

SUPER HISTORY

This write up is an informal light hearted remembrance by Gordon Chase relating his experiences from his perspective with superconducting materials and his co-workers. He has always considered himself with his abilities as a metallurgical engineer as support to the Physicists who were the pioneers of superconductivity. And God knows they needed it.

Atomics International

Gordon Chase began his career in 1963, with [Atomics International](#) (AI), fresh out of college ([Go Gators](#)) with a Bachelors degree in Metallurgical Engineering. He had some experience in refractory metals from working in college on grants from Oak Ridge on zirconium based nuclear fuel cladding alloys. His initial work at AI was in zirconium hydride modulated fuel rods. Berlincourt, [Hake](#), Tomash, Barnes and others were already at AI and had done the initial work of determining the upper critical fields of the niobium binary alloys, including Niobium Titanium, Niobium Zirconium and Niobium Tantalum. By that time, the commercial superconducting wire was Nb-Zr, begun at [Wah Chang](#) by George Kneip & Jimmy Wong, and commercialized by [Supercon](#). Nb-Ti was commercialized by Westinghouse. Nb-Zr wire would carry more current, but Nb-Ti had a higher upper critical field. These wires were copper plated monofilament and would perform satisfactorily in direct current constant field laboratory magnets if carefully charged. The Nb-Zr laboratory magnets typically produced a solenoid field of about 3.5 Tesla.

[Roger Boom](#) came to AI from Oak Ridge and began a group in superconducting materials. Jim Vetrano, an AI chemist, and Boom began looking at niobium titanium Alloys. Chase transferred to this group as a metallurgical engineer with experience in metallography of refractory metals and some knowledge of fabrication. The early materials were made from arc melted alloys, rolled into strips and tested for critical currents at 3.5 Tesla. Initial results indicated that a 35 w/o Nb balance Ti alloy, aged at 400 °C for a few hours would carry a large amount of current at 3.5 Tesla. This is basically an age hardening titanium alloy, and in fact a variation was later used as a rivet alloy for aerospace by Wah Chang. Clay [Whetstone](#) came to AI, with a PhD in Physics from Vanderbilt. [Al McInturff](#) came in from Vanderbilt a year later. Boom, Whetstone, and McInturff had all collaborated in superconductivity at Oak Ridge with Betterton, Kneip & Pickelsimer and made early measurements of the upper critical field of Nb₃Sn using a 25 Tesla pulsed magnet at Vanderbilt.

The Al group decided to fabricate enough conductor to make a demonstration magnet. Small billets of 35w/o Nb Alloy were cast in a cold hearth arc furnace and swaged into rod (those swagers are now in [Tallahassee](#) via Wisconsin). Crude wire drawing equipment was fashioned, and 10 mil wire was drawn using Molydisulfide as a lubricant. The operators, including Chase, resembled [Al Jolson's](#) Black Faced Minstrel character at the end of the day. The wire was electroplated with copper, just as the other commercial wires of the day. All this work was done in house at Atomics International by the superconducting group. The plated wire was taken by Whetstone to [Brookhaven National Lab](#), tin-silver alloy solder coated and formed into a solid stranded cable. The cable was insulated with a spiral wrap of nylon line to allow complete liquid helium cooling and wound into a solenoid. The magnet was tested and ran right up to design current and field ¹. Voltage probes indicated random flux jumps, quenches and recoveries. It was determined that the open winding scheme along with the cable surface finish kept the quench areas in a nucleate boiling mode as opposed to film boiling, and the regions recovered ². Unbeknownst to the physicists, (metallurgists had no clue) the cable winding pitch was just about right to provide superb stability. This phenomenon was not understood until sometime later as McInturff discovered.

