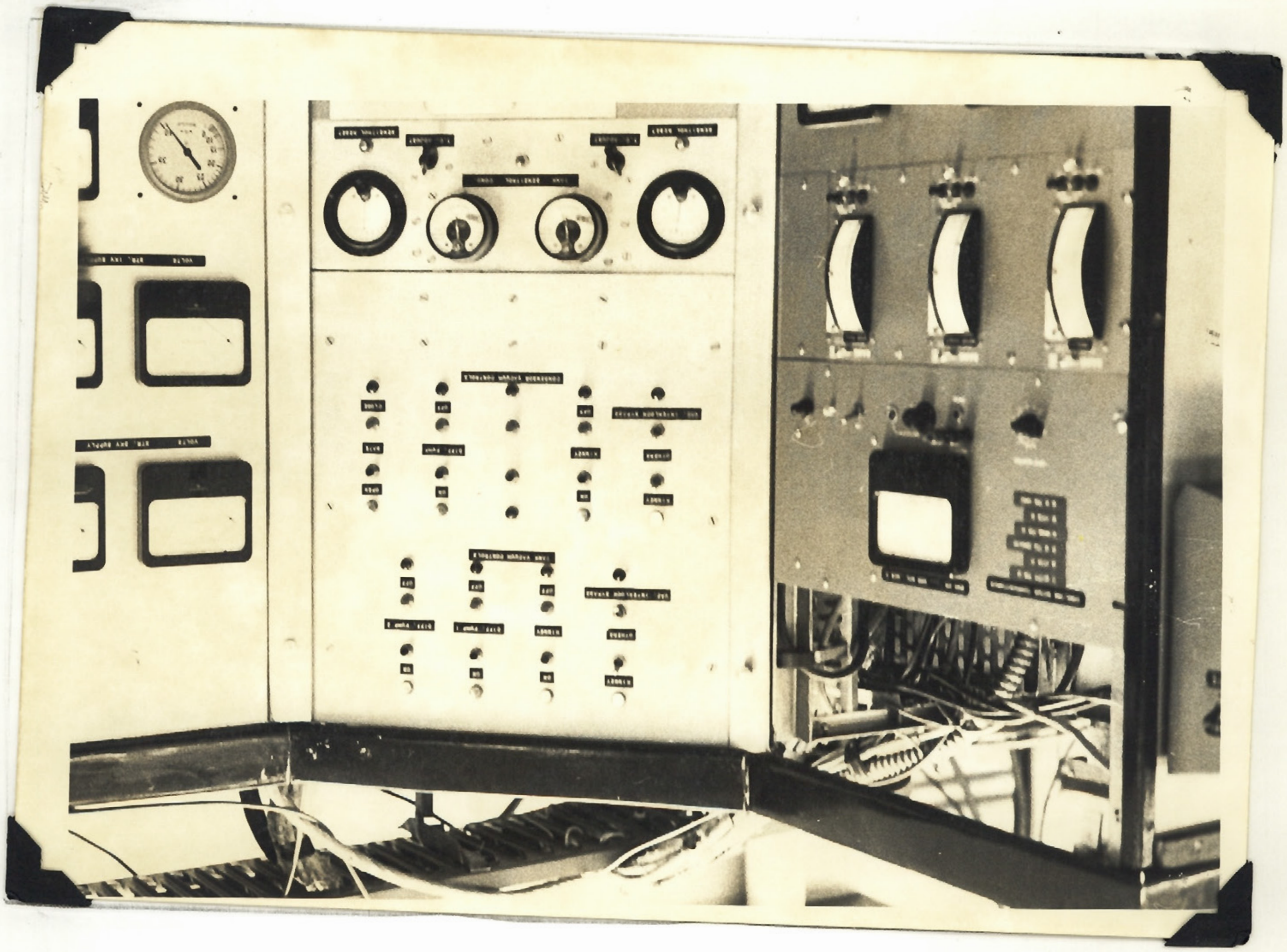


This is a close-up of a larger graph(preceeding page) which shows this section in detail. Any section of the graph can be enlarged by merely pointing at it with a light pen.

