

Review of the Oslo Cyclotron Laboratory

Introduction

At the request of the Faculty of Mathematics and Natural Sciences of the University in Oslo, a review was performed of the Oslo Cyclotron Laboratory. The committee consisted of Professor Gary Mitchell, North Carolina State University, Raleigh, North Carolina, USA; Professor Örjan Skeppstedt, Manne Siegbahn Laboratory, Stockholm, Sweden; Professor Arne Skretting, The Norwegian Radium Hospital, Oslo, Norway. The specific charges were as follows:

1. evaluate the scientific results of the activity at the Cyclotron Laboratory and their importance in a national and international context.
2. evaluate the suitability of the cyclotron as a scientific instrument for future research in experimental nuclear physics.
3. evaluate possible advantages of an “in-house” laboratory compared with an “off-site” research program in relation to research and education, from scientific, pedagogical, and economical perspectives.
4. evaluate the future role for the Cyclotron laboratory for research in other disciplines, such as Chemistry, Medicine, and the planned PET-network.
5. evaluate the production of master and doctor candidates over the last five years.

A large amount of documentation was provided to the committee prior to the review. The committee spent one day with key representatives of the Cyclotron Laboratory and with related researchers and several present and ex-students from the laboratory. The committee then spent an additional day in discussing our individual evaluations of the strengths and weaknesses of the overall program at the Cyclotron Laboratory and the future prospects under various options.

Below we address the five mandates presented as our charge in the evaluation process. Then we summarize briefly our conclusions and recommendations.

1. Scientific results of the activity within nuclear physics at the cyclotron laboratory

Within nuclear physics the primary scientific focus of the Oslo Cyclotron Group in recent years has been on a method that determines simultaneously the nuclear level density *and* the γ -ray strength function from a set of primary γ -ray spectra. The basic assumption behind the method is that the probability of γ decay is proportional to the product of the final state level density ρ and a γ energy dependent factor F . (The factor F is proportional to the γ -ray strength function.) Via an iterative method, the factors ρ and F are separately determined.

This unique approach is important for a variety of reasons: the method permits the determination of the level density in a region that is very difficult to measure experimentally (above the low-lying states and below the nucleon separation energy) and perhaps even more importantly provides a determination of the γ -ray strength function at rather low γ -ray energies. This approach has attracted a great deal of attention internationally. Naturally the primary attention has been on the anomalies observed – plateaus in the level density have been interpreted as the breaking of nucleon pairs, secondary (pygmy) resonances have been observed in the γ -ray strength functions, and even

more strikingly there is evidence of enhancement of the γ -ray strength function at low energies in light and medium weight nuclei. These results are very important for astrophysical processes and highly relevant for studies of nuclei far from stability (the driving forces behind the RIA project).

These efforts are certainly well respected by the international nuclear physics community. What is even more striking is that this (recent) high volume and high quality work has been achieved by such a small group with such limited resources. Much of the recent increase in research productivity (publications and talks) may have been the result of a natural cycle – following extensive development of equipment and analysis methods, the recent focus has been on experimental results.

The recent results have attracted significant theoretical interest. The anomalies in the level density are widely accepted as evidence of pair breaking; the “pygmy” resonances will attract much attention once their character is definitively established; if confirmed the enhancement of the γ -ray strength function at low γ -ray energies will attract even more attention. The various thermodynamic interpretations are quite interesting and provocative, but speculative. The statistical mechanics of such a small isolated system remains a topic to be fully developed.

A number of the publications are quite important: for example in the past three years key papers include reference #'s 46, 57, 67, 83, 87, 90, 105, 108, and 116. Concrete evidence of the international interest is displayed by the large number of talks at key international conferences, such as reference #'s 49, 50, 51, 52, 64, 78, 81, and 109.

In summary, the Oslo Cyclotron Group has produced a large body of work that is well received internationally. Of special note is the recent upsurge both in publications and in recognition.