Atomics International built up a fabrication facility to make 35w/o Nb Ti wire cable. Nb-Ti Rods were purchased outside, inserted into copper tubes, drawn directly into wire, and cabled on a newly fabricated hot solder dip cabling machine. McInturff headed up a project to make a multi sectioned large bore solenoid for [Prof. H. Brechna](#) at the [Stanford Linear Accelerator](#). The sections were graded with different amounts of solid copper and copper clad superconductor. By this time it was observed that the amount of cold work in the 35w/o conductor was far less than required in the early commercial wires, because this wire was drawn to size, heat treated and that was it. Precipitation alone provided the flux pinning sites. All the other commercial wires had complex draw, heat treat, and draw schedules. It was also observed that within a fairly broad surface to volume range that the critical current was constant, and not size dependent ³. So McInturff made one section of the magnet with one fairly large copper clad superconductor wire, with copper strands around it. This section was totally unstable and was replaced by a multi strand conductor cable. Perhaps the physicists began to ponder as to why.

¹ Whetstone, C.; Chase, G.; Raymond, J.; Vetrano, J.; Boom, R.; Prodell, A.; Worwetz, H.; , "Thermal stability for Ti-22 atomic percent Nb superconducting cables and solenoids," *Magnetics*, IEEE Transactions on , vol.2, no.3, pp. 307- 310, Sep 1966
<http://dx.doi.org/10.1109/TMAG.1966.1065844>

² Whetstone, C.N. ; Boom, R.W., "Nucleate Cooling Stability for Super conductor-Normal Metal Composite Conductors in Liquid Helium, *Advances in Cryogenic Engineering*, Advances in Cryo. Eng., 13: 68-79 (1967).

³ A. D. McInturff, G. G. Chase, C. N. Whetstone, R. W. Boom, H. Brechna, and W. Haldemann, "Size Effect and Critical Transport Current in Titanium (22 at.% Niobium)," *Journal of Applied Physics* 38, no. 2 (1967): 524.
<http://dx.doi.org/10.1063/1.1709368>

In the meantime, McInturff and Chase, were methodically heat treating, cold working, and measuring critical currents of a large range of Nb-Ti alloys, all on the titanium rich side. This work was published considerably later. Out of this effort, they concluded that a Nb-Ti alloy conductor of about 45 w/o Nb, still Ti rich could be very competitive in the present market. This alloy could be drawn directly to size, heat treated for several days in the 350 °C range and shipped. Considerably higher critical currents could be obtained by a modified single heat treatment and cold work. For the direct draw and heat treatment process, fabrication costs were very favorable. Making one more draw after heat treat was still favorable.

For whatever reason, in 1966, Atomics International, abruptly decided to terminate the superconducting effort which had been internally funded. The group had been doing quite well technically, but perhaps, not economically. Chase flew to Boston and was interviewed by the ZJJ Steckly and was offered a job, but he wisely declined. Chase went to work with IBM in Boulder CO. McInturff went to Brookhaven. Whetstone went to AirCo in New Jersey. Boom went to the University of Wisconsin. Bob Remsbottom, a machinist technician went to Wisconsin with Boom.

When Whetstone joined Airco in New Jersey. Eric Gregory and Bruce Zeitlin were there. Whetstone led the development efforts for some of the early techniques for production of monolithic multi-strand Nb-Ti conductors.

Cryomagnetics

In 1967, Whetstone secured private funding and formed Cryomagnetics, in Denver Colorado to produce superconducting wire. The startup effort was in the facilities of Cryenco, a very successful cryostat & Dewar manufacturing facility. After showing early commercial interest, Cryomagnetics built their own facility near to Cryenco. In 1969, Chase joined Cryomagnetics full time and McInturff became a part, although retaining his position at Brookhaven. John Ternus, an experienced wire man from Los Angeles ran the manufacturing operation. The Cryomagnetics (Cryomag') employee age group was in the late 20's or early 30's, and they were fearless. Incentives to work overtime were cases of cold Coors (Colorado) beer supplied by Whetstone . He was right there with the working crew.

