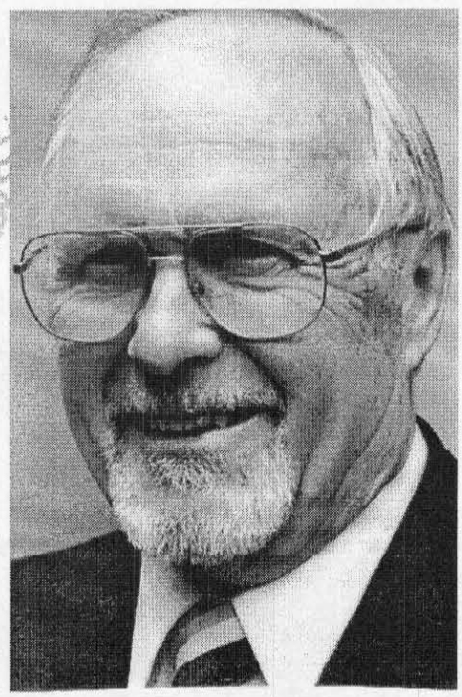
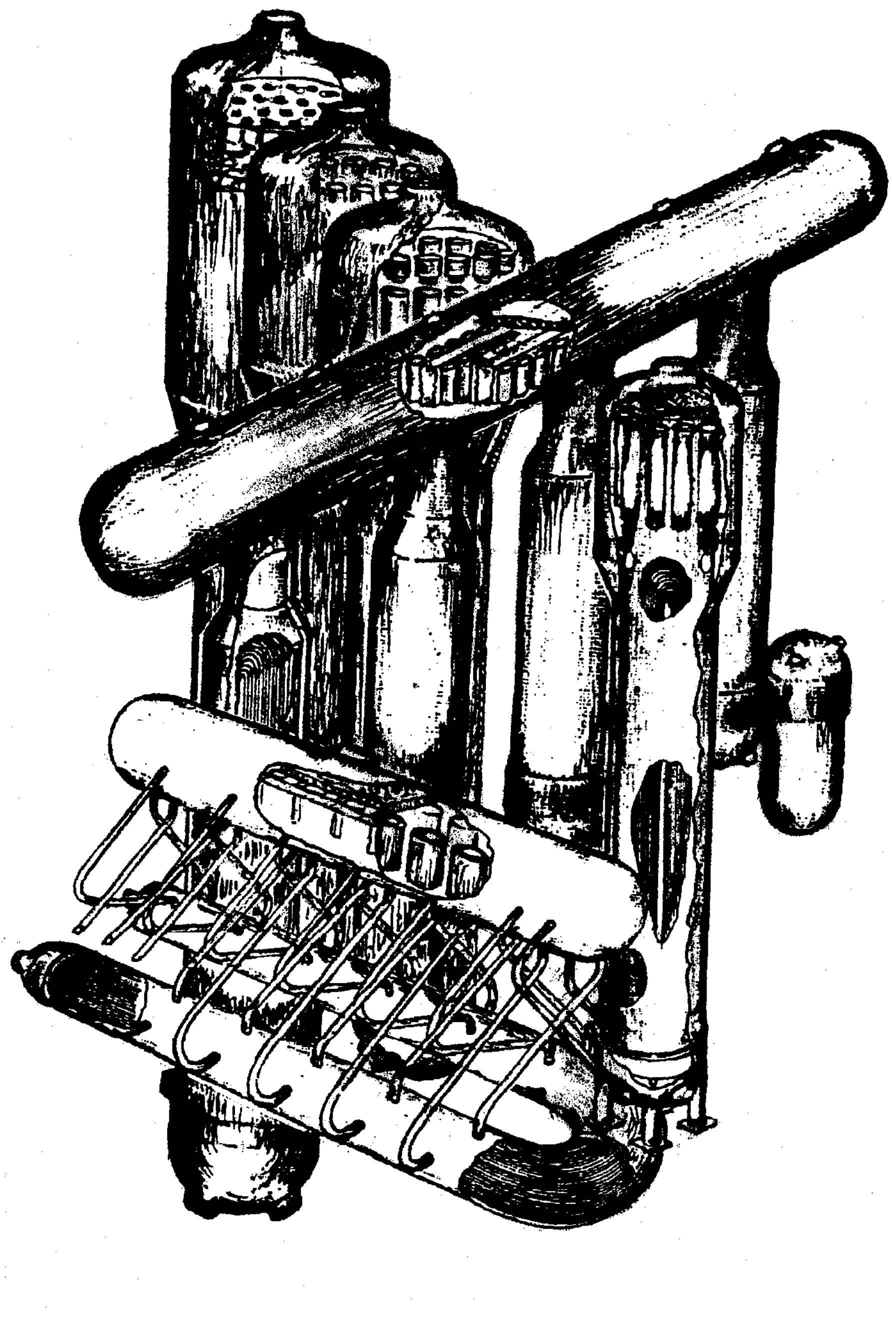
Memories of my Life as a Professional Engineer in the Royal Canadian Navy and the Canadian Boiler Industry

by John M. Dykc B.A.Sc., P. Eng.
ASME. U of T 1943 Mechanical



Memory provides the foundation for hope.
It is my wish that my memories will endure, through this tome,
to bring new and continued development of nuclear power.