2. The cyclotron as an instrument for future research in nuclear physics

The suitability of the cyclotron as an instrument for scientific research divides rather naturally in shorter and longer-term time scales. In the shorter term – at least three years, perhaps five – we anticipate a natural development and extension of the existing research activities. This new method has provided a number of interesting results, which deserve more detailed study. One could fruitfully study the pair quenching, the “pygmy” resonances, and γ -ray strength function enhancement for several years. The group should thoroughly establish the range of validity of the method – a few measurements have been made in light and medium mass nuclei, but these should be extended. This extension to lighter masses will increase interest in the method, with added attention from astrophysicists and applied physicists. These efforts can be performed with the present equipment, but would be greatly enhanced with improved detector systems. The cyclotron itself seems reliable and adequate for these efforts.

Naturally the available personnel limit these efforts. With additional personnel it should be possible to pursue these efforts much more aggressively, or to branch out in other directions. There are very few places in the world to perform the experiments that the Oslo group has pioneered, and probably none that permit lengthy experimental studies of these phenomena. It would seem very natural to have increased use of the cyclotron by outside researchers; increased collaborations that utilize the Oslo cyclotron should be encouraged, as should an increased number of scientific visitors.

For the longer term the cyclotron itself should continue to be a serviceable scientific instrument. Modernization of the control systems would seem in order. The issue of future scientific research direction is more problematic. This choice will be critical for the long-term viability of the research

program. The group suggested that the addition of a neutron detector array would permit extension of the present studies above the neutron threshold. This is a very interesting idea that fits within the framework of past and present research efforts, but such an important decision can only be evaluated on the basis of a detailed proposal. A proposal that focuses on the longer term research activities at the cyclotron would appear warranted on the three to five year time scale. Extending the present approach to include neutron detection is certainly one very interesting possibility.

3. The cyclotron as an “in house” laboratory

As pointed out in the earlier sections, there are few places in the world to perform the research that the Oslo group has pioneered. The beams and detector set up are well suited for these projects. Lengthy experiments to obtain the statistical accuracy that is required for these experiments are very unlikely to be approved at larger laboratories. In this respect one can consider the Oslo laboratory “tailored” for the well-recognized work that the group is performing.

The running cost of the cyclotron is, according to what has been presented to us, extremely low. The funding for variable costs for the period 1999 – 2002 was of the order 700 – 800 NOK per year, half of which typically has been used for cyclotron maintenance. The technical staff consists of two senior engineers: Eivind Atle Olsen works 100% and Jon Wikne 40% of full time for the laboratory. The scientific staff consists of three professors, who also have major educational and administrative obligations; the group is also running a research programme in energy physics. It is estimated that prof. Magne Guttormsen devotes 40% of his time for research at the cyclotron, prof. Jon Rekstad 20% and prof. Finn Ingebretsen 10%. In addition, the group presently has two temporary post. doc. positions, funded by the Norwegian Research Council and the Norwegian credit bank for students, “Laanekassa”.

The permanent staff, scientific as well as technical, is thus extremely small and the funding of post docs seems unstable and may vary from year to year. The evaluation group has discussed this situation in depth - a very small group runs the laboratory with a small amount of funding for variable costs. In addition to the nuclear physics programme and operating the cyclotron for this purpose, the group is involved in an energy research programme and the cyclotron crew is responsible for running the cyclotron for programmes in nuclear chemistry and medicine.

A number of aspects should be considered in the assessment of the utilization of the cyclotron as an “in house laboratory” as compared to making use of experimental facilities at other institutions.

- The nuclear physics group in Oslo is the only group in Norway presently working in the field of low-energy nuclear physics. The group has through the years recruited students, who have gone abroad for postdoctoral work. The possibility to work at the cyclotron has doubtless been an important factor in their choice of research field for their Ph.D. studies. The cyclotron laboratory has been an excellent training environment for them before going abroad for postdoctoral work.
- The cyclotron laboratory also constitutes an excellent training laboratory for Cand. Scient. (master) theses work. As the Cand. Scient. degree education is an essential part of the Norwegian university system; this is an important aspect of the value of the existence of the laboratory. The Cand. Scient. students spend at least a year within the research groups and thus in this case a year at the cyclotron laboratory for the main thesis work (hovedfagsoppgave).