Cryomag used the Ti 45 w/o Nb alloy that had been identified at Atomics International. The initial production scheme used a stack of interlocking copper pancakes with a drilled filament pattern inside of a copper can. The stacked billet was loaded with Ti Nb rod purchased from [Kawecki Berylco](#) or Wah Chang. Homogeneity problems were encountered with the Kawecki rod, and all subsequent Ti-Nb was purchased from Wah Chang. Cryomag developed a good working environment with Bill Maur and Bill MacDonald at Wah Chang. Several extrusions were done at Wah Chang.

The initial billets were hot extruded into rod at vendors, drawn to size, twisted, heat treated, insulated if the customer desired, and shipped. The pancake billets required a relatively high extrusion temperature to insure component bonding. This was good in a way because it allowed high extrusion ratio reductions, and lowered the rod to wire reductions. However, Cu-Ti intermetallic compounds were formed at the high temperatures, and as smaller and smaller filaments were desired, this became a problem. Drilling 4 inch pancakes was easy and economical; gun drilling of 24 inch billets was very expensive at the time. With a solid monolithic billet, extrusion temperatures could be chosen, and a tradeoff of reduction ratio and copper to titanium reaction and bonding could be selected. Reaction bonding of the Ti-Nb to copper became the rule for the high field, high niobium Nb-Ti conductors. This was to prevent the sausaging defect, caused by the increased flow stress of the Nb-Ti filaments after heat treating. This was unimportant for the Ti rich conductors. The low Nb alloys could be extruded at low temperatures, drawn to size, age heat treated and delivered. Sausaging was never a problem.

Cryomag built a furnace for an investment molding process. Eight and ten inch diameter billets (up to 600 pounds in weight) were cast by melting [OFHC](#) copper in a graphite crucible, sinking a quartz tube array into the melt, and progressively cooling the casting with a liquid cooled chill block on the crucible bottom. The quartz investment core was initially removed by immersing the billet in molten sodium hydroxide. A large riveted iron hot crucible was used at 700 plus degrees Celsius (that's red hot). The leaching operation, performed outside, required a lot of operational time, as well as energy; not to mention that a sodium hydroxide leak from the riveted iron crucible violently reacted with the concrete on the floor.

An improved quartz removal system was devised. The billets were immersed in a 70 per cent fuming hydrofluoric acid. 55 gallon drums were brought in and a progressive set up was made on the outside work area. The billets were first immersed in the weakest solution to the next to the fresh drum. This process required no cost for energy, could be done at a chosen schedule and was very effective. Chase did all of this handling in a green suit and mask, primarily because of his knowledge of chemistry. The fumes do clear ones sinuses. The building super next door talked to John Ternus, the plant manager, and mentioned that their building windows had become frosted. John says, "you know, our windows are frosted too, I don't know what it could be."

The cast copper was a very pure form of [ETP copper](#), high in oxygen, but because it was from [OFHC](#) billet, was very low in all other impurities. The final wire always had an excellent resistant ratio, but with high oxygen content. The oxygen provided a little extra flow stress, more closely matching the Ti-Nb. This matrix allowed Cryomag wires to be drawn directly to very small size. Cryomag had designed and built unique high speed twisting equipment for small wire (The physicists had figured out why and determined the required twist pitch by then). Cryo-

mag double extruded a 10 inch billet at moderate temperature at Wah Chang with over 200 filaments and drew it down to 0.010 wire, twisted, heat treated and formed into a braid. Small lengths were drawn to 0.003" diameter. There were no smaller dies available to Cryomag.

Cryomag now had monolithic billets with Ti-Nb alloy rod, although field limited, that filled the requirements of a large part of the market place. Production costs were comparatively low, and the lower Nb content of the rod lowered the cost. Cryomag was clearly in a good position.

Cryomag's most significant project was the HYBUC magnet system for the Max Planck Institute briefly described as follows.