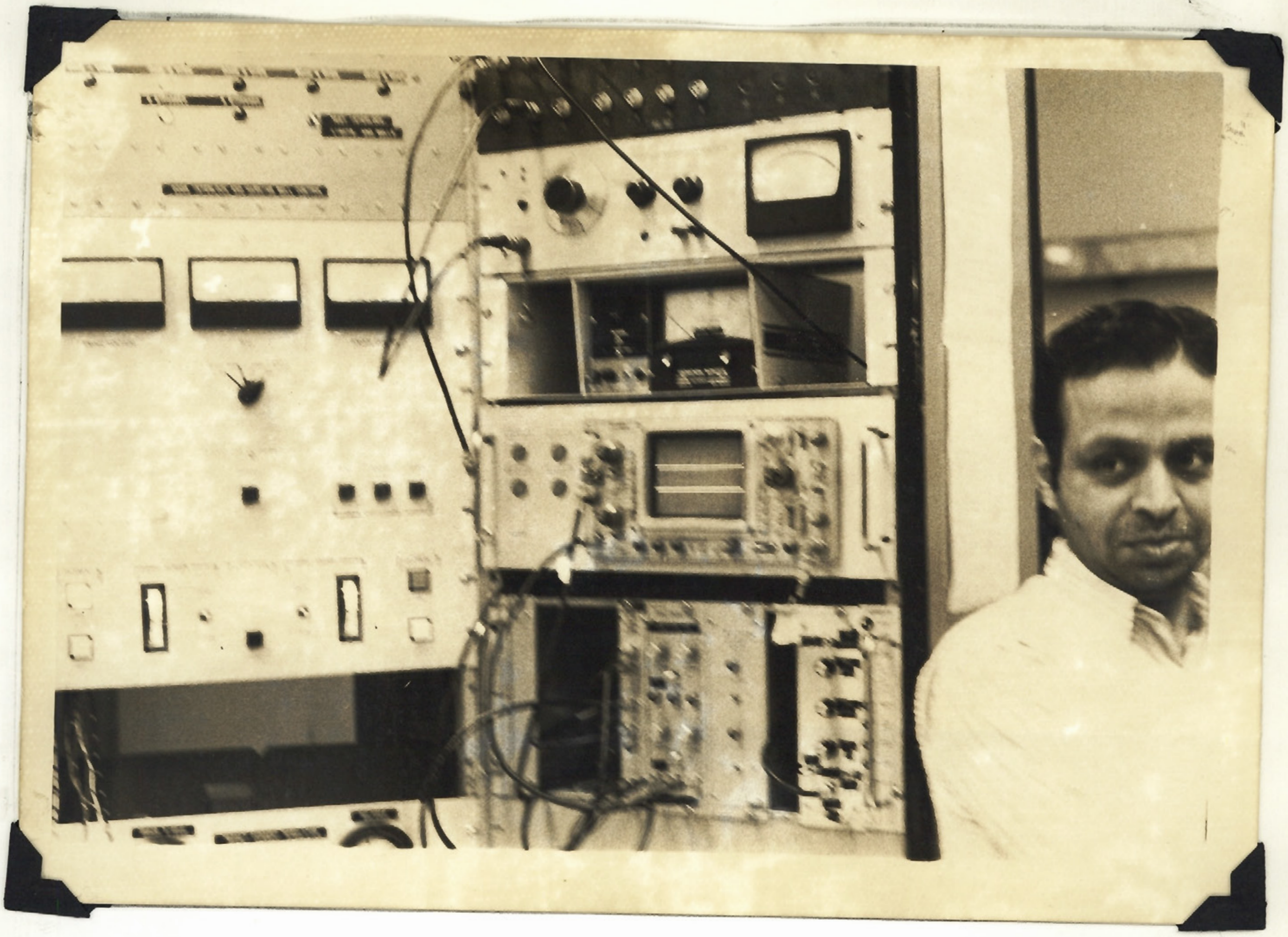
Viewed here is the status indicators of the cyclotron. The beam intensity and other factors are displayed here so that the physicist may adjust for optimum results. The current is displayed on the dark meter, bottom center. The circular object on top can also be used to measure time.