Boilers Built by Babcock & Wilcox Canada from 1956 to 1980

Summary

John Dyke, at age 80, has the sole distinction of being the only professional engineer still alive who experienced the development of the CANDU Nuclear steam generators in Canada from the beginning. He was associated with Canada's first Nuclear Power Demonstration plant while employed with Babcock & Wilcox Canada (BWC). He was involved to varying degrees in all the CANDU steam generators installations. These include OH's 200 MW Douglas Point station in 1968; AECL's 600MW stations for NB Power and Hydro Quebec; and OH's 900 MW Darlington station in 1980, the last CANDU station to be built in Canada. This also includes Hydro Quebec's 200mw Boiling Water Reactor, now decommissioned.

John's story covers 50 years, from his life as a boy in the 1930s, to his retirement in 1980 as Senior Project Manager, Nuclear for Babcock & Wilcox Canada. It is told from his point of view and it offers a challenge to engineers: to maintain a desire to keep learning, to build on the past and remember not to forget its lessons. Doing so, he believes, is to repeat its mistakes. John's philosophy echoes a quote from Louis Pasteur, that "chance favours only the mind which is prepared."

Fran Gregory, Editor

Disclaimer

This document represents John Dyke's own recollections and opinions. It is not endorsed by Babcock & Wilcox Canada, AECL, Ontario Hydro, Westinghouse, Foster Wheeler, or Combustion Engineering nor does it reflect their opinions.

I start this tome with an extract from the conclusion of the book entitled -"A History of Babcock & Wilcox Canada – 1844-1977".

"In April of 1978, an event occurred that was to signal the beginning of a major upheaval in the Company's affairs. In that month, Ontario Hydro verbally notified the company, that some eddy current test probes had become stuck during routine inspections in a steam generator at the Pickering site. There followed a series of events that resulted in the cessation of all work on the Bruce and Pickering steam generators in December 1978. The subsequent Nuclear Steam Generator Recovery Program was possibly the most severe test to which the Company was ever put. The execution of that program, which is a saga unto itself, dominated the next five to six years of the Company's history. However, the present history will end at December 31,1977, since the current[1987] chronicler wearies at the mere thought of recounting that epoch tale."

In the year 2001, this writer will attempt to do so. It might be difficult for the reader to try to follow this story as a chronological sequence of events. However, memory doesn't allow me to write it as such. As senior project manager of nuclear products, all the major events of each contract came to my attention through my direct reports and through my involvement in early marketing activities. If the events told here appear to run into each other, they are a reflection of the dynamic environment during the early days of nuclear power as we were all trying to succeed and do our best.

Preamble

A couple of years ago my family thought that, in my retirement, I should have a computer. Therefore, I bought one on my 76th birthday. Quickly, I found that playing games was not for me. I'd rather write. I learned to type, though it is more of a hunt-and-peck style than the smooth fingering of a good typist. However, what should I write about? When I read that Canadian Professional Engineering Organizations were anxious to collect historical records of the early engineers and their achievements, I decided to put my memories to paper, while I'm still able to do so. One of these historians is Andrew H. Wilson, P.Eng., Chair of the History & Archives committee of the Engineering Institute of Canada. Andrew, or Drew as I know him, encouraged me to undertake the work of writing about my career and involvement in nuclear steam generator design and the development of a unique boiler for the CANDU. Therefore, I am doing my best to recount the major events that make up the history of that industry, from my point of view.

What is recorded in this piece may be one of Canada's best kept industrial secrets of the nuclear industry in the twentieth century. It is my hope that this narrative will help Canada's engineers feel pride in the accomplishments that Canada has made. It is also my hope that by exploring our past, future generations will feel confident to embrace the challenges of the future. It is our responsibility to push the limits, to make mistakes and learn from them, and to keep Canada in the forefront of engineering progress on all fronts.

In the beginning

My story starts in 1930 when my family lived in St. Lambert, P.Q. across the St. Lawrence River from Montreal. At the age of ten, I had a bicycle as most boys did. To enhance its enjoyment, we attached the lid of a cigarette carton to the front wheel forks with clothespins. As the wheels turned, the spokes hit the cigarette lid. They made a lovely purring noise. We likened it to an engine with tremendous horsepower. We certainly believed that the noise added to our progress over the road!

I was luckier than most. My dad brought home large elastic bands, which I thought when stretched across the handlebars of my bike, would make a noise when the air activated the elastic bands as we peddled along the road. They did! And what a sound! I imagined an engine of greater horsepower than with the cigarette box lids. I also began to think about the differences between the cigarette boxes and the elastic bands. Moreover, I found that I could stop the engine noise by holding one or both bands with my fingers, or by filling the gap between the bands with two fingers. What I had discovered was how a pair of elastic bodies could vibrate in a stream of air, and how to stop them. Interesting then, but time passed and I went on to other things and places.

The Royal Canadian Navy

I attended the University of Toronto from 1939 to 1943, graduating with a degree in Mechanical Engineering. The privilege of completing my university studies and then joining the forces was deemed the best course of action in wartime. It was thought that a graduate engineer could be more useful to the country's war effort, than otherwise.

Engineering graduates from any university in Canada could volunteer to join any branch of the services. I chose to join the Royal Canadian Naval Volunteer Reserve [RCNVR] to become an Engineer Officer on one of the Canadian ships, as did about ten of my classmates from the University of Toronto.