Between 1968 and 1970 Cryomagnetics designed and assembled a 12 inch bore 11 Tesla magnet for bubble chamber experiments at CERN. The project was funded by the Max Planck Institute in Munich, Germany in conjunction with Dr. C.E. Roos at Vanderbilt University in Nashville, TN. The solenoid was constructed with a Nb-Ti outer section using a graded conductor design mated with a Nb₃Sn inner section. The project was made possible by the cooperation of several members of the early commercial superconductivity community.

The Nb₃Sn inner section was produced by [Carl Rosner's](#) Group at General Electric. The Nb-Ti coil form was designed by A. D. McInturff and Clay Whetstone at Cryomagnetics in conjunction with the Franklin Institute in Philadelphia, PA. The Franklin Institute did stress calculations for various critical separators used in the Nb-Ti coil form design. The multifilament Nb-Ti conductor was produced by Cryomagnetics.

This magnet required a large variety of rectangular shaped wire of different sizes aspect ratios and superconductor content. A capstan draw machine with large drums was built that formed the twisted wire with a [turks head](#) and finished with a shaped die that produced the final size with rounded corners and no casting. The finished wire was insulated with a heavy coating of copper oxide run through a single strand hot tank and oiled. Once the oxide tank was running to specification with pure copper wire, the entire run for the Max Planck magnet was processed. This took over 48 hours of continuous operation and maintenance performed by Ternus and Chase.

The Nb-Ti coil was wound at [American Magnetics in Oak Ridge](#), Tennessee by David Coffey and E. T. Henson. The helium containment vessel was designed by [Glen McIntosh](#) at Cryenco in Denver, Co.

The Nb₃Sn section was positioned and welded to the Nb-Ti outer section at Cryenco. Cryenco then built the outer liquid helium containment vessel around the assembled magnet structure using Efferson type counter flow leads to connect the magnet to the outside world.

Clay Whetstone took the magnet to CERN where the [bubble chamber](#) was installed into the bore of the magnet. The magnet was designed to reach 11 Tesla but actually trained to 11.5 Tesla. The operating field was chosen to be 11 Tesla to assure continued operation of the system during particle physics experiments.

The [HYBUC magnet system](#) and bubble chamber was very successful for such an early effort. The system provided the capability to measure the magnetic moment of the sigma plus and sigma minus particles with much higher statistical accuracy than had been previously possible.

At this time, the majority of business and wire orders came from various government funded projects. The fledgling superconducting wire companies were eagerly awaiting the large scale entry of private industry, for example magnetically levitated trains or large energy storage systems. Medical NMR imaging magnets had not yet emerged. The Cryomagnetics wire would have been ideal for NMR magnet application. The required field strengths were right in line with the Ti 45w/o alloy. Because of the very even filaments, the field uniformity would have been excellent and persistent joints could be more easily made. A welded and locally heat treated joint carried a surprising amount of current.

About 1971, government funding began to decrease, and Cryomagnetics, could not economically continue. Cryomagnetics was sold to Alcoa, and Whetstone went to Pittsburgh with the technology and his expertise. Chase left the field of superconductivity for several years and went to work at Ford Aeronutronic on advanced sodium sulfur battery systems. Ternus, returned to Los Angeles and became the plant manager and VP in charge of operations for a large carbon and stainless steel wire plant.

The name Cryomagnetics was coined by Whetstone when he started the company in August 1967. When the assets of Cryomag were sold to Alcoa the company name did not go with the acquisition. Whetstone gave the name to Dave Coffey in Oak Ridge, TN who formed a separate company using the Cryomagnetics name. The new Cryomagnetics company produced superconductor magnets and other cryogenic apparatus for many years.

