Intermagnetics Remembered: From Superconductor-Based GE Spin-Off to Billion Dollar Valuation

Carl H. Rosner, Former CEO & Chairman Emeritus
Intermagnetics General Corporation
e-mail: crosner@cardiomag.com

***Abstract* – Intermagnetics General Corp. (IGC) was formed in 1971 as a novel spin-off operation from GE. IGC's management pursued a mission to exploit superconductivity (SC) for many applications through the design and fabrication of electromagnetic SC devices that would offer huge energy savings. In ensuing decades, IGC developed many successful products, most notably, high-field SC materials and magnets culminating in global distribution of MRI magnet systems. The company, having grown to over 1150 employees, was acquired in 2006 by Royal Philips Electronics for 1.3 Billion Dollars. The path from fledgling start-up to worldwide leader in the SC industry was far from linear, as IGC overcame several difficult challenges along the way. This paper outlines key events in the history of IGC, as recalled by its principal co-founder, and describes some of the fateful events and critical decisions that catalyzed the successful growth of the company over 35 years, culminating in its acquisition by Philips.**

Submitted September 9, 2011 ; accepted January 20, 2012 . Reference No. RN22; Categories 5, 6, 11

***Keywords* – Intermagnetics, superconductivity, superconducting composite conductor, superconducting magnet, Magnetic Resonance Imaging, MRI**

I. LAYING THE FOUNDATION AT GENERAL ELECTRIC

After a turbulent youth, growing up in Germany during World War II, I was able to restart my education in Sweden, while I worked as a lab assistant and met my wife Frieda. In late 1952, we moved to the U.S. and when I accepted a job offer from GE's Research Laboratory to work on the development of scientific instrumentation, we moved to Schenectady, NY in 1955.

By 1959, I had become Supervisor of GE's Electrical and Magnetic Measurement (E&MM) laboratory within the Metallurgy and Ceramics (M&C) Department. With this new role on the GE research staff, I was leading a group that was testing and characterizing a variety of potentially promising new materials being developed by scientists in the M&C Department, as well as in other GE research departments.

In February 1961, an event occurred that would alter my career path as well as that of many other scientists and engineers around the world. Bell Telephone Laboratories (Bell Labs) published an electrifying discovery and with their subsequent accomplishment of building a superconducting high-field magnet, sent research departments at numerous universities, government laboratories, and large industrial organizations around the world into a state of virtual frenzy. Bell Labs had discovered that, at liquid helium (LHe) temperatures around 4 K, the recently discovered material compound niobium-tin (Nb_3Sn) could carry large electric currents in a lossless manner in the presence of very high magnetic fields [1]. They demonstrated that possibility by later building a 70 kilogauss (7 T) magnet with Nb_3Sn wire winding [2].

Hence, after 50 years of slowly improving theoretical understanding, yet futility in the quest to find practical applications for the unique phenomenon of superconductivity (SC), this discovery seemed at last to open the door for a new lossless, electrical power-based SC technology that could be commercially viable. For GE, the question was: might that technology be useful to or have the potential to transform the electric power industry towards much higher energy efficiency?

Several dozen members from throughout GE's Research Laboratory, especially from the Physics, Chemistry and the Metallurgy & Ceramics (M&C) Departments, set to work with much enthusiasm, in a race competing with numerous industrial labs, universities and government institutions around the country and around the world, to understand and duplicate the Bell Labs achievement. All were striving in various ways to better understand the phenomenon's unique characteristics and determine its usefulness, as well as its possible limitations. Simultaneously, efforts were made to find and develop additional types of improved superconducting wires that could be incorporated into prototype magnets.

Throughout the first couple of years, from 1961-1963, there was much progress in identifying and fabricating several other useful superconducting materials, but unexpected problems were also encountered. The quest to identify the best materials for commercial usage was constrained by laboratory manufacturing difficulties, especially those associated with intermetallic compounds such as Nb_3Sn. The requirement and availability of liquid helium to cool the materials provided another constraint. Fortunately, GE Cryogenics Lab had a complex helium liquefier and we at the research laboratory could use their glass dewars – still very similar to those used by H.K.Onnes. (See Figure 1) Making matters more challenging, we soon realized that resistance-free operation of magnets and devices was only possibly under direct current (dc) conditions and that alternating currents (ac) caused resistive losses, and hence boil-off of helium.

Fig. 1. T. Ross, C. Kolbe, C. Rosner, W. DeSorbo (left to right) testing of one of many SC small coils**.**

We fabricated dozens of test magnets, but could not yet build high-field ones. In early 1963, our team traveled to the MIT magnet lab in Boston[1], where huge water-cooled resistive Bitter-type magnets provided the test environment needed to measure the performance of GE superconductive materials. We were racing to determine which metallurgical variables would lead to materials most suitable to produce magnetic fields above 100 kilogauss. Our team worked through the night to test all of our samples and select the best ones.

Both Bell Labs and GE utilized Nb_3Sn superconductors, deemed to be the most practical materials that had high-current performance characteristics for generation of high-fields, and also superior to many alloys and other intermetallic compounds that had been discovered to be superconductors since the late 1950's, especially by Bernd Matthias and also John Hulm [3].

The earliest noteworthy achievement of the GE team effort emerged a few months later, when after many attempts, a Nb_3Sn wire magnet reached a field of 101 kilogauss, the first such magnet in the world to reach this field level (see Figure 2) [4]. Unfortunately, it could not be operated again, because it was damaged after reaching that field. The accomplishment of this milestone beat the earlier record by Bell Labs, and fulfilled the original aspiration of H.K. Onnes, the discoverer of superconductivity back in 1911, who wanted to build a 100 kilogauss superconducting magnet already then [5].

Fig. 2. 101 kGauss, Nb_3Sn magnet, fabricated and tested by:
L. Martin, C. Bruch, M. Benz and C. Rosner (left to right)

The excitement at this record achievement, as well as the related multidisciplinary challenges associated with the high-field performance had an overwhelming impact upon me. The complex theories put forth, primarily the BCS theory, were still insufficient to understand the behavior of high-field superconductors. All of this intrigued me sufficiently that I wanted to continue exploring the broader application of superconductivity. I became convinced that this unique phenomenon, which would lead to new technology, could open up a whole new range of technical and economic possibilities, including the potential to revolutionize many existing

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[1] The Francis Bitter Magnet Laboratory.

applications and hopefully create new ones, in our increasingly electronic and electric-power-dependent society.

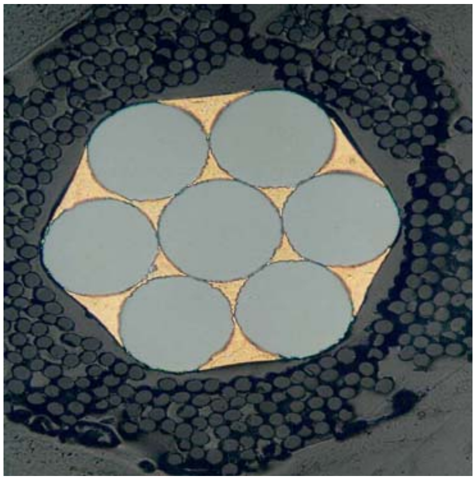

Fig. 3. Cross section of long length wire with Nb strands for the first 101 kGauss SC Magnet. Yellow color is the tin (Sn) matrix.

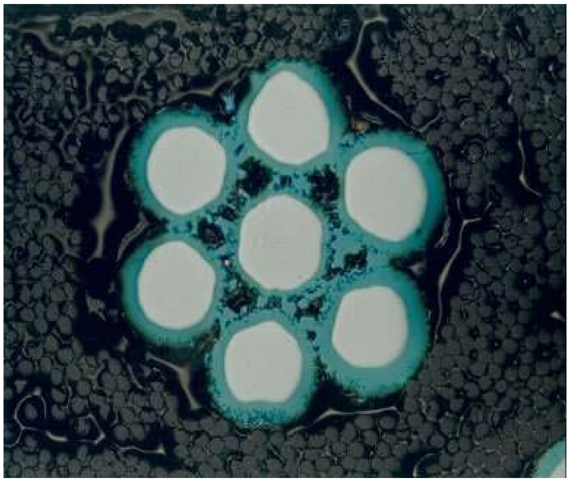

Fig. 4. Cross section of the same wire after the heat treatment. Blue color is the Nb_3Sn layer formed Grey is the remaining Nb core.

Our elation which followed our 101 kGauss (now 10 Tesla) 10T magnet accomplishment was gradually deflated by the realization of many practical difficulties. It was a major challenge to manufacture and utilize Nb_3Sn wires in magnets, because such wires needed long-term, high-temperature heat-treatment – almost 1000°C - to convert the Nb and Sn elements into the Nb_3Sn compound. The subsequent brittleness of wires caused many of them to break easily, if not handled with the utmost care. Even today Nb_3Sn in wire and cable form continues to be developed and improved for use in large high-field magnets, e.g., for fusion reactors [6].

An important and viable solution was developed by Mark Benz and colleagues by switching from wires to tin-coated very thin niobium tapes that could be heat-treated continuously, and then readily handled without breaking, albeit still with some care [7].

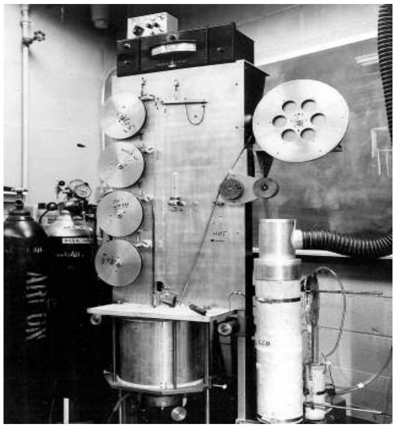

Fig. 5. Continuous tin-coating and heat treatment of long Nb Tapes, subsequently laminated with copper tapes.