We had basic training by army non-commissioned officers (NCO) in depots near to our hometowns. Then we were given Navy uniforms and transported to Halifax, Nova Scotia to take the engineer officer's training course at HMCS Stadacona, the shore base in Halifax. Upper-deck officer trainees (University graduates in the Arts) reported to Dalhousie University the shore base for their training program in Halifax.

In the spring of 1943, about 40 engineers from across Canada were being indoctrinated into navy ways in the short time of about 3 months. We were split into two classes and each group was assigned to a training officer. These groups became very competitive, as the officers pitted each group against the other to become better sailors. There was another challenge for the student engineers to graduate with the highest marks in engineering subjects of both groups.

One trainee in our group was an outstanding honour student from McGill University, so we thought that we should win easily. We did! However, I made the highest grades of both groups, much to the delight of my close friends. We had proven our superiority for our alma mater, the 'U of T'. Then came the real test. Our training officers challenged the Upper Deck Trainees from Dalhousie to a boxing match, the Navy's traditional sport. They refused. The engineers had a reputation for being rough and ready for anything at University and on shore in Halifax too! We were delighted at this turn of events because we thought we were off the hook. Our instructor said, "You can't get off that easy. You'll fight yourselves!" So, a list was made up giving height, weight, reach, and experience to select opponents amongst our group.

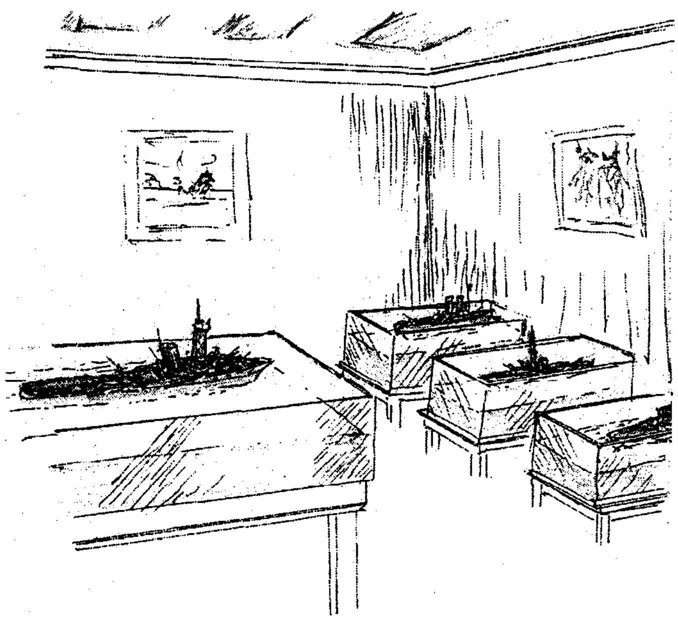
As background, I came from a very non-aggressive household. I was the youngest of four. The eldest, my only brother, was quite a few years older than I and left home early. So, there were two girls to bring me up, and no physical fighting occurred. I was terrified at the thought of this match, as I had never before worn boxing gloves. Added to that, I drew as an opponent, a boxing champion from McGill University. I lay in my bunk, sulking a bit at my luck. What was the Navy doing to me? I didn't join up to fight a Canadian boxing champ, I thought. I came to fight for Canada. I wanted to go home. This was no place for me. Everything was going wrong. How could I get out of here? Finally, fight time came. I was fitted into the gloves and, with trunks adorned, was pushed into the ring with 600 sailors shouting and screaming, "Kill him! Kill him!" With one tremendous right hand blow to the jaw, I saw stars. There was a tremendous roar from the crowd as I hit the mat. They rose to their feet, everyone screaming in delight. In one second or less, it was "lights out".

I remembered nothing else until I woke up with my buddies pouring rye whiskey down my gullet, and slapping my cheeks. I was put to bed to sleep it off. Next morning a chum awakened me and told me I was on duty for church parade. I was in charge of a platoon of ratings that I had to direct to the church service. All the while I was really thinking, "What happened to me? What was I doing here, with a thick head and marching these dummies to church?" Certainly, this was no place for me. At stand easy, the NCO of the platoon came up to me and asked, "Were you at the fights last night? Did you see that blond officer get creamed?" "Yes," I said as I lifted my cap to show him my fair hair. "It was me." His reaction said it all, he turned and scurried into the troops assembled on the parade grounds...never, to be seen again. As I directed the platoon off the parade grounds to dismissal at the barracks, I was proud to be in the senior service. Six hundred sailors knew me!

On completion of basic training and the naval engineering course in Halifax, I was posted to the Royal Navy in the United Kingdom to obtain my engineers' watch keeping ticket, overseas. After two Royal Navy RN postings, the HMS Londonderry and the HMS Jed, and hundreds of miles of convoy duty in the Mediterranean Sea, I received my watch keeping ticket. This ended my tour of overseas duty, and I was directed to return to Canada. This experience also gave me a promotion to the rank of Lieutenant 'Engineering', in the Canadian Navy.