ALCOA

Whetstone began a project to produce aluminum stabilized conductor at Alcoa. This had promise, because the resistance ratio of pure aluminum was very high, and the magneto restrictive resistance was very low. A light weight composite could find a use in rotating machinery. The primary obstacle was the tremendous difference in flow stress of aluminum and Ti Nb, even with the lower flow stress of the Ti 45w/o alloy. Super high purity aluminum would not work at room temperature, i.e., recrystallized in your hand. Aluminum could be easily strengthened

with additions, but the resistance ratio went dramatically down where it could offer no cryogenic stabilization. Collaboration with the extrusion experts at Alcoa devised a system where a super high purity aluminum core could be put into a Ti-Nb tube which was distributed in a matrix of an aluminum alloy that matched the flow stress of the Ti-Nb. Remember this for later. Sigmoid die shapes were developed that kept the reduction flow pressures and shear forces uniform throughout the extrusion process. This procedure allowed for a tubular composite to be extruded into rod, where the core had negligible flow stress. Unfortunately this concept again found no immediate commercial application.

Pacific Magnetic Structures

Whetstone had been working on his own with a unique method of making magnetic recording head material. In 1972 Whetstone resigned from Alcoa and moved to San Diego, CA. and formed Pacific Magnetic Structures (PMS). The girls always answered the phone by saying "Pacific Magnetic Structures" never "PMS".

ALCOA sold the aluminum stabilized technology to Magnetic Corporation of America (MCA). MCA had been formed sometime earlier by DeWinter, Steckly, and Lucas. Whetstone, although not obligated, continued as a consultant to MCA.

Chase was working for Ford Aerospace in collaboration with Ford Research in Newport Beach, CA on the sodium sulfur battery project. He finished up his work on the seal and container for the battery cell, resigned from Ford, and joined Whetstone in San Diego in his magnetic material business.

MCA had a portion of the Fermi Lab wire production contract. The metallurgists at MCA were Bruce Strauss and Hemachalam Kanithi (Hem). Harvey Siegel was a young physicist at MCA.

MCA encountered production difficulties early on with wire breakage and not meeting minimum length requirements. DeWinter hired Whetstone and Chase to help out. All failures were sent to San Diego and Chase metallographically analyzed the failed rod and wire. He concluded that Euler buckling of random rods during extrusion, Ti Cu irregular intermetallic particles in some billets and not others, and an irregular wire entrance into the draw dies because of slack loops were causing multiple failures. A Herborn cone draw machine was used for small wire reduction. By compacting the assembled billets with an open sink die, employing sigmoidal extrusion dies, dictating careful control of the Billet preheating temperature and holding time, using 16 degree included angle dies with very long approach lengths along with zero reduction guide dies, all precisely sized to the Herborn draw cones, the breakage problems were solved. Towards the end of

the production contract, the wire had to be cut into two lengths in order to be handled by the Herborn. Several billets were drawn with no breakage.

HOLEC Draad

At about the same time, Whetstone and Chase were introduced into the Holland Project. Ted DeWinter was a native of Holland. He had contacts with Holec Draad (wire) and the national energy center of Holland ([ECN](#)). The ECN had concocted a powder cored tubular filament (PIT) Nb₃Sn wire concept. The Holland government graciously supported the project with significant funding. ECN worked with the University in Apeldoorn to develop an extrusion process. Apeldoorn used a vertical hydraulic press and extruded a number of small diameter billets containing 18 tubular filaments. Niobium filaments were filled with NbSn₂ powder and a small amount of copper powder and assembled into a multifilament billet. The powders were supplied by [CERAC](#), a US company in Wisconsin. At the same time, HOLEC Wire in Nijmegen was brought in to provide wire reduction. Well, none of the extruded rod could be drawn, it all broke up. DeWinter suggested to the HOLEC people that he knew of some folks that had developed tubular extrusion techniques (Whetstone at ALCOA) and really knew composite wire reduction (Chase and Whetstone) for their assistance to MCA with Fermi Wire.

DeWinter arranged for a team from HOLEC led by Andre Van Vess to come to San Diego for a meeting. They brought samples of extruded rod and failed wire. The failures were metallographically analyzed by Chase over a two day period, and the results presented to the HOLEC Team. At that time, all of the technically educated Netherlanders spoke fluent English, so communication was easy. The powder cores, although certified to a very small Fisher powder size and to composition, had large particles of NbSn₂, equally large particles of an unidentified hard material, probably grinding media, and large particles of copper that had been transformed into extra large particles of bronze indicating free tin in the mix. In a sense, the entire powder core after extrusion was a sort of solidified concrete.