To provide for current transfer as protection in the case of magnet "quench" (resistive transition), copper tapes were laminated with (soldered to) each side of the 12.5 mm wide Nb_3Sn tape, thereby keeping it at the "neutral axis" so that it was protected, yet remained flexible. Moreover, for mechanical strength support to withstand the electromagnetic forces during high-field current ramp-up, stainless steel tapes could readily be added. Over the next few years this approach to magnet design and construction in a "pancake" assembly became the basis for fabrication of several 10T and higher field, small-bore research type magnets, one of which (to the delight of the GE management, was bought by Bell Labs for their continuing research.

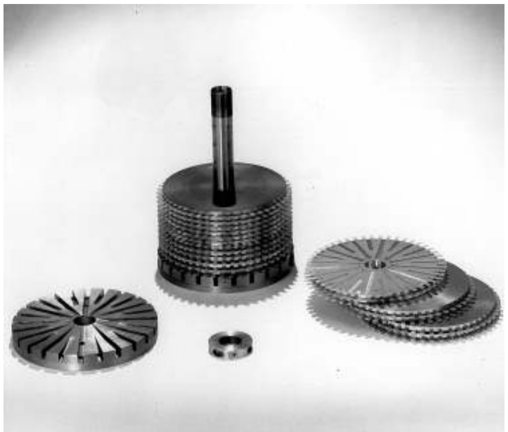

Fig. 6. Typical Nb_3Sn tape magnet "pancakes".

Fig. 7. Seven 10 to 15 T Nb_3Sn tape magnets for testing.

In parallel with Nb_3Sn wires and magnets, exploration of many other SC materials was carried out by teams of GE metallurgical scientists [7]. Studies to determine whether the effect of ac losses in superconductors could be significantly reduced or even eliminated were also conducted by a number of physicists. A team supported by Roland Schmitt and led by Charles Bean and John Fisher attempted to understand the fundamentals governing the presence of superconductivity at higher fields and the role of microstructure that could improve current density [8,9]. They were also able to explain some of the peculiar behavior of our magnets; *i.e.*, sudden and premature magnetic instabilities, that caused transition to resistive behavior – we called it "quench" – thought to be triggered by flux jumps. Bean and Swartz subsequently developed a theoretical understanding of the impact of changing magnetic flux patterns as currents were raised to increase the magnetic fields [10]. That understanding helped Howard Hart, Chad Graham and Paul Swartz to develop magnet design criteria that allowed us to circumvent flux jumps [11] and build a range of different high-field magnets that operated successfully and reliably, while avoiding "quenches", so that a commercial market would more likely be achieved.

Nevertheless, despite these promising breakthroughs and accomplishments, by the late 1960's an awareness set in within the GE R&D Center management that the high expectations for practical utilization of superconductive technology would not materialize over the near-term.

II. THE SPIN-OFF THAT BECAME INTERMAGNETICS

During 1969, GE engaged in an extensive business study to determine the role that superconductivity would play within the company. This study spawned the creation of a new section named the Superconductive Products Operation (SPO), for which I formed a small group of scientists and engineers that began as a GE approach to "intrapreneurship".

That operation was subsequently co-located with the GE Vacuum Products division, which was also utilizing technology that traced back to developments by GE's Research Lab.

At the time, a physicist and friend, David BenDaniel, was Manager of Advanced Programs at GE's Research Lab and I turned to him to discuss options available for development and growth of the SPO. He told me that back in 1966, GE had set up a group called the Technology Market Operation, to help GE establish criteria for when to terminate its investments in research projects that, despite their technical promise, seemed unlikely to transfer as successful businesses from the Research Lab into the Company itself. That group's job was to collect intriguing but "unused" GE technology, create packages consisting of patent licenses and know-how, and sell them to other industries. This operation proved not to be a universal answer, and BenDaniel grew concerned about the demoralizing impact of cancellation of R&D projects to which its scientists were deeply committed. BenDaniel's boss and Director of Research at GE, Art Bueche, encouraged BenDaniel to spend a year at the Harvard Business School (HBS) in order to explore new strategies to deal with these challenges. While at HBS, BenDaniel spent a year teaching a course on technological innovation, but also formulated a way for GE to "have its cake and eat it too." The solution was for GE to spin-off these "stepchildren" so that it would not need to make any further investments, but still retain an equity stake so as to benefit from any upside.

When BenDaniel returned to GE in 1970, the SPO, now with annual sales of around $300,000, seemed to be a prime candidate for this spin-off strategy. By that time, it had become clear that many other departments within GE did not share my optimism for the commercial viability of SC-based technology. This was due to the fact that throughout the 1960's, periods of promising SC breakthroughs alternated with the appearance of disconcerting technological barriers that seemed insurmountable to many colleagues pursuing the idea of commercial applications of SC.

Likewise, many other industrial groups in the country, which had initially embraced and enthusiastically fostered the development of SC materials and magnets, had concluded by the late 1960's that meaningful commercialization of SC appeared difficult, costly and too far off. The general view held was that the ultimate payoff from a technological and economic point of view was less certain than they had initially thought. Despite having collectively spent hundred millions of dollars in search of large-scale commercial applications, the large organizations involved, such as Alcoa, RCA, AVCO, Norton Co., LINDE, Atomics International, Corning, and many others, left the SC field rather abruptly. Similarly, larger-scale government projects and university funding tapered off, and many experts in the physics community subsequently abandoned their efforts. Interestingly, thanks to John Hulm, Westinghouse – another long-term participant promoting SC research -- maintained its positive outlook. Discouraged by the many defections by industrial participants, GE was also considering completely giving up as well, but I believe my continued conviction and enthusiasm led BenDaniel, who had become Manager of the Technical Venture Operation, to coax senior management to instead help SPO become the first spin-off. Even though it was a very small operation, this step required special approval by GE's Board of Directors, which was finally obtained.

I decided on the name "Intermagnetics General Corporation" (IGC) for the new company. I chose it to indicate that one of our early goals was to create many special-purpose SC electromagnets and conductors for a general (*i.e.*, broad) range of applications, including research and prototype motors and generators, and to cater to an international customer base, thereby eventually transforming the electric power industry.

A formal spin-off deal was then struck to be effective June 1971. In exchange for the \$500,000 in GE assets, including the tape processing equipment used to fabricate Nb_3Sn for application to high field magnets, as well as a slew of US and international patents[2] that GE transferred to IGC, GE maintained a 46% equity stake in Intermagnetics. In addition, IGC signed a \$150,000 long-term loan document to pay for part of the GE assets. Several outside investors bought in at the same share price as GE, contributing a total of \$200,000 in cash in exchange for a 19% equity stake. The remaining 35% of IGC equity was partially paid for by several key employees, and the rest was made available to all employees. More than half of that 35% share was purchased by myself and my co-founding partner, Paul Swartz, formerly a close collaborator at GE R&D Labs, who became V.P. of Marketing. So we satisfied BenDaniel's requirement that any spin-off candidate's prospective entrepreneurs believe so strongly in what they're doing that they are willing to invest their own money "up to the neck". Paul left GE earlier, but I hired him back, in part because he was technically very capable and an excellent communicator.

Soon after our launch, we attracted a number of investors, the most prominent one being Exxon who made in 1973 a substantial investment in IGC. Shortly thereafter, BenDaniel left GE to go to Exxon, but remained on IGC's board, now representing the Exxon's ownership position.

III. THE FIRST DECADE AS AN INDEPENDENT ENTITY, 1971 - 1981

A. Personnel and Early Nb_3Sn Magnets

As most entrepreneurial entities discover, the first several years of a start-up are the most challenging and survival is often questionable. Having had the benefit of essentially operating in an "incubator" at GE's R&D, we were clearly lucky that we could get off the ground relatively quickly as a separate business. We had technology, patents, and most importantly customers.

Intermagnetics formally began its operations with a team of 15 employees to focus on expanding the manufacture of Nb_3Sn tape and high-field magnets, while continuing SC materials R&D. Several of these employees had left GE to join IGC, giving up the big-company security blanket to work in the exciting field of superconductivity. Also, we attracted to IGC a number of key individuals from other U.S. industrial organizations that discontinued or downgraded earlier strong efforts in superconductivity, due to their disappointingly slow progress toward commercialization. Among these individuals was Edward Schrader who formerly headed RCA's effort in SC, and became IGC's first V.P. of Technology Development [12]. When he unfortunately passed away very suddenly, we were able to hire Carl Henning from Livermore Labs to replace him. Similarly, over the next few years, we hired additional outstandingly capable researchers and managers such as Richard Rhodenizer, Bruce Zeitlin, Michael Walker, Richard Blaugher, William Fietz and John Stekly, as well as several others, who had

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[2] These patents were expensive to maintain and proved to be useless.

demonstrated good theoretical and practical understanding of SC materials and magnets. Likewise, we relied on experienced new employees to later on establish and quickly expand our cryogenic manufacturing capabilities.

In its first month of operation, even though we took salary reductions, the fledgling company racked up \$32,000 in expenses, while bringing in only \$6,000 in revenue. This situation, along with the further outflow of financial resources, became a major challenge and proved to be an area that continuously, over many years, influenced corporate decisions, including how extensively to support necessary R&D and business expansion. Indeed, beyond obvious technical challenges and achievements, financial matters played a huge role in repeatedly causing or ameliorating difficult periods throughout the company’s history. As we quickly learned, availability of cash as well as financial control and critical planning are key issues that have enormous impact on business survival and success.

Our collective perseverance and commitment led to the first profitable fiscal year in 1973, with a profit of \$60,000 on sales of \$1.21 million. This milestone represented a feeling of relief that the company was no longer just fighting for its month-to-month existence. We continued to fabricate a series of field-record-setting Nb_3Sn magnets for a number of new research applications, which established the company's reputation for technical leadership and honed our design and manufacturing skills. IGC designed, built and sold a wide range of diverse high-field SC magnets and materials throughout the world. We succeeded in this by understanding theoretical design criteria for SC materials at low temperatures, as well as the electromagnetic design and its limitations. Indeed, the versatility and mechanical strength of Nb_3Sn pancake type magnets were exemplary. They contained either 12.5 mm or 5 mm wide sections that could operate effectively through ranges of differential thermal expansion and levels of strong forces at high magnetic fields and cryogenic temperatures.