Stan Lowe, John Storey and I, now commissioned Lt.[E] Engineer Officers, were en route home. We were directed to attend to RN damage control course in

London, England which was indeed a great privilege as only a few were chosen. The course demonstrated how



Royal Navy Damage Control School, London, England

the German Navy sunk Her Majesties' ships, by using model ships floating in tanks of water. Valves were attached to the model ship's hull, in the exact position where a torpedo would have struck the ship. Opening the valve and letting the water into the compartment caused the model to list in the same manner as in the real battle. Thus, the actual sinking of the ship was duplicated in the tank, one step at a time, until the target ship floundered and sunk to the bottom of the tank. Then analysis took place, demonstrating how one could avoid sinking of the ship by controlling the water flow from one watertight compartment to another. When I returned to Canada, I wrote a report on the status of damage control on board Canadian ships. I recommended that all ships' damage control colour codes be updated and applied to the ships' machinery before being taken over by the Navy. I also proposed that the ship's company should include a damage control group to be trained in this necessary function. This was adopted and all HMCS ships were upgraded and made safer.

As the damage control course ended after two weeks, we received a signal to return to Londonderry, Ireland, to take passage to Canada. John Storey wished to proceed to Londonderry that Friday evening to be sure that he did not miss the convoy. Stan and I wanted to spend our last weekend in London. We asked permission to extend our leave and it was granted.

On Monday morning, we arrived late in 'Derry' just as the convoy's ships were raising steam to cast off for Canada. We were informed that there was one berth left on the Frigate Valleyfield. Originally there were two berths, but as John Storey had arrived early, he occupied one. We were advised that the Corvette Frontenac had two berths as an alternative. So, we had a choice. Naturally, the frigate was the desirable choice as it was the larger ship. Therefore, as is the custom in the navy, we agreed to toss a coin to determine the winner of the last berth on the Valleyfield. I took a shilling out of my pocket, tossed it up into the air. It fell to the ground. I put my foot on it, and said to Stan, "We've had a good time together these last two weeks why split up now?" So we took the two berths on the Frontenac. The Valleyfield was sunk on the way home. Unfortunately, John Storey didn't make it

In early May 1944, heavy fog settled on the Atlantic Ocean off the coast of Newfoundland. Because of the fog, the German submarine U 548, which was cruising the North Atlantic for prey, had to submerge and navigate by depth sounder from the ocean floor by dead reckoning. The German submarine proceeded to a position where it could engage the enemy. Earlier, escort group C-1 consisting of six Canadian warships: the frigate HMCS Valleyfield, and the corvettes, HMCS Halifax, Frontenac, Giffard, Edmunston, and Fredricton departed Londonderry, Ireland on April 27, 1944. At the western meeting point the escorts C1 broke-off from the convoy and passed the responsibility of the 75 ships to the new escort group W-4, who proceeded to New York. Having done this, the escorts for C1 immediately steamed a straight course home to Newfoundland. At this point, reports placed the nearest submarine about 150 miles east or south of Cape Race. The captain of the Valleyfield was very tired, as he had been up almost the whole trip because of the dense fog. The weather cleared and everyone was looking forward to a pleasant run and leave ashore. It seems reasonable, under the circumstances, that normal fighting procedures could be safely relaxed. They steamed through slushy ice, which interfered with their sonar detection gear, straight over the German submarine U 584 lying on the bottom of the ocean bed. The Sub fired one torpedo that blew the Valleyfield in two pieces. The bow section sunk in 90 seconds, while the stern held on for 5 to 6 minutes. Of Valleyfield's total complement of 163, only 38 survived. This was the worst Canadian naval disaster of WWII.

Looking back, I remembered that night aboard the Frontenac. Stan and I played records of Jeanette MacDonald and Nelson Eddy's songs on an old wreck of a mechanical record player donated to the ship's officers by some very thoughtful Valleyfield citizens. To be heard on the bridge, it was necessary to hold the Gramophone up in the air above our heads next to the voice pipe, with great effort and discomfort for us. But we did it to keep the bridge officers' spirits up, and really enjoyed their requests for more. Now when I hear those records, I stop and remember those we lost.

After hunting for the submarine for four more long days and nights at sea, hard tack for rations and then the formalities ashore in St. Johns, Newfoundland to bury the dead, I finally returned to Toronto.

Commodore Cuthbert Taylor, Royal Canadian Navy, Flag Officer, Newfoundland, stands to attention with cane tucked under his arm as the funeral party bearing the flag-draped coffin of Valleyfield's Lieutenant Frank Reynolds, RCNVR, arrives at the hillside cemetery in St. John's, Newfoundland. John Dyke is pictured far left.

I traveled overland via "The Newfie Bullet", the last narrow gauge railway in existence in the country, and then completed the trip via the CNR Transcontinental train to Toronto. I was able to do this, as after the Valleyfield disaster, we were given the choice of going home via boat to Halifax or over land across Newfoundland, then by ferry to Moncton, then on to Toronto by train. I was a model train buff; I naturally wanted to travel by train. I'm glad I did. The "the Newfie Bullet" was a Canadian treasure from years gone by. It didn't survive the passage of time and it was dismantled after the war. When I arrived in Toronto, I had a month-long holiday to enjoy.

The CAT Gear

After leave, I returned to Halifax and reported to the duty officer. I was surprised to find that my university lab partner, Doug Darling, was now the officer in charge of posting personnel to their new duties after leave. Knowing that I was not a very good sailor, he asked if I was interested in a shore job at the Naval Research Establishment in Halifax.