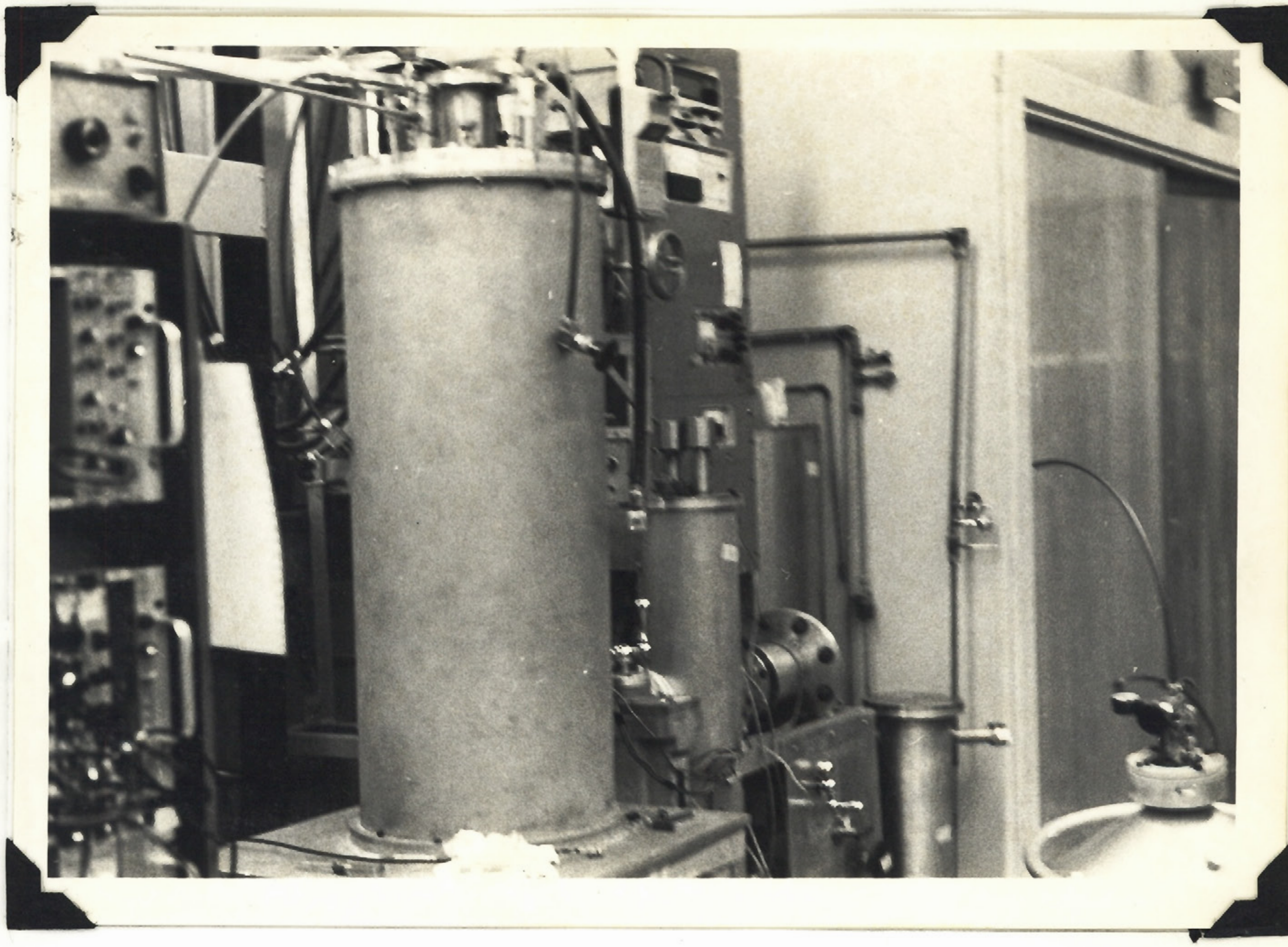
Seen below are some controls for the cyclotron. These are mostly for the control of the vacuum that must be maintained in



the cyclotron. There are safeguards to allow for system shut-down in case of malfunctions. This is necessary because the diffusion pumps which maintain the vacuum would otherwise be destroyed.