For several more years, the majority of revenue came from sales of special purpose Nb_3Sn superconductive materials and one-of-a-kind, custom designed high-field magnets that we supplied to physics research institutions around the world, including sales to Germany, Japan, Brazil, and the Soviet Union. These research institutions valued the strong, 10 to 17.5 T, and very uniform magnetic fields of our Nb_3Sn magnets, not yet obtainable elsewhere. (See Figures 10 to 21 in Section III.C). The tape and pancake magnet design and assembly approach allowed us also to readily build split magnet configurations with multiple optical access to the higher-field space. Also, when necessary, pancakes could be replaced or reconfigured, especially in the radial end-field sections, where specific design stability modifications allowed us to avoid flux jumps and magnet quench prior to achieving the design field.

B. Introduction of NbTi Wires and Magnets

While the success of our Nb_3Sn magnets was encouraging, I decided to widen our capability and product lines to include the technology and larger-scale manufacture of niobium-titanium (NbTi) alloy composite wires and lower-field magnets. While NbTi has lower critical field, B_c, and lower critical temperature, T_c, than Nb_3Sn, it has commercially attractive characteristics such as flexibility and ease of fabrication into wires at lower cost. Thus NbTi lends itself more readily to construction of larger scale devices and more demanding, complex winding configurations. In addition, we were now able to offer combination and optimized higher-field magnet systems using larger diameter outer NbTi coils containing Nb_3Sn inserts. Lower magnetic field systems often required different engineering design approaches, especially for high-energy physics particle accelerators. Hiring Bruce Zeitlin, who had established NbTi manufacturing facilities for AIRCO and Magnetics Corp. of America, both of whom exited the SC business, permitted me to rapidly implement this NbTi strategy (see Figures 8 and 9). According to the longtime IGC employee Gary Morrow, the establishment of production of NbTi wires and magnets was a pivotal step that paved the way to our company's participation in large scale government-funded experimental high-energy physics applications in the US. During the same time period, IGC also broadened its reach through the design and manufacturing of low-temperature cryostats required as helium containers for all SC devices. Each of these strategically advantageous decisions to extend our involvement into systems-related technologies challenged the management of our limited financial resources. Nevertheless, during the ensuing years, our company's ability to provide the international research community with high-field magnets, SC wires and cryogenic dewars led to a meaningful business that supported both our internal R&D and commercial sales. Examples of the latter are illustrated below in Section III.C.

Fig. 8. NbTi rod assembly into copper billet at IGC.

Fig.9. Typical IGC NbTi multifilament Cu-clad wire.

C. Examples of a Variety of IGC Magnets

Unfortunately, by lack of space, I cannot describe our early Nb_3Sn and NbTi magnets in any detail. Nevertheless, for historical record, I would like to at least show photos (Figures 10 to 21) of some of our early custom-tailored products for diverse exploratory applications ranging from fusion studies to a motor for ship propulsion.

Fig. 10. Early 10 T tape magnet powered. with "Buchhold" Flux Pump.

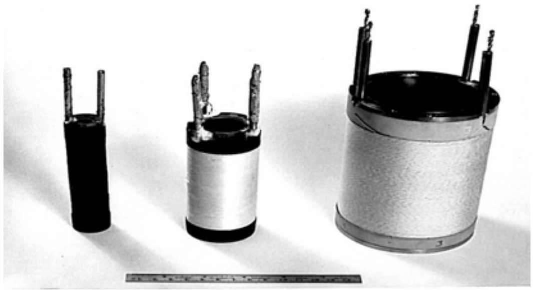

Fig. 11. Early segmented design approaches to reach 10 T with Nb_3Sn wire magnets.

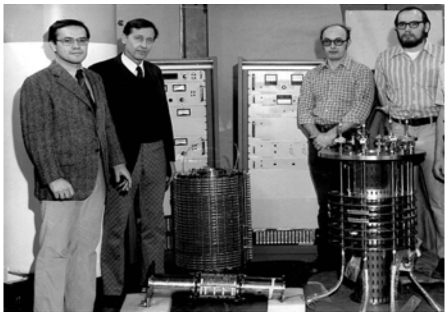

Fig. 12. Concentric Section 17.5 T Magnet for National Research Institute for Metals in Japan.

Fig. 13. Room temprature.(RT) access split pair Magnet for Fusion Studies.

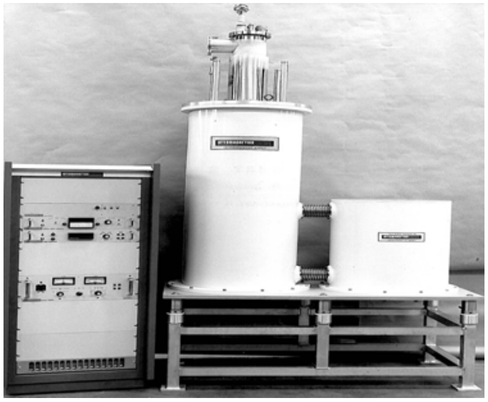

Fig. 14. Early IGC magnet system with RT access to hi-field region.

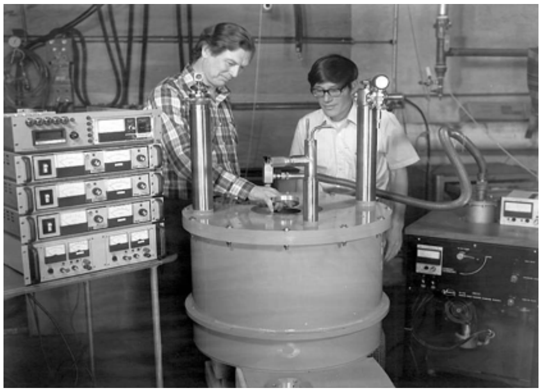

Fig. 15. System for 95 GHz Gyrotron.

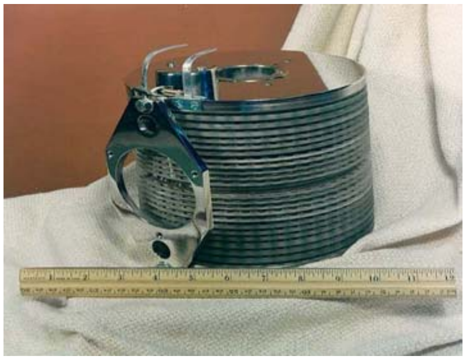

Fig. 16. 11 T split magnet for horizontal or vertical mounting.

Fig. 17. Nb-Ti system for inspection of commercial nuclear fuel rods.

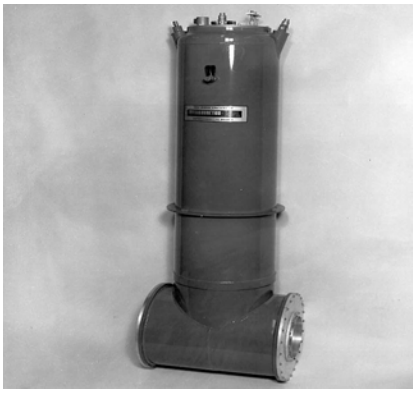

Fig. 18. RT access to high-field region

Fig. 19. 11.5 T magnet for Mössbauer Studies.

Fig. 20. Test of 3,000 HP S.C. motor for ship propulsion

IGC Personnel Examine New MINIBRUTE 100

MINIBRUTE 100 weighs only 11 pounds and produces 100 kG in a 1 inch bore at a current of 110 amps.

Fig. 21. E. Mains, T. Haller, K. Pickard, E. Knopf testing smallest 10 T magnet.

D. Early Financial Troubles and Fleeting Project Opportunities

Without warning, our first financial calamity hit in 1974. The Schenectady Trust Bank (TrustCo) had given IGC a $305,000 renewable loan at the time of the spin-off from GE. Conceivably, the bank assumed that GE was effectively the guarantor of these loans. Three years thereafter, a new bank officer took over and when our loan renewal time came around he wanted GE to co-sign. GE would not give IGC such backing, and Schenectady Trust decided that it therefore wouldn't renew the loan. For the next few months, IGC was in serious danger of going under due to having very limited cash, and we really struggled to survive. Fortunately, I was able to secure bank loans from KeyBank and Manufacturer's Hanover Bank and managed to pay off that earlier TrustCo loan.

Interestingly, in the wake of the October 1973 Middle East War and the resulting OPEC oil embargo on the United States, the US government began to look with an increasing urgency for energy-saving alternatives to oil. One result was the rapid expansion in government funding of superconductivity-based R&D projects. The hope was that potentially enormous energy savings could be achieved using SC magnets for fusion power, electric motors and generators, energy storage systems, power transmission lines [13], *etc*., all of which could conceivably reduce US dependence on fossil fuels. For IGC the good news was that the pursuit of these ambitious goals would require large quantities of SC wires and magnets, and also the likelihood of large funding support. The primary beneficiaries of this government largesse, however, were the National

Laboratories who greatly expanded their SC research and development. While collaboration with industry was officially encouraged, we were primarily used as vendors and subcontractors when needed, rather than allowed to be collaborators with the National Labs in developments that would benefit us and allow our involvement in likely future industrial SC electric power projects. These diverging interests were periodically the subject of serious discourse between emerging SC industry companies and government laboratory management, who only seemed to be concerned about funding for their own projects, yet whenever challenged to show benefits to society for funding their research, they claimed credit for private industry achievements [14].

A second, more dramatic iteration of a spike in government funding occurred due to the Iranian Revolution and the resulting oil crisis in 1979. The high price of oil effectively caused for the second time the surge in government funding for SC applications that again promised to yield huge energy savings. As a result, large companies were encouraged to significantly increase their interest and investment in SC, thus benefiting from the availability of much new financing, now also from government laboratories. These organizations had not only pursued large scale SC high-energy physics projects, but also engaged in programs that explored and designed SC prototypes of electromagnetic equipment, including motors, generators and power transmission lines. Thus, the promise to confirm large-scale energy savings through the use of SC equipment looked possible again.