The project was to design a mechanism to make the Canadian Anti-Acoustic Torpedo Gear (CAT Mk II), a fully tactical weapon system for operation at sea. The CAT Mk II was just short of being a successful innovation, its only flaw was that it could not be turned on or off at will. While it lured the German acoustic torpedo (Gant) away from the ship by making a noise from its vibrating bars, once streamed, it blanked out the sonar detecting gear on board the ship from finding the submarine. It was a stand off. It also made so much noise that other submarines in the area detected where the action was taking place, and came to support the endangered sub.

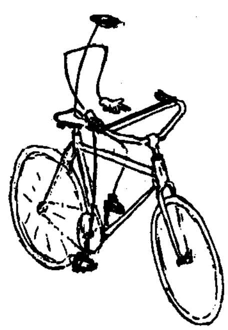
With the Japanese entering the war, it became imperative to improve the CAT because the German navy had given their acoustic torpedo technology to the Japanese. The Japanese were quickly upgrading their torpedoes by installing two microphones in the nose of the weapon to detect the sound of the ship's propeller, and thus, through linkages to the rudder. Thus the torpedo could steer itself towards the ship's stern. No matter what course the ship steered the torpedo followed.

I accepted the posting and started work immediately. The challenge was too great to resist! In retrospect, I think Doug planned, all along, to get me to accept this posting.

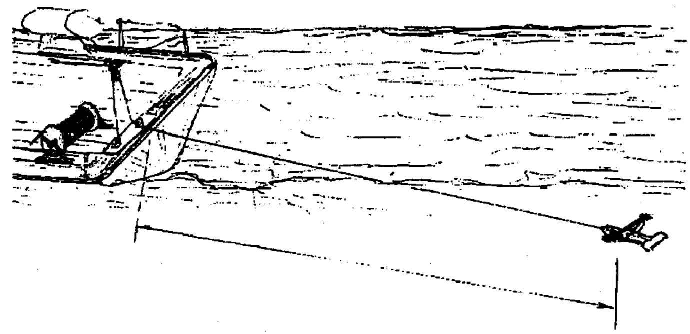
My first idea was to determine a way to manually lock and unlock the CAT's bars. This is similar, I thought, to that of a car trunk operating mechanism. This first idea was followed by many others and much time was spent trying out various ideas and concentrating on a few. We finally settled on slipping a bight in the towline that created an impulse in the line to the CAT being towed behind the ship. This impulse compressed a spring and the motion turned a cam. This alternately allowed the water flowing over the two bars of the CAT and through the gap between them to make them vibrate or not. It worked but was so big and cumbersome that we had to abandon the concept.

Sea trials in Bedford Basin however, proved that the bight would work. We were not aware of the fact until very late at night. While ashore, listening again to the 'wire' recorder (the forerunner of the tape recorder) for the 'umpteenth' time, I noticed a strange silence from the speaker. "Listen." I said. "There is no noise from the CAT!" The bight had turned the trip to shut off the CAT, which silenced the noise. We were ecstatic! This aroused new energy in the group to proceed with the next steps. In the morning we arranged a meeting with senior staff to hear the trip work, and received approval to proceed to design a lighter, improved trip gear.

Then one night, I remembered the elastic bands stretched across the handlebars of my bike in my St. Lambert days and how I could stop them from vibrating with my fingers. That would work! I couldn't wait until morning came. I went straight to work on new drawings. I also talked to the Commander of HMCS Dockyards into making two sets of parts. This way, if we lost one set during sea trials, we would have another set to work with immediately. The redesign of the trip changed from rotating the bars to rotating a tongue into the space between the bars to stop the bars from vibrating, or alternately remove the tongue from the gap to allow the bars to vibrate. This resulted in a reduction in the size and weight of the assembly to 70 pounds, light enough to be launched over the side of the ship by one strong sailor.

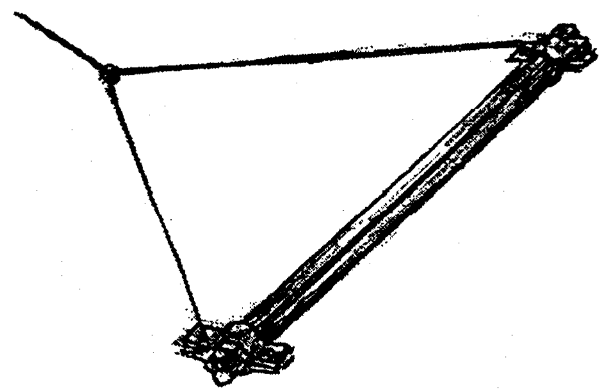


Early Experiments— Rubber Band Stretched Across Handle Bars (1930).

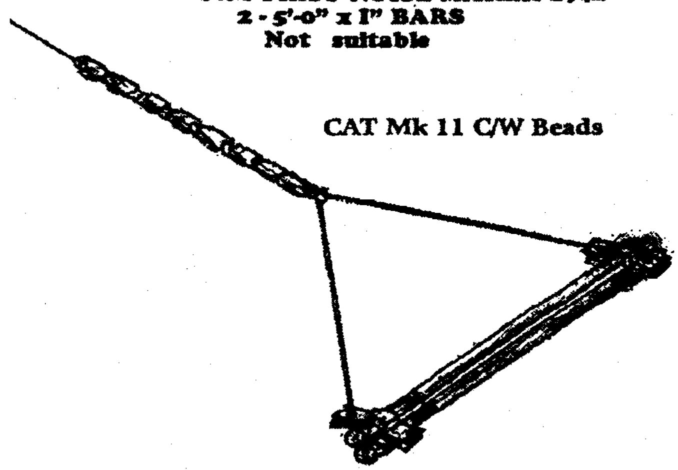


CAT Towing Arrangement—Slipping a bight in the tow line causes an impulse in the CAT gear spring which rotates the cam. This turns the CAT "on" or "off".