- Norway has not been actively participating on a national basis in current European collaborations for building advanced and expensive facilities for low-energy nuclear research, as for example Sweden and Denmark have been. These countries are active partners in for instance the EUROBALL and EXOGAM detector collaborations or the REX ISOLDE facility for radioactive beams at CERN. There are and have been Norwegian scientists and postdoctoral students participating on an individual basis in the research at these facilities, but Norway has not chosen to make any investments in such joint endeavours for at least the last decade.
- An alternative to operating the cyclotron laboratory, that would maintain knowledge and competence as well as educational opportunities in low-energy nuclear physics, would be an organized participation on the national level in one – or more – European collaborations. This would require investments, say, of the order of 2-3 MNOK per year and a “running cost budget” for the programme of the same order as is now spent on running costs of the cyclotron. This would guarantee a Norwegian participation at the international frontline of low-energy nuclear physics. There are, however, drawbacks with such a scenario: a) It would be very difficult to have a large Cand. Scient. educational programme based on thesis work in nuclear physics. In addition, one would lose the possibility to define interdisciplinary thesis subjects. The cyclotron laboratory constitutes an excellent environment for interdisciplinary work within the fields of nuclear physics, energy physics, nuclear chemistry, and accelerator physics, as well as detector and computer techniques, etc. b) Replacement of the cyclotron programme in nuclear physics with a Norwegian participation in large European collaborations projects would with rather high probability result in a much lower recognition of the Oslo group compared to the “niche programme” in nuclear physics as presently run at the cyclotron – assuming a continued publication and activity rate as demonstrated during recent years. c) Termination of the cyclotron nuclear physics programme – to be replaced with a “travel research programme” would have the consequence that the important basis for development of techniques, as well as experimental preparations, for the internationally successful nuclear chemistry programme of the department of Nuclear Chemistry in Oslo would disappear. The same conclusion is of course also valid for the current programme in radionuclide production for medical purposes at the cyclotron.

The evaluation group comes to the conclusion that as long as the nuclear physics group can maintain their activity at a high international level with a good publication rate and participation at international conferences, the cyclotron should be continued as an in-house laboratory. The interplay between the disciplines around the cyclotron and the involvement of the nuclear physics group in the energy research is considered to be constructive. Nevertheless the evaluation group is concerned about the working load on the cyclotron crew and on the scientific staff of the nuclear physics group. Strengthening of the staff is strongly recommended.

4. The cyclotron as a laboratory for research in nuclear chemistry and medicine

4.1 Production of ^{211}At for development of new radiopharmaceuticals to be used in radiotherapy of cancer.

The Radiochemistry group of the University has worked with the alpha emitter ^{211}At , supplied by the Oslo Cyclotron, for a long time (since the late 80s) and developed and tested in animals several new ^{211}At -labelled compounds. These include compounds with possible roles in the treatment of lymphoma, ovarian cancer, malignant melanoma and bone metastasis. The group also co-operated with international groups that aim at treating gliomas (a brain cancer) with compounds containing ^{211}At . While it is theoretically feasible to import this radionuclide (half-life 7.22 hours), supplies are

highly irregular and much of the activity would be lost during transportation. Because of the steady supply of ^{211}At from the cyclotron, the group was able to take a leading role within this field in Europe. The group has published 13 papers on ^{211}At -related work in peer refereed journal and 5 PhD students have worked within this field. Twelve main theses have also resulted from the project. The evaluation committee agrees that this is important work, and that the group has contributed significantly within this field. The group should therefore be given the possibility to continue the local production of ^{211}At .

The committee noted that the Oslo cyclotron is not able to produce amounts sufficient for therapy of patients, so if the compounds are put to general use there will be a need for a more powerful production site.