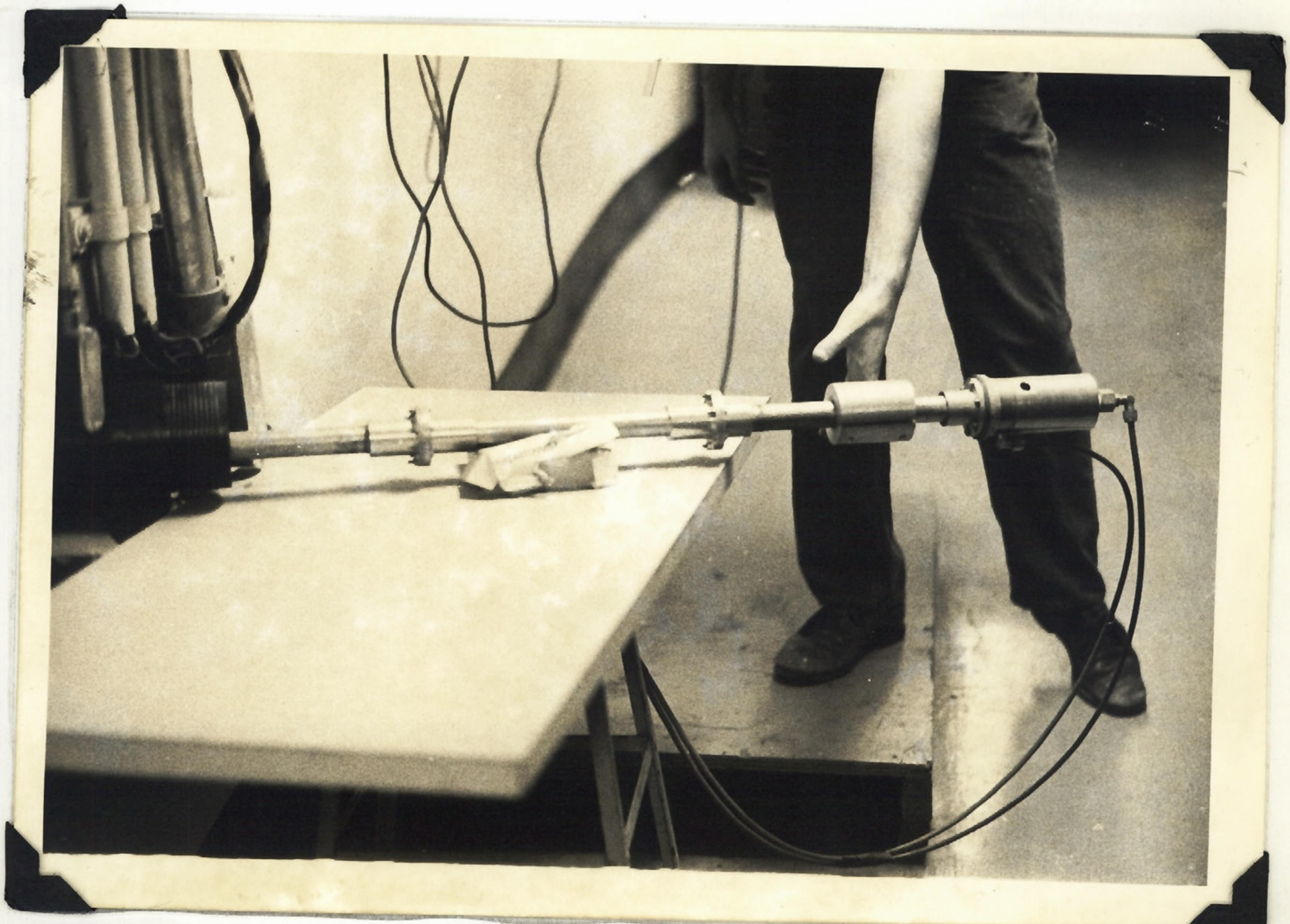
Pictured above are more controls for the operation of the cyclotron. At the bottom are devices which regulate the ejection of protons from the ion source to synchronize them with the changing accelerating field. At the top are more safeguards that insure that the cyclotron is inaccessable during operation. This is because of the dangerous radiation emmited.