We rushed to tie up all the loose ends, and the production of the necessary parts.

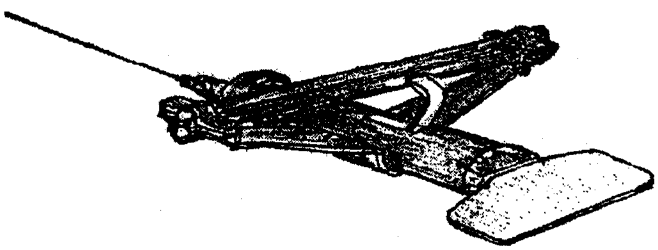


THE FIRST NOISE MAKER 1942
2 - 5'-0" x 1" BARS
Not suitable



RCN NOISE MAKER 1943
2 - 2'- 6" x 1/2" Diam. Bars

Sea trials were conducted in the Bay of Fundy. I was asked to run the sea trials but refused because of the urgency to get them on to ships taking part in the Pacific theatre. I said that, no matter what, I would make the gear work. So, to get unbiased results, someone else should run the trials. In May 1945 the new design was successfully tested and hailed by the Royal Navy as the best device for towing the CAT, of any design. After sea trials to correct some items and improve its towing characteristics, the CAT was issued to the Allied Navies.



"CAT Mk 111 Trip Gear Revised in 1945"

I was honourably discharged from the Navy in June 1945. A friend of the family was chief engineer of a Canadian manufacturing company who needed staff. They wrote to Ottawa requesting my release, which was granted almost by return mail. I left behind all the glory of the CAT Gear's impact on the RCN and its continuing role in submarine warfare. My commanding officer received a bar to his Distinguished Service Order (DSO) medal. I started back in civvies in earnest, attempting to regain ground in engineering that I thought I lost while in the service. I was glad to leave it all behind.

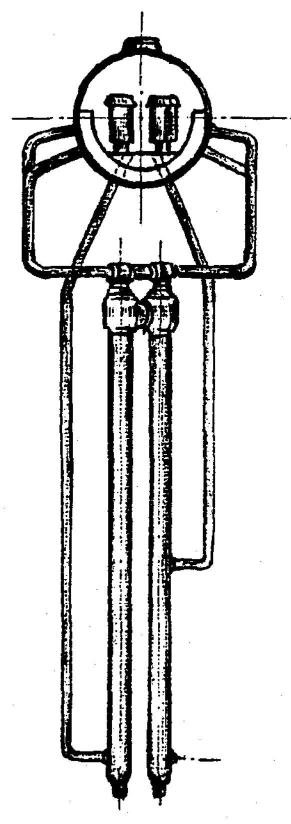
I tried my luck at various jobs, all related to steam boilers from 1945 to 1958.

Canadian Boiler Companies and AECL

In 1958, Dominion Bridge Co. Ltd. of Lachine, Quebec employed me as chief engineer in the fledging boiler department of this great bridge building company. While I was there, Atomic Energy of Canada Limited (AECL) set up a course for engineers of Canadian companies to learn about the peaceful use of the atom to produce electrical power. Their goal was to get those in industries that were interested, involved in this new technology. Fortunately, I was elected to attend the course, which lasted about two months. We learned all about nuclear technology at Chalk River Nuclear Laboratories, in the town of Chalk River, Ontario. We finished the course with a smattering of knowledge about fission, fusion, heavy water, natural uranium, and neutrons. This proved to be a very good introduction to enter the field.

Following this, AECL launched a boiler design competition amongst Canadian boiler companies to design a boiler unique to the heavy water reactor (HWR). This boiler would use heavy water as the primary coolant and natural uranium as the fuel for the reactor. This is different than the pressurized, or light, water reactor (PWR) used in the United States, which requires enriched uranium as the fuel in the reactor and light water as the coolant.

Atomic Energy of Canada Limited (AECL) issued specifications and rules for the competition, and provided reviews and input from time to time. Dominion Bridge (DB) was in competition with the other larger and more experienced Canadian boiler companies, such as, Babcock & Wilcox Canada Ltd. (BWC), Combustion Engineering Ltd. (CE), and Foster Wheeler Canada Ltd. (FW). Dominion Bridge was concerned that these competitors had U.S. naval boiler designs to build upon and concluded that they, Dominion Bridge, would be wasting time to offer a natural circulation boiler of this type. Instead, Dominion Bridge relied on its considerable expertise in designing forced circulation boilers, and chose to investigate this alternative, if only to eliminate it from consideration. The competition was won by Combustion Engineering.



Design Competition for CANDU Steam Generators— C-E Design.

AECL subsequently modified this design and issued specifications for Douglas Point, a 200 Megawatt (MW) plant, and the first commercial nuclear station in Canada.

AECL Design for Douglas Point.

