PROPER AND IMPROPER ACCELERATORS – IN PRAISE OF CYCLOTRONS AND THEIR BUILDERS*

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Ladies and Gentlemen – Finding a speaker for this evening has been something of a saga. I had hoped to be able to introduce a distinguished Canadian scientist, renowned for his erudition and wit. Unfortunately, our invitee was forced to cancel and we were unable to find an appropriate replacement. Last week, therefore, we arranged some musical entertainment, but once again fate struck and the day before the conference I learned that the father of one of the duo had died, and that they would be unable to perform today, the funeral day. So the long and short of it is that you are stuck with me for the rest of the evening. At least I have the consolation of knowing from your applause for the Trio Grazioso that you enjoyed the entertainment provided earlier this evening by this group, all ex-students from the University of British Columbia School of Music.

Because of our lack of control over the human element in the program, we felt it necessary to demonstrate that at least the conference organizers were in full control of inanimate factors. In this respect many delegates have noted our successful control of the weather – how the rain stopped in time for the outdoor barbecue at UBC on Monday, how it rained again during the sessions on Tuesday, and how the clouds cleared as the buses left for the Wednesday afternoon excursions. A number of people have commented on this "good luck" with the weather. Some of the the organizers were deeply offended by such lack of recognition of their tour de force in weather control, but most took it in good part, realizing that in many places such skills are totally unknown. Any fool can organize a whole week of unbroken sunshine – they do it all the time in California – but it takes real skill to arrange rain for the week of the conference when there has been a drought for several months, and then interrupt it exactly at the time of the excursions. In case any of you have to organize conferences, I can recommend it as a real crowd-pleaser – the sunshine is all the better appreciated for being uncertain until the last moment.

Well, putting aside the tribulations and triumfs of conference organization, I had to select a theme that would be popular with the listeners, and ideally even keep them awake. With an audience of the world's experts on cyclotrons, what could be more popular than speaking "In praise of cyclotrons and their builders"? Cyclotrons I will leave until a little later, when there will be time to explain how their design entitles them to be described as "proper" accelerators, as opposed to other, somewhat "improper" ones. But first, ever courting popularity, praise for the builders! And in praising the explorers of physics, it may be helpful – or at least topical – to refer to some famous explorers of the globe. This year it is maritime explorers who have been particularly in the public eye. In his welcoming remarks on Monday, Professor Vogt pointed out that 1992 is not only the 500th anniversary of Columbus' exploration of the Caribbean, but the 200th anniversary of Vancouver's exploration of the Pacific Northwest. Captain George Vancouver was an Englishman with Dutch ancestors who had sailed as a boy with Captain Cook. In describing this, the last inhabitable coastline in the world to be discovered and settled by Europeans, Vancouver wrote[1]:

> "To describe the beauties of this region, will on some future occasion, be a very grateful task to the pen of a skilful panegyrist. The serenity of the climate, the innumerable pleasing landscapes, and the abundant fertility that unassisted nature puts forth, require only to be enriched by the industry of man with villages, mansions, cottages, and other buildings, to render it the most lovely country that can be imagined; whilst the labour of the inhabitants would be amply rewarded, in the bounties which nature seems ready to bestow on cultivation."

I am sure that those of you who have an opportunity to explore this region following the conference will agree that Vancouver's description is still recognizable and his prophecies largely fulfilled – even to such sophisticated bounties as cyclotrons.

You will understand then that George Vancouver is to B.C. what Christopher Columbus is to the USA. The

*Based on remarks made following the Conference dinner in the Hotel Vancouver name of British Columbia is of course in itself a celebration of Columbus. And mentioning Columbus gives me an opportunity to come back to cyclotron builders by way of the memorable analogy made by Weisskopf(2):

"Instrument construction was and will remain for some time the most important precondition to further progress of our knowledge of the basic structure of matter. High Energy Physics today is an exploratory science; it is still far from its explanatory stage. It may appear surprising to an outside observer that, in spite of this, theorists dominate the field and the names of the instrument builders do not appear on the title pages of the publications of discoveries.
The situation has been compared to Columbus' trip to the West in 1492: The accelerator physicists are the ship-builders and navigators who made possible the crossing of oceans; the experimental physicists are the people who stepped upon the new territories exploring the plains, mountains, streams, and the strange people and animals; the theorists are those who remained in Madrid and predicted that Columbus would land in India."