The HOLEC team suggested that Chase and Whetstone come to Holland for a couple weeks, tour all the facilities, make some evaluations and offer advice. Whetstone and Chase traveled to Holland, toured the facilities Petten, Utrecht (HOLEC Corporate) Nijmegen, Apeldoorn and met with all the participants. Chase and Whetstone evaluated the problems, and Whetstone gave a convincing presentation at ECN that outlined what needed to be done to achieve success. The objective was to assemble billets, extrude to rod and draw into wire. ECN and HOLEC asked if Chase could stay on for six weeks as a participant. Chase, being single, and having no overhead expense in California, readily agreed. Chase was set up in a Hotel in Alkmaar, several Kilometers from the ECN and provided a car. The hotel room was about \$20 USD per night breakfast

provided, meals were reasonable in an excellent dining room. A large draft of Heinekens or Amstel in the saloon cost about 30 ¢ US. The folks in the saloons always wanted to talk to Americans. They loved American TV. Kojac and Dallas were their favorites. Some of the storefront window decorations were fabulous. Chase reasoned that this could be a fun and economical time. As it turned out, Chase was invited back for six week intervals off and on for several years. In the off times Chase analyzed samples and wrote reports in San Diego. The PMS contract was in USD. The increasing interest rates in the US enhanced the exchange rate. The true measure of the exchange rate of dollars to guilders was the cost of Amstel beer in a crate at the Super Coop. The best was 17 ¢ US per bottle. Now back to business.

The first step was to fabricate the powder in house at ECN. ECN had powder processing equipment from earlier work in nuclear fuel rods (it only glowed a little bit). Chase had always been an outstanding inorganic chemistry student in theory and lab and understood the processes. His previous experience at Ford with sodium sulfur compounds was beneficial. If one could ask for an opportunity that fit, this was it. The powder mix would use eta bronze rather than pure copper as the required copper bearing component. This was necessary because some elemental tin could always be present in the NbSn₂ powder and pure copper would form large cemented bronze particles. The extrusion ratios were dictated at 16 to 1 area reduction and whatever tin was present would melt from adiabatic heating. Whetstone's experience in tubular conductors with low flow stress cores, and literature research indicated that a low liquid content slurry could be extruded as a core, mechanically at least. Powder was fabricated, blended, loaded into niobium tubing reduced into compacted rod, assembled into a billet and extruded in Boston in conjunction with MCA. The extrusion was done at ambient temperature with a sigmoid die. The billet extruded according to plan. Metallography indicated that the molten tin, even at relatively small amounts and low temperatures reacted with the niobium tube, causing intergranular penetration. Perhaps even further damaging was an effect of shear banding. Something not well understood at the time. It was concluded that the billets could not be extruded if molten tin was present, and furthermore, the flow stress of the core must be more closely matched to the niobium to prevent "shear banding". PMS had fulfilled their contract but had not succeeded in the objectives to provide extruded rod.

But wait, there's more. HOLEC and ECN inquired if PMS could make a drawn product. PMS had assumed that ECN (they were always pretty closed mouth) had made enough drawn wire for testing. This was not the case. ECN had an excellent laboratory set up for producing experimental wire, a small draw bench, quality swaging machines, a large capstan block, and an accomplished technician. PMS agreed to do so. In analyzing the ECN draw problems, Chase concluded that the ECN used Cerac powder, full of rocks, and more importantly used very small draw die reductions. For a composite material, the preferred plan is to draw at just below tensile failure with a low angle reduction die, slip fit guide die, balancing die friction, die angle, and reduction ratio (that was a mouthful). Chase