Montreal Locomotive Works (MLW) also joined the competition but had little experience in designing large capacity boilers of any kind, other than locomotives. As locomotives were being replaced by diesels, MLW was anxious to expand its product line. They had developed a specialty in heat exchangers for process loops such as those used in refineries. These products were small industrial-type heat exchangers, mainly liquid to liquid. The nuclear heat exchanger was liquid (Heavy Water) to steaming water. It is to be noted, MLW had no experience or license arrangements with companies who designed and built steam cyclone separators. These are necessary to the operation of large capacity steam boilers. Nevertheless, MLW won the order for the AECL-designed boilers for Douglas Point generators without much discussion.

While at Dominion Bridge, I did prepare a bid for the AECL boilers for the 200 MW Douglas Point Plant. I also prepared a bid for the live steam reheaters for the Turbines. DB was the Canadian agent for Unifin Inc., maker of air-cooled heat exchangers for the oil industry. I adapted the design to the turbine conditions (e.g. steam-to-steam rather than water to air as in the commercial applications.) DB was awarded the order for the reheaters.

In building the elements for the nuclear application, Unifin manufacturing standards proved to be inadequate for those required for nuclear products. The bend radii of the tube elements were too tight and the tube walls cracked. I learned from this to avoid similar layouts. Then, later when I was at BWC designing the tube bundle for the Pickering A boiler, I laid out the tubes to eliminate all the tight radii bends at the inner rows. This became a BWC standard. Because of this arrangement, BWC's boilers did not suffer stress corrosion cracking of the innermost tubes of the tube bundle, as did all others in North America!

From scratch

In 1964, I joined Babcock & Wilcox Canada to become project engineer for one of the 500 MW fossil-fired plants that OH was going to build on the shores of the Great Lakes. This new expansion was needed to meet the anticipated electrical demands of the province.

In 1967, OH began the process to drop fossil fuels in favour of uranium as fuel, because of economic advantages and the potential of cleaning up the atmosphere from greenhouse gases. OH had gone nuclear and I could be out of a career job! At the time, there were three engineers at BWC who also had nuclear experience: Dick Green, chief engineer; Don Stelliga, assistant chief engineer; and Jack Paxton, chief draftsman. They each had more seniority in the fossil department than I did. I suspect that they preferred to stay where they had established expertise, rather than branch out into the new endeavours. However, as I had taken the AECL course at Chalk River and had nuclear engineering experience at Dominion Bridge, I was selected to lead the newly formed, nuclear steam generation section of Babcock & Wilcox Canada. So I began this new section, reporting to Dick Green, by setting up a nuclear department with one person—me!

So where to start? BWC hadn't been active in the market place after NPD's success, but had taken a wait-and-see position. As expressed by then-president Mort Robertson, B&W in Canada was a top designer of fossil boilers and the U.S. Company was in a similar position for both nuclear and fossil boilers, in the USA. BWC should not consider building a nuclear boiler designed by others." This was not acceptable," he said, "under any circumstances." What follows shows how this goal fell into place.

It should be noted that all of the engineering design information for any type of Babcock & Wilcox fossil boiler is well documented, contained in manuals and now on computers. Through a technology exchange agreement, the parent company shared this proprietary information with Babcock & Wilcox Canada (BWC), with updates and support. For nuclear boilers in 1967, however, there was no information in BWC's library nor did the Canadian company have any formal agreement with the U.S. parent company to discuss nuclear technology. In addition, even if we could, there are big differences between the U.S. (light) water reactor (PWR) and the Canadian heavy water reactor (HWR). Although the steam boiler heating surface calculation is very similar (i.e. boiling heat transfer), there are differences in other areas affecting the application of the heating surface. The U.S. company said that they could not afford to support the engineering for two cycles, the PWR & HWR, Therefore we should "go it alone." They would give us all the help that was applicable from their base.

The above was discussed at a meeting with management of both the U.S. and Canadian divisions of B&W. With that limitation, the U.S. Company agreed to have an engineering exchange similar to that in fossil engineering. The goal was an 'open exchange' in nuclear engineering information, wherever possible, on materials application, in-service operating experience, manufacturing technology, etc. In the case of U.S. Navy technology, engineering information was obtained that was not protected by the confidentiality provisions in working with the U.S. Navy.

We were fortunate that the U.S. Navy had the need for a new high capacity steam separator for their submarine boilers at the same time BWC needed a separator for the 'Light Bulb-Type' steam Generator [RSG] for the CANDU. So, the two companies shared the costs of the research. The result was a design of steam cyclones second to none in the industry. Bill Schneider of BWC coordinated the testing, and actively participated in the good work.

We didn't have a back up library and we didn't have our own research labs. I decided that the design details of the new Pickering A boiler must be based upon documented information in the 'public' domain. In any case, a simple logical extrapolation of the parameters based on engineering principals should be applied to the conditions of the nuclear boiler from the fossil boiler, or other base. In addition, I felt we must continue to collect a body of nuclear information—on tube failures, manufacturing processes and operating data upon which to base our decisions. We must be as knowledgeable as possible in water chemistry and metallurgy, sufficient to justify to ourselves that the design would work. Our most staunch critics were engineers who, though experts in their fields, tended to think that they had the answers to all our troubles. The metallurgists suggested and were searching for a wonder material that would resist all attacks, and the chemical engineers suggested a water treatment that would protect all the parts of the boiler from every disaster!