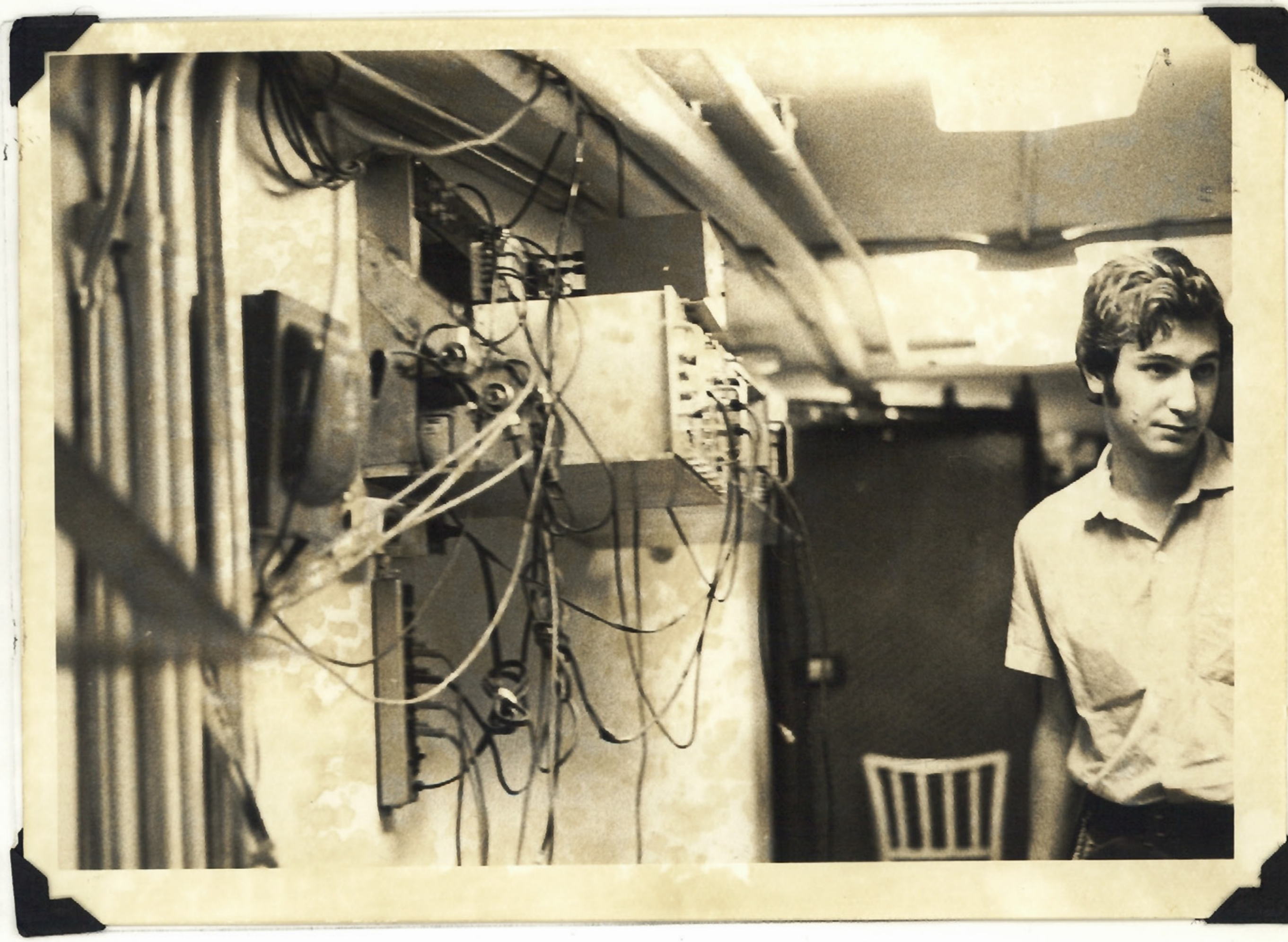
Here we see the super-cooling tank where gamma radiation is studied. The detection is based on charges rather than mass of the particles, and it runs on Helium.

These are the controls and data collecting apparatii for the super-cooling tank pictured on the preceeding page.

Photographed here is the probe where the target with the short half-lives are projected from the synclo at a speed of about 320 km/hour. Here they are tested and returned for further bombardment and retesting.



Seen below are the controls for the automatic operation the probe seen on the preceeding page.