had measured the flow stress of NbSn₂ composites with compression samples and determined that a 20 percent pure tin addition to the powder would provide the best mix for ambient temperature reduction. An 18 filament rod was assembled with Fermi lab hexagonal copper tubes from MCA in a copper can. Respect for center burst kept the central hex as solid copper and shaped copper fillers were used. Chase dictated that a small, no reduction, compaction pass would be made followed by a 32% reduction pass. This raised a lot of eyebrows at ECN. When the rod drawing process was started, a substantial audience from the upper floors (mostly physicists) gathered in the basement laboratory. The pull chain picked the carriage up off the draw bench track, began to hum and groan, and then started to draw. When the rod cleared the die, it sounded like a cannon shot, and slammed against the end wall. Chase looked at the audience and gave them a thumbs up. From then on, the lab tech and Chase worked well together with mutual respect. The rod was subsequently drawn down to fine wire using a graded reduction schedule. This provided the ECN with their first real test samples. The ECN internally measured superconducting results were impressive, and PMS was invited to continue. Further 18 and 36 filament drawn composites were proposed and subsequently fabricated over time. On Chase's final day at the ECN Lab, the tech brought in a bottle of [Bols Oude Genever](#) in the ceramic flask, and they had a fine final afternoon.

At about this time, LIPS in Drunen was introduced into the mix. Thank you, Holland government for funding. LIPS was the Holy Grail for fabrication. LIPS was the producer of copper and brass tubing for Holland and most of Europe. The tubing section was separated from the ship propulsion business. LIPS provided cast propellers, gear boxes, and shafts for the world. As a metallurgist, Chase was resoundingly impressed with the facilities. The top end was an ASEA hydrostatic extrusion press which handled a 36 inch long 6 inch diameter billet. Still interested in economical production, test billets containing Ti-Nb rod were extruded at high reduction ratios. That is another story and is a good one because it emphasizes the requirement of billet temperature for Ti Nb conductors. A Nb₃Sn tubular billet was assembled and cooled to minus 40 C in acetone a CO₂ and extruded at 16 to 1 reduction ratio. It was drawn into wire, but was not completely successful. Chase regrets to this day that he did not press early on for multiple ASEA tooling that went from 6 inch to 3 inch to 1½ inch and onto the large draw benches at LIPS. That would have done it. Unfortunately, the Holland government cut off funding, the problem that all superconducting projects have been faced with and the project was terminated. The drawn product, which had been continued, showed high current capacity, and in fact demonstrated the highest current density at that time (1984).

Chase retired from the field of superconductivity and in 1984, joined the Department of Defense, Navy Lab in San Diego as a "Rocket Scientist". He worked with the MK 46 lightweight torpedo and the Vertical Launch Anti Submarine Rocket (that's a another mouthful) Chase retired from DOD in 2001, at age 62.

Dispersion Strengthened Alloys (DSP)

With the urging of McInturff, Chase applied for and received several SBIR grants in the area of tubular filament Nb₃Sn conductors. The projects emphasized the assembly, extrusion, and drawing of composite tubular conductors using dispersion strengthened tin base powder alloys (DSP). Clay Whetstone and John Ternus were major players in the DSP grants. Ternus provided for and participated in all the rod and wire reduction efforts. Chase ultimately concluded that the optimum Nb₃Sn conductors would be made from a system that diffused tin inwardly into niobium strands, and not outwardly as in the tubular process. This is because the reaction is driven towards stoichiometric Nb₃Sn for inward diffusion. The concept was demonstrated by the record breaking current densities of wire produced by [Oxford Instruments](#). The difficulties with the Oxford wire were that during heat treatment, the tin had to be diffused from tin reservoirs to niobium filaments at variable distances. The ultimate solution is to distribute niobium filaments in a high flow stress tin alloy matrix, reduce to wire, and uniformly heat treat. DSP alloy powder can provide that matrix. This was shown to be feasible with a MacDonald Jelly Roll conductor that was assembled, extruded and drawn to wire. The ideal form would be to slurry coat niobium rods with DSP, assemble into billets, multiple extrude, draw and heat treat.

Gordon Chase
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