4.2 Continuous rapid chemical investigation of the transactinides (the SISAK co-operation)

The cyclotron in Oslo is being used to test equipment that will be used in large facilities where transactinides can be produced (Lawrence Berkeley Nat. Lab. LBNL). Besides LBNL, collaboration partners come from Chalmers Technical University in Gothenburg, Sweden, and from the University of Mainz, Germany. The group in Oslo has built a system whereby isotopes of homologue elements (of lower atomic numbers) are produced and carried by a gas-jet transport into an equipment that is optimised and later taken to the foreign facility for the real experiments. Because of the duration of the testing, typically involving experiments (cyclotron runs) each second week followed by analysis/redesign between experiments for a total period of 6-18 months, it is not possible to carry out this kind of modelling as a guest at a large facility. The cost of staying abroad and possibly having to pay for production time would hinder participation, in particular by undergraduate students, in the project as part of a research team. Several of the SISAK experiments would not have been performed if the group had lacked access to the Oslo cyclotron facility. The Oslo group is now the most active in the SISAK co-operation, and the local staff today consists of two senior scientists, two PhD students and one student working on a main thesis. A technician is participating in the project on a full-time basis. If students become available, there is a potential to accept more students into the group. The SISAK activities are now totally dependent on the activities in Oslo for their future work. During the last 6 years, the work has resulted in 12 publications in international journals (including one paper in press and two recently submitted) and one congress abstract. The evaluation committee agrees that the availability of the cyclotron is imperative for the continuation of the SISAK activities in the university of Oslo.

4.3 Production of radionuclides for positron emission tomography

The Oslo cyclotron has been used for the last 3 years for routine production of ^{18}F . In co-operation with the Institute of Energy Technology, this positron emitter is used to produce ^{18}F -fluorodeoxyglucose (FDG) that is used by the Norwegian Radium Hospital and the National Hospital for positron emission tomography (PET) studies. Until a planned Norwegian Medical Cyclotron Laboratory is established in the National Hospital, the Oslo cyclotron will remain the only source of this short-lived radionuclide. The airline companies need too much paper handling time to make international supplies (e.g. from Copenhagen) available. It adds to the difficulties that the aircraft captain is sovereign to decide if he will accept radioactivity on board. PET is an important medical examination and has to be continued.

It has been foreseen that the Oslo cyclotron will act as a backup once the medical cyclotron laboratory has been established. If the medical cyclotron runs with an uptime of 95%, the usefulness of the backup facility may be questioned. However, especially with relevance to dosimetry in radiotherapy with radioactive compounds, e.g., antibodies labelled with radionuclides, it is of great interest to have access to positron-emitting isotopes of the elements used for such

purposes. Examples of such radionuclides are ^{110}In , ^{68}Ga , ^{76}Br , ^{86}Y , ^{124}I and ^{134}La . The radiochemistry group in the University has also worked with labelling of radiopharmaceuticals with ^{131}I . This know-how is of course easily translated to labelling with ^{124}I , and the group intends to embark on such projects if the possibility arises. The iodine isotopes may relatively easily be used to label peptides and proteins. In addition there are many similarities between iodine chemistry and the ^{211}At chemistry with which the group presently works. The above-mentioned radionuclides cannot be produced in a medical (negative ion) cyclotron, or at least not in sufficient amounts.

The reason for the interest in positron emitters is that quantitative measurements of radioactivity within a tumour can be done much more accurately with PET compared to conventional nuclear medicine methods (conventional planar and tomographic SPECT (single emission computed tomography) studies).

5. The production of master and doctor candidates within nuclear physics at the cyclotron laboratory

As noted above, the cyclotron laboratory constitutes a very good environment for thesis research work. The nuclear physics program at the laboratory offers the students opportunities to choose subjects that are of scientific relevance. The results of thesis work at both the master and doctoral level have normally been published in high quality scientific journals. The thesis research efforts have contributed significantly to the scientific output from the laboratory. The interdisciplinary nature of the laboratory with significant activities in nuclear chemistry and nuclear medicine, is a clear advantage for the students. Rich opportunities are provided to broaden their scientific perspective and competence. This should be important for their professional activities in their future careers, whether within or outside the university.