# APPENDICES

DETECTING AND COUNTING ATOMIC PARTICLES:

When Rutherford developed his theories about the atom, he and his assistants had to spend hour after hour in front of scintillation screens. These screens were of zinc blende (Sidot's blende)— a mineral consisting zinc sulphide with a slight impurity of copper. Zinc blende was found to give off flashes of light when hit by alpha particles. This made it possible to count how many alpha particles were being deflected through a certain angle by counting the number of flashes within that region. There were many problems with this method of course: you could only count up to 20 particles a minute; the counting had to be done in complete darkness; frequent breaks had to be taken because there was a heavy strain on the eyes; and there was a tendency due to fatigue or excitement to imagine scintillations. In 1908, Rutherford and Hans Geiger designed an instrument that worked on the principle that an alpha particle passing through a gas would ionize about 100,000 molecules. This could then be detected. This device was faster than the former method and an indication of how many molecules were ionized by a particle was also possible. However, at the time, great discoveries did require the sophistication of today. The scintillation method continued to be the primary observation procedure. After the First World War, vacuum tubes made the detection of alpha particles by the ionizing method more accurate and also more pratical. The above apparati could be used for the counting of alpha particles and prot ons. Neutrons could also be detected by the results of their colliding with an atom sending out fast-moving protrons.

There are other forms of radiation cannot be measured in the above ways. Beta rays (fast-moving electrons) and gamma rays (high frequency radiation similar to X-rays) do not cause large amounts of molecules to be ionized. Until 1928 it was necessary to use photographic plates or electroscopes to study the accumalative results of many such occurences. In 1928, Geiger and W. Müller found a modification to the Rutherford—Geiger counter that would allow the detection of a particle even if only one ion was created. They did by raising the voltage so that one ion would cause an "avalanche". The idea involved is the same as "super-saturation" in a gas tube diode. As soon as an ion is formed, it is attracted by the high voltage. The voltage accelerates the ion to a speed that is sufficent to ionize any molcule it happens to hit. These new ions are also sped up and strike other molecules causing even more ions to be formed. They also figured out a way of suppressing the discharge automatically

The number of discharges is counted by a device attached to the tube. The physicist had only to check the counter before and after the time period he was interested in studying.

Walter Bothe was the first one to think of using two counters to detect simultaneous events. For instance, a scientist could the number of times a beta particle was emitted accompanied by a quatum of gamma radiation. There are limitations with this device also. The time between the particle's entering the counter's tube and the corresponding electric discharge varies from one particle to another by about one-millionth of a second. Therefore, the time delay between the two events you wish to observe cannot be less than one one-millionth of a second because otherwise you would miss some of the events you wished to study.

The Geiger counter also has a slow recovery time of 1/10,000 of a second before it can detect the next occurence. It is also a poor detector of photons. These problems were overcome with a brillant new type of counter. What is this fantastic device? It's merely the good ol' scintillator with one important difference: a photomultiplier replaces the human observer. The new breed of scintillators can resolve "coincidences" down to one ten-billionth of a second. They can also be used to sort the detected particles into different energy levels.

These particle detectors play an important role in nuclear physics. No matter how large an accelerator you have, it is completely useless unless you can find out what happens when the beam hits the target. The detectors described above help the scientist know what is happening. Together with particle accelerators, they are helping science unravel the mysteries of the atom.

ATOMIC PARTICLES:

In dealing with accelerators, we mustn't limit ourselves to the machine itself. For, as any physicist will tell you, the machine is just a tool used to discover new particles or in some cases to examine the properties in detail of 'old' particles. It was quite an event when the atom was found to have internal constituents, namely the neutron, proton and electron. However, with the research data obtained in the experiments using the accelerators, these 'fundemental particles' were found to have constituents themselves. Today, we know of over three hundred (the last count we found in our references) 'elementary' particles amongst which are the muons, pions, neutrinos, mesons, hyperons, etc. Further research with higher power accelerators might reveal constituents for these and constituents for the constituents, ad infinitum. In this chapter, we will discuss a few of these particles which are the result of experiments using particle accelerators.

When dealing with particles, physicists like to obtain a picture which seems to explain everything as simply and precisely as possible. When the electron was identified just before the turn of the century (as being a part of the atom), this upset the nice, neutral equilibrium. Since it was contained in every atom, and had negative charge, this gave an all-around negative aspect to our universe. When, twenty years later, the proton was discovered and found to have the same magnitude but different sign charge as the electron, this made physicists happy because it restored the neutrality of matter, in that the positive and negative charge cancelled out. But the relief was only temporary. Scientists started wondering why electrons were always negative, and protons always positive. The answer? They weren't. Positrons, identical to electrons but opposite in charge were discovered in 1933. What had made them so elusive as particles is that when a positron passes through matter, it has a high probability of encountering its 'anti-particle', the electron. When these two collide, they not only neutralize but rather annihilate each other. As a result of this and because of the law of conservation of mass-energy (see figure 4:1), electromagnetism (electromagnetic waves) are given off. The only reason positrons were discovered at all is because they were produced by artificial means with accelerators, or they occured naturally as a result of the decomposition of unstable particles.