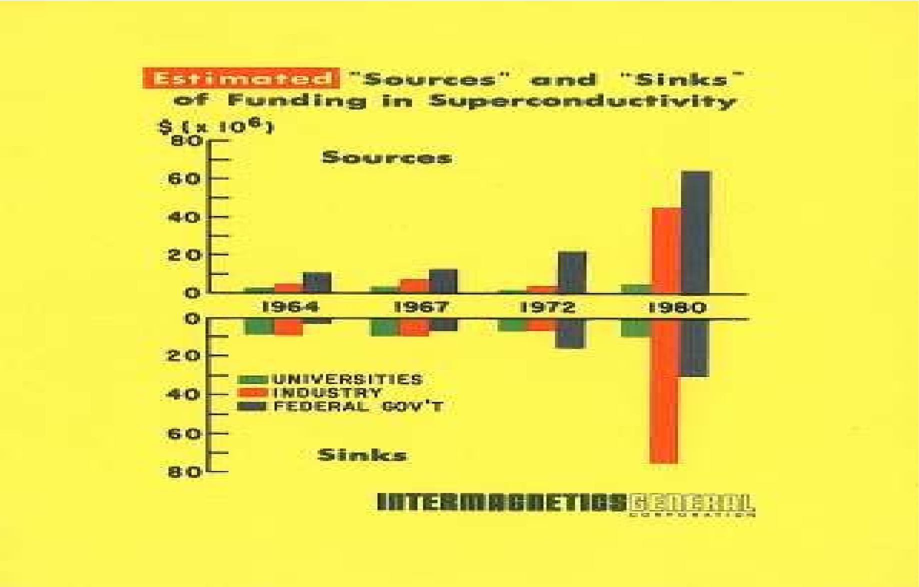

Fig. 22. Estimate of funding provided and expended by industries, universities and US government agencies through 1980.

That promising tide turned quickly in 1981 with the combination of a recession and the downturn in oil prices. Thus, much of the excitement and investment in SC that had grown since 1973 and again in 1979, dissipated once more. Unfortunately, it had become clear that the multidisciplinary nature of SC technology, and demonstration projects of potential applications for the electric power industry required more money and time, more acceptance of risk, and more patience than the past investors in SC and the electric utility companies were willing to bring to the table. We noticed with some dismay that as far as large corporations were concerned, including GE, only as long as government funding was available, did they seem to be interested in making investments in a technology like SC. By the end of the 1970's, the volatility in SC research funding over the course of the past decade underscored the need for IGC to secure more stable sources of funding to supplement revenue from individual product orders. Our continued technical efforts, R&D and exploration of new applications seemed to consistently require more resources than were available so far.

IV. GENERAL ELECTRIC'S RE-ACQUISITION PROPOSAL

The contractual IGC spin-off from GE included a buy-back option, stipulating that within three years, GE would have the option to repurchase the remaining original ownership of the company. Following the spin-off, GE's investment in IGC was monitored from a corporate office in New York City that supervised similar investments. These decision-makers allowed the buy-back option to expire in 1974.

However, beginning in 1976, GE had restarted an internal SC operation that gradually began to compete with IGC for government R&D contracts. Moreover, GE's large equity and thus effective "control" ownership prevented IGC from being considered as a "small company", entitled to compete for set-aside government R&D contracts. In 1979, after a number of discussions and our proposals to buy-back IGC's common shares from GE, and thus eliminate that small business handicap and be able to raise more capital, GE suddenly presented us with a virtual 30-day ultimatum as follows: IGC could buy GE's ownership shares back for one million dollars or GE would have the right to buy the remaining ownership from IGC for the same $1,000,000 amount. We were excited about this proposal, but also fearful that our raising of money may not succeed. Even today, to raise 1 million dollars in 30 days is quite difficult, and the goal was certainly more daunting in 1979.

In my opinion, GE had the expectation that it would be impossible for IGC to secure $1 million in such a short time frame. In spite of my awareness that it was a long shot, I feverishly began setting up meetings with investors to try to obtain this money. I raced around the country and contacted as many investors as possible without much success. Suddenly, almost three weeks into the allowed timeframe, I received an encouraging call from a Vice President of Teck Mining Corp. in Canada, whom I had met in Japan one year earlier. I had been attending a conference focusing on an SC magnetically levitated (Mag Lev) train demonstration [15] in Japan when I met Brian St. John, the Vice President for Teck Ventures. It was the investment arm of Teck Corp., a mining company based in Vancouver, British Columbia. Brian was in Japan to look into potential applications for niobium, because Teck owned a niobium mine at the time. During this trip, while both of us were adjusting to and enjoying the foreign culture of Japan, Brian and I became friends. He surprisingly called me saying that Teck was interested in investing in IGC in order to better monitor the niobium marketplace. I told Brian that his call could not have come at a better time, and filled him in on IGC's opportunity to buy out GE's ownership share if Teck would be able to move quickly. I already had plans to meet with other investors in California a few days later, so we made plans for me to swing up to Vancouver, while I was on the West Coast. When we met there, I offered Teck a 40% share ownership in IGC in exchange for $1.5 million in cash. After meeting with the Teck president and their Board of Directors, we were able to strike a deal. Everybody who has heard this story was doubtful that any other investor would have made such a commitment on this short notice. I had met other investors who were strongly interested, but wanted more than a month to conduct due diligence. A bit of luck and strategic personal networking ultimately allowed us to take advantage of GE's tricky offer. We were thus able to achieve our complete independence from GE, along with an extra $500,000 in cash for additional working capital.

V. IMPACT OF CHANGES IN MANAGEMENT

As mentioned earlier, the many corporations that decided to exit SC in the late 1960's and early 1970's, provided significant benefit to IGC, because I was able to hire key leaders of some of these company's SC operations. It may seem a bit unconventional to hire former "rivals," but my strategy was to hire the most experienced people, regardless of which "side" they had been on in the past. It turned out that much of IGC's success can be attributed to our ability always to look for and to hire outstandingly capable individuals, even if they had earlier worked for competitors.

The ultimate embodiment of this approach can be seen in the following example. In the mid 1970's, we had held a series of meetings with AIRCO's SC operation about a potential merger with IGC. Ultimately, we were not able to make this merger a reality, since AIRCO's technical leader, Eric Gregory, was a staunch opponent. However, much later, IGC's principal competitor, Oxford Instruments, formed a joint venture with AIRCO to exploit NbTi wire manufacture, and Eric Gregory was let go from his position. Despite past differences, I and Bruce Zeitlin jumped at the opportunity to hire someone with his kind of extensive experience in the industry, and Eric Gregory proved to be a key contributor in the further development of the Nb_3Sn wire technology at IGC.

In another variation on the theme of individual contributions and "crossover" within the field, my own position with IGC went through a transition as a result of Teck's new role. Following the course of my meetings with the Board of Teck Ventures back in 1979, and implementation of the investment strategy, they asked me years later to move to Canada to manage Teck's entrepreneurial Development Company (TDC), the operating arm of Teck Ventures, and effectively oversee Teck's investments in other emerging companies, including IGC. This exciting opportunity to gain exposure to a wider variety of industries while remaining involved with IGC, appeared too good to pass up. This meant my IGC role changed by stepping away from being in daily attendance, yet being able to initially staying on as CEO and Chairman. While in Canada and starting in late 1980 (first in Vancouver and then in Toronto), I was able to continue to oversee the operations of IGC, commuting frequently and trusting that key members of the IGC management team, under the direction of Paul Swartz as president, would be able to handle the day-to-day operations well during my physical absence. Paul also interacted well with IGC's Board and shareholders.

This transition was possible because I had already turned over the position of IGC president to a replacement in 1978. Thus I had stepped away from the corporate operating position, but as Chairman and CEO could devote more time to strategic planning towards corporate growth.

Initially, we hired a former GE Vice President to be president of IGC, but then transferred that function and responsibilities to Paul Swartz, who became President in late 1980, when my family and I moved to Canada.

VI. EXPANDING R&D MARKET TOWARDS PRODUCT LINE MANUFACTURING

Several key developments in the mid to late 1970's helped position IGC to become one of the leading magnet suppliers, including the early nuclear magnetic resonance (NMR) magnet market[3]. In 1976, IGC received an order from the University of Wisconsin for a large-bore NbTi magnet that could "accept" a human being. Researchers at this time were secretive about their intentions for such magnets, but it is likely that these university researchers were investigating what magnetic fields could do to blood flow in humans. They were thus working on a pre-cursor to MRI technology. By that time, IGC had already developed a unique reputation for complex, high-quality, special-purpose research magnets, which is probably why the Wisconsin researchers approached IGC. A short time later, IGC received an order for another large-bore magnet from General Dynamics. These sales brought a significant amount of revenue to IGC, but more importantly, they forced IGC to develop the technical capability to produce large, whole-body sized magnets and meet specifications for very high uniformity of magnetic fields in large volumes. Our key magnet designers Denis Markiewicz and Robert Wilcox were excellent at going from challenging magnet design approaches for smaller magnets to much larger diameter lower- and medium field NbTi magnets requiring large volume of high-uniformity field. Their designs were effectively supported by IGC's ability to provide special NbTi multifilament wire configurations, designed to enhance operating stability and field uniformity.

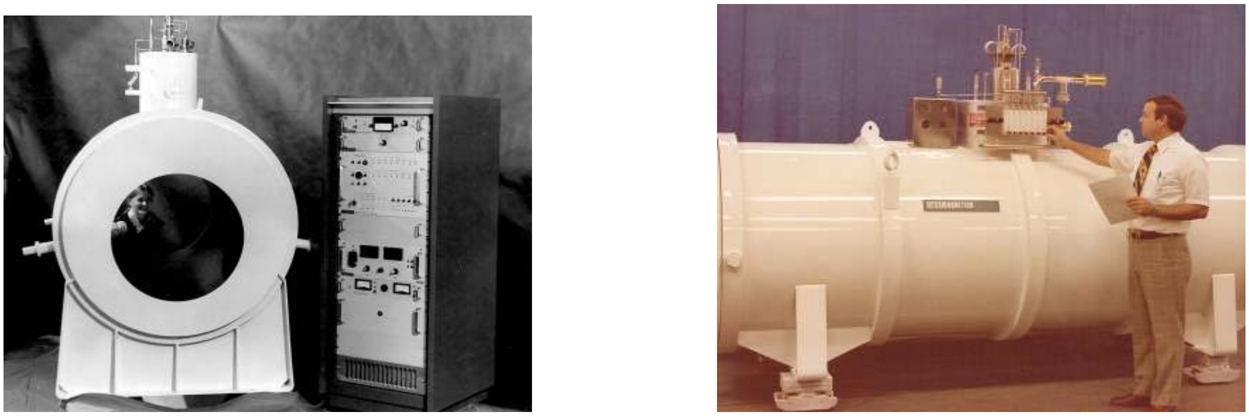

Fig. 23. Large-bore 2 T NbTi magnet with its electronic control panel (left); IGC's precursor to NMR large-bore magnet (right).