While we "ship-builders and navigators" all bask in the praise of accelerator builders as a group, this is also an appropriate occasion for us to praise three individuals among us tonight. I mean of course Reg Richardson, Henry Blosser and Bob Pollock, who have recently been awarded major prizes by the American Physical Society. It is surely a tribute to the degree of genius within this small cyclotron community that recognition has come so generously from the wider physics world. You will notice that I have inveigled all three of the prize winners to sit with me this evening – I am still hoping that some of their genius will brush off!

Starting with the most senior, everyone at TRIUMF was delighted last year to learn that Professor J. Reginald Richardson, (Figure 1) ex-director of the UCLA and TRIUMF cyclotrons, had been awarded the 1991 Robert R. Wilson prize, jointly established by the APS Divisions of Particles & Fields and Physics of Beams "to recognize and encourage outstanding achievement in the physics of particle accelerators". The citation reads:

"For his original contributions to the development of cyclotrons. These include the first experimental demonstration of phase stability, the first synchrocyclotron, and the first sector-focused cyclotron. This work is the basis of numerous cyclotrons that have had and continue to have major impact on nuclear physics, solid state physics, chemistry and medicine."

It's a particular pleasure to be able to recognize this award in Vancouver, which is essentially Reg's home town. Although born in Edmonton, across the mountains, his family soon moved to Vancouver and he spent his boyhood years just a few blocks from here, close to Stanley Park. Then at the age of 12 he moved with his family to California, later enrolling at Berkeley and, already showing that talent for recognizing the best scientific opportunities available, acquiring Ernest Lawrence as his Ph.D. supervisor. The rest, as they say, is history. The phase-stability principle itself should have been enough for one man. After all, all high-energy accelerators, up to and beyond the SSC, depend on it for their operation, and without it virtually nothing of modern particle physics would have been discovered.

Figure 1: Reg Richardson

But Reg's achievements have not only been demonstrations of principle. The major facilities he has built have themselves led to the opening up of new fields in science and medicine. Chief among these facilities of course is the TRIUMF cyclotron – unfortunately only a mere shadow of its original conception as a 750 MeV meson factory for UCLA. I count myself fortunate to have been here in 1964, in time to take a significant role in selecting Reg's design for TRIUMF, and thereby to have had some hand in bringing him back permanently to his old haunts. In fact the B.C. connection was already there, in that Reg had maintained a summer home on Galiano Island, 40 km from here across the Strait of Georgia, since the 1940s. (Galiano, incidentally, was the Spanish captain whose meeting with Vancouver near UBC in June 1792 he commemorated with the local place names Spanish Banks and English Bay.) Indeed, the TRIUMF cyclotron was conceived on Galiano Island, so it seems not inappropriate that it should be built close by. But even the meson factory was not enough. Hardly had Reg retired as director but another relaxing summer on Galiano produced schemes of kaon factories. And the ink on the 30 GeV KAON proposal was hardly dry before he had schemes afoot for the addition of a superconducting ring to reach 100 GeV.

Reg, you are the dean of the cyclotron community. As you approach your 80th birthday later this year we offer our heartiest congratulations to you on the award of the Wilson Prize, and our best wishes to you and Louise for the future. And please slow down, the rest of us can't stand the pace!

Now I turn to the joint winners of the 1992 Bonner Prize of the APS Division of Nuclear Physics, Henry Blosser and Robert Pollock. These are the second-generation cyclotron builders – the precision men and introducers of new technologies! Their citation reads:

> "For their pioneering development of innovative accelerator configurations which have allowed new levels of precision and flexibility for nuclear physics research. The room temperature and superconducting cyclotron developments and the novel beam cooling techniques have formed the basis for a new generation of facilities throughout the world which are currently providing important tools to advance our understanding of nuclear and particle properties in the medium energy regime. Their developments have also led to important advances in accelerator techniques for the neighbouring disciplines of atomic and medical physics."