In 1930, a Swiss scientist, Pauli, postulated the existence of a new, yet unknown particle which the Italian scientists would soon call the "neutrino". His hypothesis was based on the fact that beta particles given off in the radioactive decay of the neutron did not always have the same energy. In order to keep the aforementioned law of conservation of mass-energy intact he proposed a neutral particle, which would be given off with randomn amounts of energy each time. At first, scientists were sceptical, but the evidence obtained by other researchers in the field soon led to the inescapable conclusion that the neutrino actually exists. In 1956, it was actually proven. It was found that when a neutron decays, a proton and electron are given off and that when a proton decays, a neutron and a positron are given off. They knew that neutrinos were also given off, but they still didn't know why. It was explained later when protons, neutrons, electrons and positrons were found to have spin. If neutrons were to turn into protons and electrons, these latter would have to have their spin add up to that of the original. But all were found to have a spin magnitude of one. Whereas this yielded a spin of one for the neutron, and either zero or two for its products, a neutrino would solve the problem if it had a spin of magnitude one also. The neutrino was therefore used to conserve spin. To this day, however, the neutrino has remained one of the most interesting and distant particles ever discovered.

The discovery of mesons was a result of many years work. Their existence had been hypothesized by a young Japanese mathematician, Hideki Yukawa in 1935. He had been trying to explain the force which holds the nucleons, (the protons and neutrons that make up the nucleus), together. It couldn't be an electric force which would repel the protons rather than have them attract and would have no consequence on the neutrons. It couldn't be a gravitational force which would be much too small and would be overcome by the greater electric force anyway. Yukawa said that the nuclear force was analagous to electromagnetic forces outside the nuclear realm. However, his nuclear quanta, implied by his nuclear force, had mass. He guessed the mass to be three hundred times the mass of the electron and to be electrically charged. Cosmic radiation, the 'fine incessant rain of very fast protons that enter our atmosphere from the depths of space', was found to contain these particles, called pi-mesons, or pions. Upon hitting a nucleus, a pion is transformed into energy, which serves as the nuclear "glue" for atoms. If a proton were to hit a nucleus the energy transmitted might be enough to split the atom and materialize the pions. This is what is done in our accelerators which can now produce pions by the millions. As an extra note, one can add that there are positive, negative and neutral pions. Whereas the positive and negative are antiparticles of each other, the neutral pion is its own antiparticle! Indeed, every existing particle is believed to have its antiparticle, with opposite spin and electrical charge (if they have any).

The use of accelerators has allowed us to discover many more of these particles and we now believe there are over 300 of them. The increasing energy of accelerators brings with it new discoveries every time, and there is apparently no limit to how high we can reach. What discoveries will some day be made, no one knows.

In order to maintain the brevity of this project, other particles such as Xi hyperons, Sigmas, K-mesons, etc. will not be discussed.

Though we previously said that research might reveal these particles to be compounds of other particles, some scientists give reason for believing that these are fundemental particles. They say that if one particle breaks up into particles which can then decay into the original, then the particles are not really compounds. My only doubt here is that this is also true of protons decaying into meutrons back into protons, and yet scientists are still searching for the supposed constituents of protons: the quarks. If quarks are ever found, it will most probably be with the use of PARTICLE ACCELERATORS.

| Name | Symbol | Mass | Lifetime | Spin | Charge |
|---|---|---|---|---|---|
| Photon | $\gamma$ | 0 | $\infty$ | 1 | 0 |
| Neutrino | $\nu$ | <2 | $\infty$ | 1/2 | 0 |
| Electron and Positron | $e^-$ $e^+$ | 1/2 | $\infty$ | 1/2 | -1 +1 |
| Mu-Meson | $\mu^\pm$ | 106 | $10^{-6}$ | 1/2 | ±1 |