At that time, I also decided to expand our NbTi manufacturing capabilities even further. This decision was in part necessitated by a difficult market environment, as SC high-field Nb_3Sn materials and magnet technology, IGC's traditional area of leadership, suffered from the effects of a worldwide economic slowdown that led to severely restricted research funding. I attempted to acquire some of the smaller NbTi manufacturers, but was unable to secure any deal. By the end of the decade, ductile NbTi alloys had emerged as the most versatile and widely used superconductors for larger bore, medium-field magnets, and IGC was already a modest participant in the manufacture of such wire and magnets.

In exploring how to most effectively and substantially expand our NbTi manufacturing capability, we became aware of a brass manufacturing company based in Waterbury,

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[3] NMR imaging was later renamed "magnetic resonance imaging" (MRI).

Connecticut, that was selling off the manufacturing assets of a factory that had closed, including a 120 meter long 70,000 kilogram powerful draw-bench (Figure 24). With the purchase of this draw-bench, IGC was able to chart a different course. Such equipment allowed us to make very long lengths of SC wires with only a minimum of joints within magnet windings. This acquisition and the construction of a complete Nb-Ti manufacturing facility around it, was guided by Bruce Zeitlin. This became the key step in making IGC the undisputed US leader in the large-volume manufacture of NbTi wire. Additionally, it paid early dividends when the planners for the Energy Doubler, that later became the Fermilab Tevatron high-energy physics accelerator in Weston, Illinois, were searching for a supplier of such wire. IGC supplied more than 90% of the wire for the first iteration of the accelerator, and Fermilab Tevatron remained an important customer when the accelerator was upgraded in subsequent years. According to Gary Morrow, a longtime sales manager in IGC's magnet division, this development was crucial because it "helped us establish a large scale manufacturing and quality assurance discipline crucial to subsequent entry into the MRI magnet market".

Fig. 24. The 120-m-long draw bench acquired for large-volume NbTi wire manufacture.

Also in 1979, IGC signed collaborative teaming arrangements with GE and General Dynamics to design and manufacture superconductors to generate fields of 8 Tesla as part of the government-funded Large Coil Program managed by the Oak Ridge National Laboratory [16].

In 1980, IGC hired a consultant, Harry Forman, to look into possible underwriters that would help us to raise additional financing. Forman secured an underwriter that gave IGC a proposal to raise $3 million in an Initial Public Offering (IPO). However, IGC's Board of Directors was not impressed with the track record of this underwriter; they preferred partnering with a better known and more prestigious firm. Forman then brought us to Allen & Co. Wasting no time, Paul Swartz and I made a presentation to them asking for the same $3 million that the other firm had proposed. Allen & Co. were quite interested, as they thought highly of IGC's business proposition and accomplishments. They were intrigued by what we suggested would be the near term potential for a transition towards more commercial applications of SC. Indeed, we explained that there might be an application in the medical field to scan human subjects.

However, they informed us that they had a policy against underwriting companies that needed less than $5 million. This was a letdown, but within a couple months we were able to modify the financial forecast in an upgraded presentation to Harold Wit of Allen & Co., justified $6 million, and also sent along a 60 page document describing the use of the funds. Within a month after that, on December 31, 1980, Allen & Co. agreed to be the underwriter, and the first Initial Public Offering (IPO) of a SC company in the US took place in March of 1981. Thus IGC became a publicly owned company, a desirable milestone for small ventures then and to this day.

It is worth noting, in the lead-up to the IPO, I had once again approached GE to tell them about our plans for a multi-million dollar IPO on NASDAQ, proposing that this would be an extremely opportune time for them to re-invest in IGC and strengthen the SC technology within GE. GE considered doing so, but presumably, in basing its valuation of IGC on its earlier 46% ownership valuation, they came back with a counter-proposal which implied a valuation of much less than half of what IGC thought we would be able to obtain on Wall Street, so I declined the offer. In subsequent years, GE made several other informal acquisition proposals, but to my mind and that of our Board of Directors, they always seemed to significantly undervalue our company, compared with the valuation that other investors were assigning to IGC.

VII. THE LONG AWAITED COMMERCIAL APPLICATION: MRI

A. IGC Early Successes and Problems

After the 1981 IPO (1 million shares at $6 per share), the company was traded on NASDAQ under the symbol INMA. For the first time, IGC seemingly had reasonable financial resources to begin to capitalize on what we perceived to be a large commercial product potential of SC. Naturally, being a publicly traded company placed additional burdens on management. We had to publish quarterly financial reports, be aware of and strictly adhere to government regulations, respond to a significantly larger shareholder group, rapidly issue news releases upon the occurrence of special situations/orders, and so on. We also had a new Board of Directors consisting of two inside and seven prestigious outside Directors who wanted to be well-informed and were anxious to participate in virtually all decisions. Hence, we had to have monthly Board of Directors meetings, for which preparation and follow-up required much effort.

Nevertheless, the timing for additional financing could not have been better. The successful completion of the initial public share offering helped to fund plans for IGC's entry into the MRI field, and we became rapidly recognized as one of only two MRI magnet suppliers in the world. Indeed, initially only one other company, Oxford Instruments (OMT, until then mainly concentrated on developing SC instrumentation), was also able to quickly muster the combined know-how in demanding SC magnet and cryogenic technology to supply the emerging and rapidly growing, sophisticated medical equipment market.

Thus, in 1981, it appeared that the stage had finally been set for promising future commercial applications of SC magnets. Presentations at medical society meetings of dramatic and intriguing images of human organs, especially of the brain, that were obtained with resistive Nuclear Magnetic Resonance (NMR) magnets, generated enormous interest in the news media. As a result, some in the medical and radiological professions became convinced of the possibility that MRI could be used for diagnostic purposes. It appeared very likely that much clearer and more specific images of softer organs could be obtained by MRI than were possible with X-ray examinations. While the initially used copper-wound magnets yielded useful diagnostic information, the images had limited clarity and contrast. IGC, as well as OMT, recognized by the late 1970's that for such an application, SC magnets could generate much sharper images by utilizing higher, more stable and uniform magnetic fields at much lower electric power than possible with low-field copper-wound magnets.

The medical industry's excitement about the increasingly impressive images of human organs, especially brain and softer organ images, was shared by many large medical equipment organizations, several of whom contacted IGC and OMT to discuss orders for SC-based MRI. Technicare (a Johnson &Johnson, J&J, subsidiary) and several others, negotiated initial orders for 0.35 T, 0.5 T and even 1.5 T magnet systems with SC winding, that became the enabling technology for MRI at reasonable financial and electric power cost. All such systems were designed to meet demanding dimensional and performance specifications, a real challenge in manufacturing.

My decision to vertically integrate by internally fabricating SC wires, magnets, cryogenic housing as well as the electronic control equipment, seemed to be well justified. Everybody wanted their magnet delivered as soon as possible and we had to shift manpower from our high-field research magnet business to the design and manufacture of NMR whole-body-sized magnets. I believe that our ability to design magnet systems incorporating internally manufactured components allowed IGC to produce MRI magnets with large volumes of exacting field uniformity and relatively low helium boil-off performance. The very first order we received for a 1.5 T magnet was from Columbia Presbyterian Medical Centers' Neurological Department for a research project sponsored by Philips. Subsequently, we received singular orders from GE, Philips, Siemens and Technicare for MRI-type magnet systems at the various field levels; the design complexity and cost increased rapidly with magnetic field level.

However, by moving directly to 1.5 T, we had underestimated the need for precision windings throughout. Differential thermal expansion upon cool-down of the several main and auxiliary winding segments and structural components tended to distort parts of the large volume of essential field uniformity throughout the 1.5 T region. Similarly, the need to control the repetitive use of hundreds of liters of helium for each test, as well as the cool-down time lost, were also problems that needed to be carefully managed and solved. As a result, we had to construct several magnet design iterations in order to meet all of the overall system performance requirements. Hence, it took until 1983 for us to successfully install our first complete 1.5 T whole body NMR magnet system at Columbia University – for what was beginning to be called MRI. That success resulted in a number of additional orders from Philips and especially Technicare. The latter ordered 18 magnets and became our largest customer.

While we were pleased with the first 1.5 T order, we became aware that in the interim OMT had outdistanced us in lower-field magnets, gaining orders and delivering many more magnet systems to the other medical companies that wanted to enter the MRI market. Apparently, most successful was their early close alliance with Siemens; it eventually led to a joint venture between Siemens and OMT for MRI magnet manufacturing.

In contrast, soon after the delivery of IGC's first successful 1.5 T MRI magnet and a number of other 0.5 T, 1.0 T and 1.5 T magnets, IGC was hit by several very serious setbacks. The first problem was that GE refused to accept a 1.5 T magnet that they had ordered because it did not meet all of its very demanding specifications, while they had accepted one from OMT with similar deficiencies. The GE purchasing manager stated to us that they could accept it under protest, but would then never order another one from IGC. So we chose to build a second one, which they also rejected as it still missed meeting a few minor specifications. Thereafter, we never sold another MRI magnet to GE. Instead GE built their own magnet factory and thus became a competitor to IGC, eschewing collaboration with their very own spin-off.