Henry Blosser (Figure 2) obtained his Ph.D. from the University of Virginia and was introduced to the mysteries of the then-novel sector focusing cyclotron while subsequently working at Oak Ridge. Fired by its possibilities, he moved to Michigan State University in 1958 and there built a 56 MeV cyclotron which became a byword for precision in both construction and performance. In doing so he gathered around him a group of talented physicists and engineers, and founded what has become the leading school of cyclotron design and innovation in the USA. Henry then made the memorable mistake (at the Vancouver conference 20 years ago – perhaps it was the air?) of predicting[3]:

> "Superconductivity then seems unlikely to make a contribution to cyclotrons in the foreseeable future, primarily because there is no overriding problem which would thereby be solved such as is the case for synchrotrons and linacs."

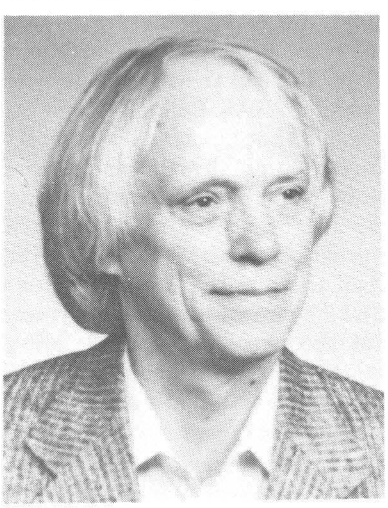

Figure 2: Henry Blosser

However, he has since redeemed himself handsomely by constructing a whole series of cyclotrons using superconducting magnets. The first of these, the K500 heavy ion machine, was of course the first to be brought into operation anywhere – much to the honour of Henry, but to the chagrin of the Canadian team at Chalk River who had started earlier but run into funding problems during construction. This was followed by the K1200, bigger and better for heavy ion physics, and the compact "flying" cyclotron, which can be swung around the patient to alter the beam direction, now in regular use for neutron therapy at the Harper Hospital. Meanwhile, these developments had led to the dedication of the National Superconducting Cyclotron Laboratory, with Henry as its first director.

Henry, we salute you for demonstrating that cyclotrons can be precision tools, for vastly extending the capabilities of cyclotrons by introducing the economies of superconductivity, and for generating a steady stream of graduate students to maintain the health of the community. You and Mamar have all our good wishes for the future. I should also add that Henry has taught me all I know about the use of a hand bell by a conference chairman.

Bob Pollock (Figure 3) is another Canadian, a graduate of the University of Manitoba, and a member of a family prominent in the early settlement of that province. After a Ph.D. and teaching at Princeton he moved on to Indiana University and became director of IUCF, where he supervised the construction of the two ring cyclotrons and various spectrometers, and the development of a very productive laboratory for light ion physics. Perhaps it was the complete separation of the sector magnets in these rings that freed his mind from conventional cyclotrons, perhaps it was the success of the Intersecting Storage Rings at CERN and the plans for a Low Energy Antiproton Ring there; whatever the reason, he conceived the brilliant notion of building a cooling and acceleration ring as the third stage of IUCF, to produce ultra-high-quality beams and raise the proton energy to 500 MeV. He then led the design and successful construction of this ring, the progenitor of a number of storage rings built for nuclear and atomic physics. While he has become a consum-

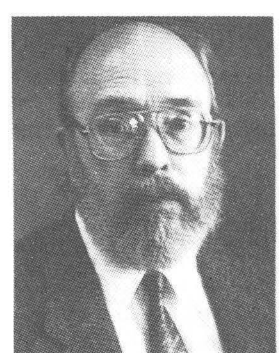

Figure 3: Bob Pollock

mate expert in accelerator design and has plans for even bigger rings in the future, he has always maintained a strong involvement in nuclear experiments, particularly meson production near threshold, and is now busy meeting the challenges posed by performing experiments in a circulating beam.

Bob has one other talent that should not pass unmentioned and uncelebrated – he can pack more information on a viewgraph than anyone else I have been exposed to in a lifetime of lecture attendance. Most of the skills cultivated by cyclotron builders and nuclear physicists are too esoteric to be of interest to the general public – but here is one that could surely make it into the Guinness Book of Records. Writers of the Lord's Prayer on the head of a pin – beware – your fame is about to be eclipsed!