a. Leptons

| Name | Symbol | Mass | Lifeline | Spin | Charge |
|---|---|---|---|---|---|
| Proton | $p$ | 938 | $\infty$ | 1/2 | +1 |
| Neutron | $n$ | 939 | 1,000 | 1/2 | 0 |
| Lambda | $\Lambda^0$ | 1115 | $10^{-10}$ | 1/2 | 0 |
| Sigma Plus | $\Sigma^+$ | 1189 | $10^{-10}$ | 1/2 | +1 |
| Sigma Zero | $\Sigma^0$ | 1193 | $10^{-14}$ | 1/2 | 0 |
| Sigma Minus | $\Sigma^-$ | 1197 | $10^{-10}$ | 1/2 | -1 |
| Cascade Minus | $\Xi^-$ | 1321 | $10^{-10}$ | 1/2 | -1 |
| Cascade Zero | $\Xi^0$ | 1314 | $10^{-10}$ | 1/2 | 0 |

b. Octet of Baryons

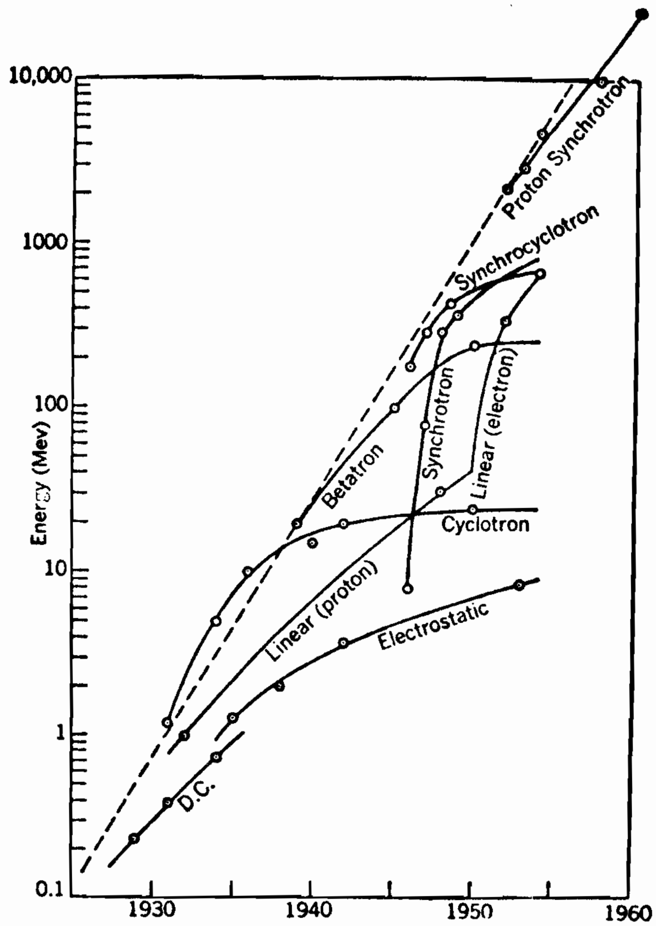
| Name | Symbol | Mass | Lifetime | Spin | Charge |
|---|---|---|---|---|---|
| Pi Plus | $\pi^+$ | 140 | $10^{-8}$ | o | +1 |
| Pi Minus | $\pi^-$ | 140 | $10^{-8}$ | o | -1 |
| Pi Zero | $\pi^0$ | 135 | $10^{-16}$ | o | o |
| Kay Plus | $K^+$ | 494 | $10^{-8}$ | o | +1 |
| Kay Zero | $K^0$ | 498 | $10^{-8}$ or $10^{-10}$ | o | o |
| Kay Zero Bar | $\bar{K}^0$ | 498 | | o | o |
| Kay Minus | $K^-$ | 494 | $10^{-8}$ | o | -1 |
| Eta | $\eta$ | 549 | $10^{-21}$ | o | o |

c. Octet of Mesons

TABLE 5–1 The "Elementary" Particles.

| Name | Symbol | Mass | Lifetime | Spin | Charge | Nucleon Number |
|---|---|---|---|---|---|---|
| $p$-Quark | $p$ | Unknown | Unknown | 1/2 | 2/3 | 1/3 |
| $n$-Quark | $n$ | " | " | 1/2 | -1/3 | 1/3 |
| $\lambda$-Quark | $\lambda$ | " | " | 1/2 | -1/3 | 1/3 |

TABLE 5–2 The Possible Fundamental Building Blocks: The Quarks.




THE RISE IN ENERGY achieved with successive types of accelerators in the last 30 years (as charted by M. S. Livingston).

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