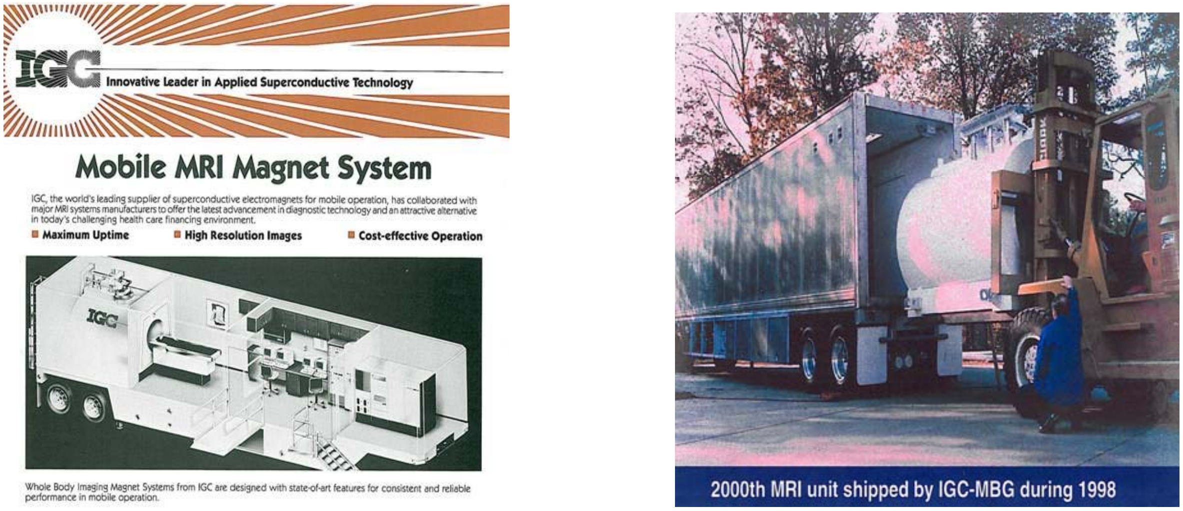
It has always been a mystery to me why IGC's relationship with GE tended always to be a delicate one. Early on, the joint research agreement and GE's large ownership stake in the company in the early 70's added a significant layer of bureaucracy to every major IGC decision, which negated the advantage that small companies usually enjoy: the ability to be flexible and nimble. In my view, GE's under-estimation of the market growth for SC products in the 1970's and beyond can be attributed to the fact that GE has been a decision-maker driven by focus on short-term results. GE accountants often were given the overriding power to make financially focused short-term decisions at the expense of other senior management, who might have been more thoughtful when considering parameters that would project potential benefits further into the future.

B. Structural Magnet Integrity Leads to Mobile Systems

A totally different major incident occurred when we shipped a seemingly successfully 1.5 T MRI magnet that had met all specifications in our factory tests and was kept cold. Shipping to Philips occurred by truck to NY City for transfer via air to the Netherlands. When the truck arrived in New York, the shipper noticed the magnet was covered by ice. We instantly realized it had lost its vacuum: the helium had boiled off. We thus decided to return the magnet to IGC rather than put it on an airplane. Our initial conclusion was that the truck ride was at fault. Fortunately, a second magnet had been manufactured and was ready to be shipped within a few months. To our horror, the same disaster happened again. Now we realized the problem was our inadequate structural design. These events led to a deferral and then cancellation of further orders by a very frustrated team at Philips. They also led to a management shake-up at IGC and my full-time return as president and CEO. Philips had every reason to be concerned and even upset, since their top management and Board of Directors had counted on IGC for success of their emerging MRI business.

Our engineers immediately re-designed the magnet such that it could withstand truck rides without damage to its vacuum enclosure during transport. We were able to build such magnet in less than 6 months, but for the time being, we had lost Philips as a customer. This saga, while enormously stressful, had a significant silver lining. As it turned out, the new, much more robust design opened up the possibility of mobile MRI: MRI systems on trailers could move from hospital to hospital overnight. IGC was able to deliver the world's first SC magnet for use in a truly mobile MRI diagnostic system in May 1984. We thus offered the market a novel distribution approach that achieved instant acceptance.

We were able to supply 0.6 T MRI magnet systems that were mounted within a large van (truck) and driven at full magnetic field between several hospitals for shared use on an almost daily exchange basis. This approach turned out to be an extremely attractive arrangement for many hospitals who could not otherwise afford to purchase a multi-million dollar MRI system for use by themselves.



IGC Innovative Leader in Applied Superconductive Technology

Mobile MRI Magnet System

IGC, the world's leading supplier of superconductive electromagnets for mobile operation, has collaborated with major MRI systems manufacturers to offer the latest advancement in diagnostic technology and an attractive alternative in today's challenging health care financing environment.

- Maximum Uptime
- High Resolution Images
- Cost-effective Operation

Whole Body Imaging Magnet Systems from IGC are designed with state-of-art features for consistent and reliable performance in mobile operation.

2000th MRI unit shipped by IGC-MBG during 1998

Fig. 25. Left: drawing of IGC mobile MRI system: IGC's 2000th MRI unit shipped in 1998.

A strong marketing effort for this product was exceedingly successful and from 1984 to 1985 allowed us to largely increase production of standard 0.6 T mobile magnets.

The slack in production by losing Philips as a customer was soon taken up by new contracts with Picker, Diasonics and Technicare. Technicare had quickly positioned itself as the most aggressive player in the MRI market and became our largest MRI customer for all magnet configurations. Thereafter, we concentrated on expanding our mobile magnet development from 0.6 T to 1.0 and 1.5 T magnets that justified building a new operations facility in Latham, NY, as well as growing our NbTi manufacturing facility in Waterbury, CT. All that was achieved within the next several years. Technicare and Picker accounted for deliveries of almost 50 MRI magnets that were installed successfully in traveling vans, mostly at 0.6 T field levels. By early 1986 we had recovered from four years of technical and financial setbacks and were confident of substantial future business growth.

C. Tylenol Poisonings and Consequences for IGC

A short time later, another devastating event occurred. We had delivered over 30 MRI magnets to Technicare (a J&J subsidiary) and had just negotiated an even larger contract, not yet signed, when I received a call on a Monday morning, informing me that Technicare was exiting the medical equipment market and would not proceed with the order.

This new disaster began (indirectly for us) with a seemingly unrelated event that now has a place in medical business annals as the paradigm for corporate responsibility. As has been chronicled in great depth, in October 1982 a malevolent person replaced Tylenol Extra-Strength capsules with cyanide-laced capsules, resealed the packages, and deposited them on shelves of at least a half-dozen or so pharmacies and food stores in the Chicago area. The poisoned capsules were purchased, and seven unsuspecting people died a horrible death. Before the incident, Tylenol had been responsible for 19 percent of J&J's corporate profits during the first three quarters of 1982, and was the absolute leader in the painkiller field accounting for a 37 percent market share. Johnson & Johnson responded to this incident in an admirably proactive manner, ordering a huge nation-wide withdrawal of Tylenol from store shelves. At the same time, they tightened their belt across the board to compensate for the loss of Tylenol revenue.

It was the second series of Tylenol poisonings that impacted IGC directly. Johnson & Johnson decided literally overnight that Technicare would be exiting the medical equipment business, even though it was totally unrelated to the Tylenol tragedy.

Before this latest event occurred, we had significantly expanded our facilities, as mentioned above. Our new manufacturing and office building was ready for occupancy. We also made other significant decisions in our anticipation of a virtual explosion of the MRI market. A new MRI R&D facility at RPI University under Ian Pykett [17] was to develop a complete MRI system for niche markets, especially for animal testing, an opportunity that we thought may be unattractive for larger companies. Also, we acquired a permanent magnet operation and had arranged to utilize both permanent and SC magnets in a materials separation business (MagSep).

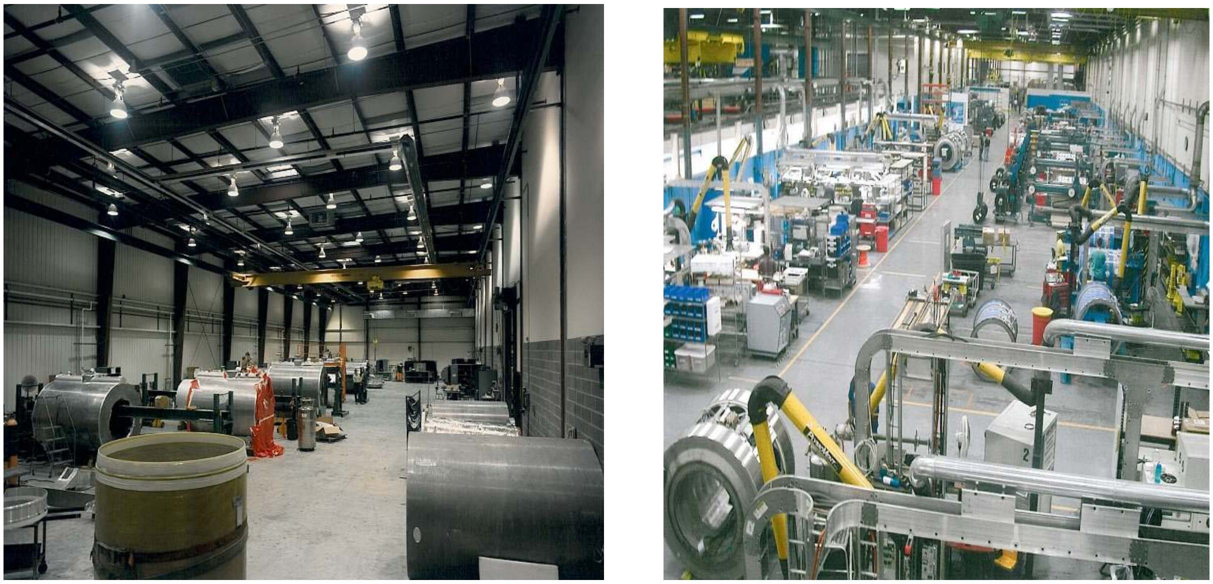


Fig. 26. Left: IGC's Early MRI magnet manufacturing facility; right: section of the new magnet factory.

While we were flying high after the successful IPO and rapid MRI business growth, the future of IGC now hung in the balance. The multi-dozen orders from Technicare that IGC had anticipated did not materialize. To make matters worse, expecting these new orders IGC had invested a great deal of money for the components needed, authorizing significant purchases of both equipment and materials. The consequences of this sudden disappearance of a "sure" order, a totally unexpected development, were immediate and devastating financially, but fortunately only for a relatively limited period. MRI had become a leading commercial application for Superconductivity. IGC was now also a more diversified company, both technically and product wise, thus able to attract and deal with a variety of customers.