It should be pointed out that the relative smallness of the laboratory – compared to international particle and nuclear physics laboratories – is a positive aspect of the laboratory for student training. The students have possibilities to participate in all phases of a project – planning, designing of the experimental set-up and data collection, running the experiment at the cyclotron, analysis of the data and publishing the results. This situation cannot be created for students at the large international facilities, as the tight beam schedules and extensive planning on a very high technical level of elaborate detector systems, etc., give few opportunities for initiatives from students who have little experience. Participation of master students in projects at large international facilities must be limited to small parts of the projects, such as work on a part of a detector system or analysis of a part of a data-set from an experiment. Due to economic and practical reasons master students cannot normally work at international facilities. At best only short visits can occur.

The evaluation group finds that the possibilities that the Oslo cyclotron laboratory offer for student education has been used efficiently for master and doctor production. This assessment is based in large measure on information that the group has about students who have continued their work within the field of nuclear physics. The group cannot judge the quality of the students who do not continue within the field of nuclear physics after the master thesis. However, it is reasonable to assume that these students also have received excellent training for professional work in various parts of Norwegian industries and communities. The Oslo group has managed in student education to exploit the advantages of the relative smallness of the laboratory. It is also clear that nuclear physics research at such an accelerator includes advanced experimental techniques and methods as well as planning and analyses that require strong academic skills.

The cyclotron was attractive to master students in the eighties and the nineties. In the 5-year period 1993-1997, 16 masters were graduated. The master production then declined to 5 graduations in the last 5-year period 1998-2002. The doctor production from the work at the cyclotron has been irregular. For instance in 1990-1991 four doctors were graduated, while in the 5-year period 1993-1997 (the period with high master production) there was no doctor produced. It is very positive to note that in the last 5-year period 1992-2002 there have been 5 doctors produced and also that the graduations have been distributed over the period with approximately one doctor every year.

The evaluation group interprets these numbers in the following way. The very successful period of master production in the middle of the nineties was followed with a stable and good production of doctors at the end of the nineties and the first years of the new century. From the scientific point of view it is a clear advantage that the main emphasis has been put on the doctor production in recent years. The doctors that have been graduated from the laboratory are of excellent quality and several of them have been identified as very promising young scientists in their postdoctoral careers at international laboratories. The scientific output from the laboratory has, as noted earlier, increased significantly in the last few years. There is a clear correlation between the increase in doctor production and the increase of the publication frequency.

The decline in master production in the last 5-year period gives reason for concern. There are natural explanations for the negative tendency. For instance there has been an over-all decline in the interest for studies of natural science and physics since the middle of the nineties. For example, the number of new master (cand. scient.) candidates within the Department of Physics of the University of Oslo has decreased about 60 % in the period 1994 – 1999 (see Ann. Rep. 1999, Dept. of Physics, Univ. of Oslo). Another reason is that there has been a reduction in the number of supervisors within the nuclear physics group due to retirements. A third reason is probably the uncertainty of the future of the cyclotron laboratory during the last few years. As has been said earlier, the evaluation group considers very positively the development in the last 5-year period at the laboratory, with a clear concentration on increased production of scientific results (publication and international-conference activity) and doctor production. Nevertheless, to ensure a healthy future development of the activities at the laboratory, strong efforts should be made to raise the level of master production again. This is important for keeping the present scientific quality of the activity, but also for utilizing the potential of the environment of the laboratory for producing well-trained master candidates for work in Norwegian industries and communities.

Conclusion

The nuclear physics group has pioneered a new approach that is well recognized in the international scientific community, and which is highly relevant to astrophysics. The Oslo Cyclotron Laboratory is probably the only site in the world where lengthy studies of this kind can be performed. The techniques and detector systems have matured sufficiently to provide the basis for three to five years research along the same lines. The staff should be strengthened in order to make the laboratory less dependent on the present key essential personnel.

The continued availability of the facilities of the Oslo Cyclotron Laboratory is of key importance to the continuation of the successful trans-actinide international research program within Nuclear Chemistry and to the activities aiming at improved radiopharmaceuticals for diagnostic and therapeutic uses. Until a medical cyclotron has been established in Oslo, the OCL remains the only supplier of ^{18}F for positron emission tomography.

The evaluation group therefore strongly recommends that the Oslo Cyclotron Laboratory should be continued for at least 5 years and that a review of the present circumstances and possible future research directions be performed in 3 years.