Bob, we congratulate you on this prize, which is a tribute to that deep understanding of accelerator design and flare for innovation which have given us the first ring cyclotron and first cooling ring dedicated to light ions. At TRIUMF you served long and faithfully on our Advisory Board and we hope you are now enjoying your retirement from that duty.

It is a special pleasure that two out of the three prize winners have Canadian roots. It is of course only an historical accident – the magnanimity of the Canadians in returning Detroit and its hinterland to the USA after the war of 1812 – that we do not lay claim to the third as well.

Having praised their builders, let's move on to the cyclotrons themselves – the first of the circular accelerators and the embodiment of all those principles which entitle them to be referred to as proper, as opposed to improper, accelerators. What do I mean by a "proper" accelerator? I mean one whose design is characterized by simplicity and symmetry. The beauty of circularity has been recognized from time immemorial – in the shapes and orbits of the sun and moon, in the paths of the planets, in the stone circles of Stonehenge in England and British Block in Alberta, in the dome of the Pantheon ... Early synchrotrons exhibited circular symmetry in perhaps a more perfect form, since they had no trace of the spirality inherent in cyclotrons, but modern machines have deviated sadly from the ideal. Linear accelerators also have a symmetry which entitles them to be called "proper", but what a clumsy and unimaginative symmetry that is, requiring separate radiofrequency fields and equipment to be provided for every step of acceleration! The linac is straight, both literally and colloquially, but not smart.

The cyclotron is not only properly symmetric, but by making repetitive use of the same accelerating system, achieves compactness and elegance of design as well. The construction of a classical cyclotron illustrates a classic response to a major design challenge, incorporating several disparate elements in a compact assembly, somewhat in analogy to nature's elegant solution to the design of fruit in spherical layers working out from the seed to the skin. Thus around the particle beam we build the accelerating structure, around that the vacuum chamber, and around that, finally, the magnet.

I have to admit, of course, that people have not been content with this classic simplicity. They have played around, complicating the design in the name of "improvements". They have allowed the radiofrequency to vary, forcing the cyclotron to operate in fits and starts as a so-called "synchrocyclotron", they have broken the magnet into separate sectors, forcing the ions to orbit in a drunken way around Lawrence's beautiful circles, they have distorted the magnet sectors from straight radial edges to contorted spirals, they have even cut out the centre – the heart – to form a "ring" cyclotron, all with the excuse of attaining higher energies. And I'm sorry to say that some of our most respected colleagues, even including Reg Richardson here, have been involved in this mad race for progress. But through it all some symmetry has been retained, maybe three-fold or six-fold rather than perfect axial symmetry, but enough for the cyclotron to retain its claim to dignity as a proper accelerator.

Freedoms beyond these, however, amount to nothing more nor less than license. The rot began with the synchrotron, once the accelerator with the most perfect circular symmetry, with the addition of short straight sections to accommodate accelerating cavities and beam transfer equipment, and by the division of the magnet into alternate focusing and defocusing sections; but at least these changes retained some higher-order axial symmetry. The process accelerated, however, with the adoption of "separated function" designs, in which focusing and bending magnets were completely separated, and with the advent of storage rings, requiring long straight sections for particle detectors, cooling systems, Siberian snakes, and so on.

Nowadays we seem to have arrived at a free-form school of design, in which an accelerator is nothing more than a beam transport line bent into a loop. In these designs it seems possible to arrange the elements almost randomly, simply for convenience, rather than in obedience to some higher principle. An early example of this dangerous trend, I'm sad to say, was perpetrated by one of our prize winners, Bob Pollock. If his cooler ring for IUCF had retained that hexagonal symmetry with which it was apparently originally conceived, there would be no question but that it should be counted as proper; but with the sides lengthened here and shortened there to meet merely practical needs, it teeters on the edge of impropriety. Then there is the Main Injector proposed at Fermilab, in which almost no signs of symmetry remain; it is true that the two long straights are parallel, but they are displaced lengthwise as if the two sides of the ring had suffered an earthquake shear. This is certainly an improper accelerator.