We scrambled trying to secure other MRI customers to replace Technicare. In the years since the Philips debacle, I had been steadfastly working to re-gain their confidence in IGC. Shortly after the Technicare loss of orders, Philips agreed to give us another chance, initially as their second-in-line high-field MRI magnet system supplier. We were able eventually – after a hiatus of almost three years – to re-establish meaningful business relationships with Philips.

Also, Allen & Co., our underwriters, indicated their willingness to arrange for another stock market equity financing round of investment. In combination with some bank loans, this allowed us to regain financial strength within the following few years. We had re-established ourselves as a high-quality MRI magnet producer that could again compete with OMT, especially by leading the market in mobile MRI systems.

Through a combination of acquisitions and joint ventures in areas of cryogenic refrigeration, materials separation and specialty SC and permanent magnet products we had been trying to diversify. Our strong growth trajectory in MRI magnet revenue we were experiencing for several years eventually leveled off. Consolidation and integration of our various activities was called for, caused by delays in expected orders. Our commitment to significantly larger internal R&D expenditures also slowed our growth in the late 1980s. Overall, we remained optimistic that the slowdown will be temporary.

VIII. HIGH-TEMPERATURE SUPERCONDUCTORS

In September of 1986 a major event occurred that even ignited a much greater worldwide excitement than had occurred in 1961: the discovery of high-temperature superconducting (HTS) ceramic-type cuprate materials was published by Bednorz and Müller [18]. During 1987, additional HTS superconducting materials were discovered that exhibited transition temperatures up to 123 K, possibly not needing cooling to LHe temperatures[4]. While exciting and seemingly very beneficial to the development of applied superconductivity, these discoveries initially shook our confidence in IGC's future growth as envisioned in our business plan. Our strategy was based upon the assumption that it was unlikely that much higher critical transition temperatures superconductors would be discovered. Hence, we had pursued an approach towards vertical product expansion that involved becoming manufacturers of low-temperature superconductors (LTS), SC magnets and cryogenic systems, as well as low-temperature refrigerators and electronic power sources, with a focus towards possibly becoming complete SC system suppliers, including liquid helium refrigerators and recondensers. Was IGC's LTS-type Nb_3Sn- and NbTi-based business possibly obsolete? At this point, many of us in the SC industry experienced a keen sense of *déjà vu*. A second race soon ensued, akin to the one that followed the 1961 Bell Labs discovery, as the major participants in the SC arena scrambled hoping to capitalize on this new technology. Many large corporations once again re-entered the SC technology development race. These discoveries had an even more dramatic publicity impact worldwide than the 1961 developments had engendered.

Indeed, it was readily believed that the progress in and demonstrated successful application feasibility of LTS would simplify larger-scale applications of HTS superconductors in multiple areas where SC coils, cables and magnets already showed promise. Many were taking for granted that the early 1960's expectations of the dramatic impact of superconductive devices on the industrial sphere and the electric power grid would soon materialize. It was expected that no liquid helium would be needed anymore and even higher critical temperature superconductors would be found. Worldwide excitement was extraordinary.

In July 1987, President Reagan addressed a national conference on commercial applications of HTS, energizing and coalescing industrial expectations of benefits that SC-based devices would be bringing to the nation [20]. He gave a remarkably insightful speech and announced eleven important government initiatives to speed developments. Similar meetings were held in many countries in Europe, and elsewhere around the world. Several international conferences

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[4] The potentially most practical ones, REBCO, where RE is a rare earth element, were discovered by Paul Chu's group [19].

overflowed with attendance, demonstrating renewed confidence in breakthroughs for applied superconductivity.

The most ambitious arrangements were made in Japan, where the International Superconductivity Technology Center (ISTEC) was established with government support and immediately joined by over 100 industrial companies, each of whom provided ISTEC with funding and manpower [21]. IGC naturally participated in many of the national and international planning meetings, but with modest expectation that meaningful collaboration would be achieved. We also established an internal HTS R&D project, but continued our LTS based business, which to the surprise of everyone continued to grow.

By the early to mid-1990s, widespread realization set in that the manufacture and use of HTS materials was much more complicated and difficult than we experienced with Nb_3Sn. This was due to three factors: brittleness of ceramic HTS materials, their complex material composition and fabrication requirements relying on expensive manufacturing equipment.

IX. DIVERSIFICATION AND INTERNATIONAL BUSINESS EXPANSION

By the time of the HTS discovery, our company was substantially diversifying. We strove to cover a range of SC materials. Also, many different SC magnet configurations were tailored for specific research areas, such as electric power systems, ship propulsion motors and medical MRI applications, as well as cryogenic and even room-temperature refrigeration. First, in December 1986, we acquired Field Effects, Inc., which gave IGC the opportunity to participate in the market for scientifically useful permanent magnets such as those used in particle beam accelerators. Also, we could enter the market for a low-cost, fully integrated MRI systems based upon permanent magnets.

Quite importantly, the acquisition in 1987 of APD, spun off from its parent company, Air Products, allowed IGC to more closely examine its cryomagnetic design integration approach that eventually led us to manufacture “Zero He boil-off” MRI systems that reduced MRI helium usage to a cost-effective level. Indeed, we expected the acquisition of APD to have an economically beneficial effect on IGC, since it was advancing our vertical integration strategy. Successful implementation of applied superconductivity for both LTS and HTS requires combining three technologies: (1) SC wires, (2) magnet technology, and (3) cooling technology. Being already engaged in the first two key elements of SC in-house, the acquisition of APD Cryogenics gave IGC internal control of all three elements of the SC product combination chain. Furthermore, it gave IGC access to other markets needing refrigeration equipment, such as the semiconductor and laboratory instruments markets that benefit from cooling technology similar to that used in the SC business. Additionally, some of the APD products were associated with cooling needs for smart defense weapons, so the acquisition gave IGC another entry into opportunities within the defense industry.

Soon, other unique product opportunities became apparent. While these were only loosely linked to our core capabilities in applied superconductivity, there was one in particular that we thought could significantly enlarge IGC’s cash flow on a more regular basis to support our escalating research costs. That was the invention in APD of a coolant, called FRIGC, that could not only be a direct replacement, but also be safely mixed with the soon-to-be-outlawed environmentally damaging FREON R-12, used in virtually all car air conditioning and stationary refrigerators. The failure of FRIGC’s commercialization is a story not related to SC and it will have to be told elsewhere. It suffices to state here that for entirely non-technical reasons our expectations of a wide use of this new regulatory approved coolant and the ensuing major increase in our revenue did not materialize, due to the interference by all 3 US auto companies that seriously stymied our plans.

To more effectively participate in the growing European market, in 1987 IGC entered a joint venture with Alsthom, a company based in Belfort, France. Under the terms of the agreement, IGC would own 45% of the new entity, GEC-Alsthom Intermagnetics, S.A. (AISA), which licensed IGC’s technology and designs for SC MRI magnets to be sold throughout the European market. Alsthom-IGC thus set the stage for their later becoming a key supplier of wire and magnets to CERN’s LHC, the Large Hadron Collider project which has achieved stable operational status by late 2009. Independently, in September 1998, IGC itself secured a contract for $16.4 million in SC wire from directly from CERN. This was the largest ever single order for SC wire, and IGC was the only US company selected to supply that wire for the LHC. Another significant diversification milestone occurred in May 1996, when we formed IMiG MRI systems, a 50-50 joint venture with Surrey Medical Imaging Systems (SMIS) having as its objective to commercialize low cost MRI systems. The company was now operating in so many diverse product and market areas, most were even geographically separated, that it became necessary to formally establish their respective Business Segments, listed in Table 1.

Table 1. IGC Business Segments.

MAGNETIC PRODUCTS	REFRIGERATION PRODUCTS
IGC Advanced Superconductors	
IGC Magnet Business Group	IGC APD Cryogenics Inc.
IGC Medical Advances Inc.	IGC Polycold Systems Inc.
IGC Technology Development	

Each of these segments was headed by a very capable manager and was measured against its individual objectives and budgets. The outlook for significant expansion of Applied Superconductivity never seemed to look as exciting and appeared to be a certainty.

X. THE SAGA OF THE SUPERCOLLIDER IN TEXAS

After many years of planning by the High-Energy Physics community and proposals for government funding at a multi-billion dollar level, the Superconducting Super Collider (SSC) [22], a particle accelerator complex located in the vicinity of Waxahachie, Texas, was authorized by the US government. It was expected to be the world's largest and most energetic physics research device (surpassing the goal of the proposed Large Hadron Collider). The system had first been envisioned in the December 1983 National Reference Designs Study, and after an extensive Department of Energy review during the mid-1980s, a site selection process began in 1987. This project necessitated the construction of roughly 10,000 SC magnets in a 3-7 year time span. It was assumed that no single company had the capability to manufacture the sheer volume of wire needed to build all of these magnets (estimated to cost hundreds of millions of dollars). The announcement of this opportunity generated quite a buzz at IGC headquarters.

However, our excitement soon gave way to concern. We were informed that while the planners wanted twelve companies from across the globe to manufacture wire for the project, they wanted all of the wire for all of the magnets to be manufactured by the exact same process. This meant that companies could only participate in the project if they shared their in-depth wire making know-how, including pivotal information such as the heat treatment and wire drawing schedule. After some internal debate, the IGC management determined that the revenue from participation in the project justified the risk of giving away our manufacturing trade secrets.

With the benefit of hindsight, this proved to be a significant error in judgment. IGC's wire was accepted as the most reliable and high-quality wire of all that were produced by the twelve chosen companies. This was ultimately reflected in the fact that IGC was selected to produce the largest proportion of that Nb-Ti wire for the SSC of any company. Nevertheless, the other eleven companies stood to benefit a lot more from having access to IGC's trade secrets than we did from access to others. What we later realized was that the sharing of our detailed manufacturing process and its adoption was the major driver for international competition being able to rapidly catch up to IGC in the ensuing decade.

To make matters worse, IGC, and all other companies, ended up receiving only a tiny fraction of the promised major revenue from the project. With nearly $2 billion already spent, mostly for facilities, and revised cost estimates escalating to more than $12 billion for the project completion, the U.S. Congress officially canceled the project in October of 1993. The aftermath of this story was that the manufacture of NbTi wire became now an internationally competitive low cost "commodity" enjoying only low profit margins, which eventually decimated the SC wire industry in the US; it no longer could justify investing in further SC wire research.

In my opinion, the whole field of US high-energy physics and also fusion development projects should have stimulated much greater industry participation. The approach by some National Laboratories to build large-scale magnet factories within their confines and not allow industry to do so, in part led to the demise of the SSC. That also reduced political support for government funding of the project, as well as the support from large corporations like GE, and electric power utilities.

With some envy, I have been watching over the years the much closer cooperation of government and industry, especially in Japan but also in Europe. They clearly recognized that it is desirable and even necessary to join forces in the development of long-term technological projects.

A number of attempts in such a direction have indeed been made in the U.S. as well as by interested industry led groups [23]. However, since most of the possible funding from government agencies went to individual national laboratories, with whom large corporations were reluctant to participate, these efforts remained ineffective.

XI. 20TH ANNIVERSARY CELEBRATION AND LOOKING AHEAD

By 1991 we were able to celebrate our 20th anniversary since the spin-off from GE, by organizing a seminar with some key U.S.A. contributors of Applied Superconductivity (see Figure 27). IGC marked 20 years of progress by achieving record revenue and earnings. We continued to serve a substantial worldwide research magnet market, also by supplying large quantities of SC wire to high-energy physics and fusion projects, and the meaningful commercial market in the area of MRI medical diagnostics. Both markets promised to enjoy substantial growth in generating demand for SC-based technology.

Outside of MRI, the overall market for SC continued to require research materials and magnet systems, both HTS and LTS, including cryogenics. IGC was now in an excellent position to continue its growth in a number of directions. That was also reflected in the company's segmented organizations – see Table 1.

The worldwide success of the primarily SC based MRI market raised much chagrin about the absence of other meaningful SC market development, especially in the electric power equipment market, the perennial key target. That area remained an R&D market, primarily pursued and funded by US Government Agencies, but not by large electric power equipment manufacturers, nor electric utility companies in the United States.

In 1996 we were able to celebrate IGC's 25th Anniversary by approaching $100 Million in revenue and record profits before taxes. At that stage we had achieved the position of being the most accomplished applied superconductivity company in the US, with 500 employees. Our sales overseas amounted to 40 percent of total revenue; thus my early objective in naming the company and envisioning it as an international leader was becoming an achievement in reality. In the 1999 Annual Report, I expressed an expectation that by 2006 the company would be a Billion Dollar entity.

Fig. 27. Key Attendees at IGC's 20th Anniversary
L to R (Back row): C. Bean, J. Goldman, W. Sampson, E. Gregory, J. Stekley, R. Boom, E. Forsyth, B. Zeitlin
L to R (Sitting): R. Schmitt, W. Robb, C. Rosner, D. BenDaniel, E. Kunzler
Missing: P. Swartz, M. Walker, D. Markiewicz, J. Hulm.

Nevertheless, for the remainder of the decade of the 1990's, IGC was able to resume its profitable growth that also favorably impacted the price of our shares traded on the public stock market.

XII. A CHANGE IN IGC LEADERSHIP AND ITS CONSEQUENCES

With my approaching retirement, the Board of Directors was eager to bring in someone younger to take the reins of the company[5]. In 1997 we were successful in hiring a successor to myself: Glenn Epstein. He had a list of impressive career experiences, including many years of working at OMT. Although employed there, he was not directly involved at the technological level, but Epstein was aware of OMT's origin and strong participation in the SC industry. Upon joining IGC as President and COO in May 1997, Epstein was given responsibility for the day-to-day operations of the company from that point forward. It was understood he would be the successor CEO. Subsequently, he was appointed to the Board of Directors in May 1998, and in November of that year we announced that I would be officially stepping down as CEO at the end of our fiscal year in May of 1999, when Glenn will take over as CEO. I remained a Director and Chairman of the Board until 2002, but was no longer involved in corporate operations [24].

While Intermagnetics had been the most exciting and successful SC company in the US, in conjunction with my planned retirement from IGC's Board of Directors, the company's new CEO decided to dramatically change its business strategy towards a MRI-focused business. While the company had now solidly profitable operations, led by expanding MRI sales, the Board of Directors, composed mainly of individuals with financial Wall Street background, was supportive of the new strategy, having an objective for the company to show more regular financial gains and short-term profit. These could be readily delivered by a range of divestitures, beginning with the sale of IGC's successful SC wire operations to Outokumpu, headquartered in Finland, and the sale of the IGC-APD cryogenic helium refrigeration business, that was sold to Sumitomo headquartered in Japan.

In the following several years IGC's new strategic philosophy took hold. With a strong customer base in MRI, thanks to Philips having agreed to make IGC its exclusive magnet system supplier, IGC continued a restructuring process. The company disconnected from its AISA Joint Venture wire and magnet operation in France, as well as its operation in the UK. In addition, the FRIGC technology and permanent magnet operation were disposed of as well. The HTS R&D operation, called SuperPower, was also slated for disposition. The final divestiture before the Philips acquisition of IGC was that of Polycold in California.

The underlying philosophy now was that the company should accept and follow the basic tenets of capitalism as expressed so successfully by GE's famous CEO, whom Epstein admired and wanted to emulate. That meant the company should attempt to maximize its short-term earnings, pursue a streamlined product line, augmented by divestitures of slow-moving operations and replacing them by more attractive acquisitions.

The divestitures killed IGC's approach to vertical integration of its product lines, primarily in support of its SC based business; that was no longer the fundamental tenet of IGC's business and, outside of MRI, IGC no longer pursued any other applied superconductivity opportunities. The new focus was now the increasingly profitable MRI magnet system operation that would soon be expanded by acquisition of INVIVO in 2005. It provided the company with a desired instrumentation arm that had medical and MRI-related product lines expected to extend the company's involvement in the broader MRI market.

One can reasonably argue that all of these divestiture decisions were strictly good business judgment in the light of slow growth in other areas of applied superconductivity. For several

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[5] Most of the Board members were also aging.

decades, many have been bemoaning the fact that such a unique scientific phenomenon, which keeps challenging fundamental and applied physics for so long, did not yield any SC products showing significant growth in the commercial market, except for MRI. The resounding success of MRI can be attributed to the fact that it was almost decisively and rapidly pushed by major industry's investment and ability to move from feasibility demonstration to commercialization within a relatively short time; i.e. in less than 10 years.

To end my IGC story, in 2006 Philips acquired our company for approximately US 1.3 billion dollars in cash. At that time IGC was employing about 1150 employees. Our headquarters in Latham, New York became the global headquarters of Philips' enlarged MRI business. Upon completion of this acquisition, Glenn Epstein joined Philips to lead the MRI business temporarily until the process of integration of IGC with Philips was complete.

XIII CLOSING REFLECTIONS AND VISION FOR THE FUTURE

Time and time again, large-scale commercial expectations of superconductivity around the world have been focused on the electric power industry as the natural beneficiary of the lossless characteristics of superconductors. This area does remain a future possibility, since a major barrier, namely the need for large quantities of liquid helium, is gradually being overcome by major and continuing progress in large-scale cryogenic refrigeration technology. Also, continuing development of HTS wires and cables may eventually lead to sufficient reduction in their cost to warrant manufacturing and acceptance by electric utilities of special-purpose equipment operating at higher temperatures. Fault current limiters and HTS transformers could lead the way towards confidence in other power equipment, *i.e.*, electric power transmission lines, already demonstrated to be possible, but not yet economically competitive. There also remains the dream that superconductors may be discovered that can operate at room temperature

I already commented in Section X on the desirability of closer cooperation between government institutions and industry. The effectiveness of such a collaborative approach is demonstrated by the successful operation of the LHC in Europe, and the recent (2011) decision by Japanese Railways to proceed with the high-speed SC magnetically levitated train project. Regrettably, in the United States both the short-term governmental election process cycles and the short-term profit planning by US business, make superconductivity an unlikely candidate for the necessary long-term collaborative support. Let us hope that such obstacles can nevertheless be overcome in time, so that the enormous energy-saving benefits possible with S.C. can be achieved.

My involvement in SQUID-based technology over the past decade, makes me also confident that electronic, as well as chip based and medical SC enabled technology will eventually experience successful acceptance around the world.

Finally, I want to highlight that a remarkable and gratifying experience in my long industry career in S.C., has been meeting and benefiting from the work of numerous extraordinarily talented individuals across the USA, Europe, Russia, Japan and China, who also maintain a life-long fascination and passion with their involvement with Superconductivity, which remains a truly remarkable and technically challenging phenomenon that has been granted up to 8 SC related Nobel prizes. The enormous number of scientifically important publications generated with the utilization of LTS technology over the last 50 years, holds valuable insight and lessons for the use of HTS and all such future discoveries. To collect all of these in a dedicated SC print and web-access reference library would be an important and useful accomplishment.

ACKNOWLEDGEMENTS

My recollections of some key events of the unique and successful history of Intermagnetics' contributions to the worldwide development of applied superconductivity may by their very nature be limited and incomplete.

I want to gratefully acknowledge that the numerous accomplishments of IGC over several decades are due to the ingenuity and exceptional skills of many more individuals than those named herein. To all of them I want to express my great admiration and gratitude for their personal and collective dedication and contributions over many years that allowed me, IGC and our Board of Directors, to overcome many individual challenges.

Specifically, I want to thank my late wife Frieda and my children, who had to share my life with the daily demands of a growing Intermagnetics. The early outline version of this paper was greatly facilitated by my grandson – Ezra Brettler. Finally, I have been very fortunate for the past 27 years to have the daily support of my Executive Assistant – Mrs. Cathy Arduini – who also deserves special thanks and acknowledgement for her invaluable support.

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