These tendencies are usually justified as making accelerators "easier" to design and build. Here we see a parallel with modern society, in which easiness is counted as a virtue – surely an unmistakable sign of a decadent civilization. The freedom that takes away constraints also takes away the challenges. When the dipoles and quadrupoles and correction magnets and rf cavities and vacuum chambers and injection systems and extraction systems can all be designed independently of each other, where are the challenges needed to transform our talented young graduates into the master craftsmen of the future? Considering this transition from formalism to freedom in accelerator design, it may be instructive to draw some parallels with the transition from classic to modern art. In music we have come from Bach to Boulez, in drama from Sophocles to Samuel Beckett, in painting from Piero de la Francesca to Pablo Picasso – analogies demonstrating that uncontrolled freedom simply leads to anarchy.

In the case of cyclotrons we have not yet reached this terminal stage, and there is even some indication of a return to basics. Dangerous flights of imagination still occasionally occur, however, even among our most sage colleagues. For instance, I was shocked earlier this week to see a poster by David Clark, in which one of the cyclotron designs considered had four sectors at the centre, dividing into eight in the outer region. I am glad to report that this was rejected in favour of a simple 8-sector spiral.

The return to basics that I mentioned and commended above has been brought about largely by the demand for superconducting cyclotrons for nuclear physics, for neutron therapy, and for radioisotope production. This is a perfect demonstration of how challenges are necessary to bring out the best in people. The advantages of using superconducting magnets are normally said to be economies of size and of dollars, but this misses the whole point. Finance is always a secondary consideration for the true craftsman. The really important factor here is the miniaturization, which sets major challenges not only for the mechanical engineering but for the voltage-holding on both rf cavities and electrostatic deflectors. So Henry Blosser at MSU, and Harvey Schneider, Clarence Hoffmann and their colleagues at Chalk River, didn't go superconducting because it was cheaper, but because it was more difficult! Here we can draw a parallel with the great sculptors of the Renaissance, who delighted in demonstrating their virtuosity by casting bronzes of greater and greater complexity, in the hope that their rivals couldn't match them. And so it is with master cyclotron builders. Great men can only demonstrate their greatness by overcoming great challenges – and this they have done best of all when working within the constraints imposed on cyclotrons as "proper" accelerators.

I will close by wishing you all success in meeting the challenges of designing and building new and better cyclotrons – provided of course they remain "proper" accelerators. And as this is the 20th anniversary of the 1972 conference held in Vancouver, we hope that if you follow this advice we can look forward to cyclotrons flourishing for another twenty years and the 2012 conference returning to Vancouver again. Perhaps we should regard this hotel as a particularly appropriate venue. In the lobby downstairs you will notice that the chandeliers are supported from mouldings clearly representing the 8 sectors of very proper sector-focused cyclotrons (Figure 4).

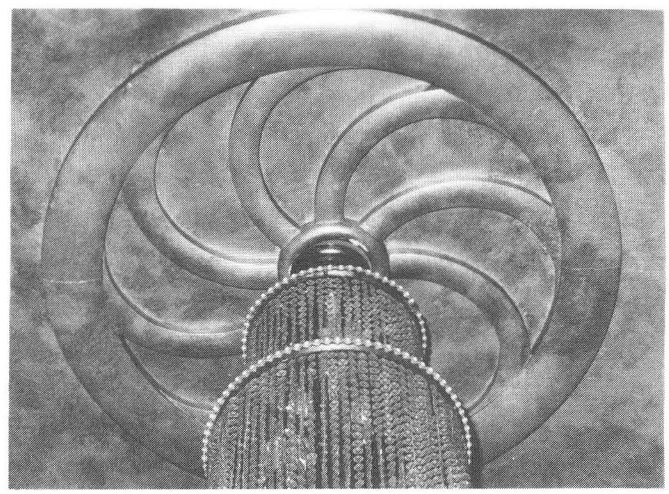

Figure 4: Ceiling moulding – Hotel Vancouver (Photo credit – Tallulah)

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