I began by reviewing data from Chalk River Nuclear Laboratories and nuclear steam generator operating data and experience worldwide. Under license agreement with YUBA[1], we had access to heat exchanger and feedwater heater data. We also had access to B&W research labs at Alliance, Ohio and Lynchburg, Virginia, for general information on nuclear systems and applications. Thus, over time, I had amassed a very large database of information.

Pickering A

In 1967, as OH projections of power consumption showed that demand would be exceeded before the next nuclear station was commissioned, OH decided to proceed immediately and issue bidding documents for the additional capacity. Pickering A was approved and specifications for a nuclear station were rushed out to bidders. The specifications called for a 500 MW version, prorated up from the 200 MW Douglas Point Station, with few changes.

This news galvanized BWC's management into action. OH was BWC's ***best*** customer and they had no product to offer them. Without a competitive nuclear boiler, their future was at stake!

At our proposal design review meeting for the 500 MW Pickering A station, I stated my case. I said that if we did not design a new boiler, we might as well not bid. Later, the committee gave me instructions to design a boiler, uniquely suitable to the Canadian heavy water cycle. With this move, in reality BWC won the AECL boiler competition of 1958, and the CANDU steam generator was born.

OH bidding rules dictated that if a company is proposing an alternative design to the specifications, they must first bid to specifications, then prepare a complete and separate bid on the alternate arrangement. In our case, this had to be designed from scratch. As it happened, the support we received from the U.S. parent company during the bidding process was very helpful.

[1] YUBA was a USA designer and manufacturer of process heat exchangers for the oil industry and feed water heaters for fossil boilers.

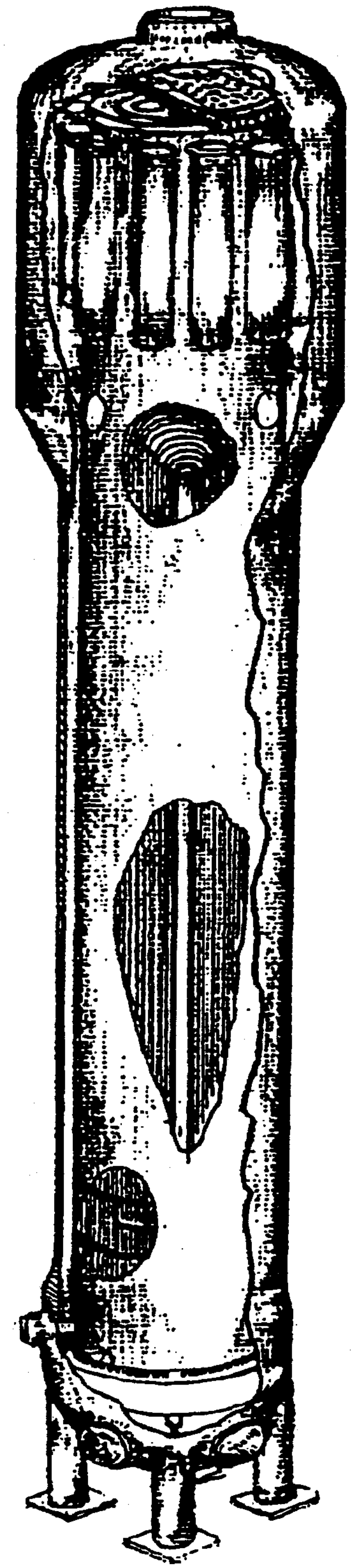
They presented experience and statistics on the Corporation's involvement in the nuclear market in the U.S., including U.S. Navy installations. This was a very unusual step, but a very welcome one from BWC's point of view. It improved our chances of receiving an order as it presented the corporation's complete dedication to the nuclear field. No other Canadian bidder could point to the same experience!

After compiling the 500 MW base bid, I started in earnest to design a new boiler for Pickering A. The task of designing a new boiler was both exciting and challenging. I had one draftsman, Art Whitham; an estimator for shop man-hours, Doug Duncan; and an estimator for the balance of materials, Tom Watson. I developed the design and managed the project.

After three or four weeks, I had a completely new concept for a Canadian version of a recirculating steam generator for the PWR. It had many distinct features, including an integral steam drum on top of the tube bundle section (named "the light bulb") and an internal economizer, as part of the tube bundle heating surface. These innovations were unique for Canada, and the internal economizer was the first in the world! Each detail was researched in depth from the body of knowledge that I had developed, in a very short period. For the internal feed water heater, or preheater, I remembered that we had a YUBA design manual. I referenced YUBA design rules to avoid fretting at the inlet nozzle, and designed it accordingly. We knew that the inlet nozzle conditions were vitally important, as NPD had failures in similar areas of the tube bundle. In fact, other designs also suffered these failures. To stress the point, at the manufacturing design stage Dick Green challenged the arrangement as it was not a usual configuration found in fossil boilers. Upon review, he was convinced, and the design remained as bid. As it turned out, BWC's design outperformed all others in the world.

It is interesting to note that Westinghouse claimed they were the first with this type of boiler arrangement. However, they withdrew their design in 1980 as the units were experiencing tremendous fretting problems. B&W's units continued to perform well.

As we finalized the designs, it was time to set the selling price. It is interesting to record how this was done. First, the company reviewed MLW's selling price for the 200 MW Douglas Point boilers a few years earlier. We prorated that to the new size of 500 MW for the Pickering A boilers. I believe we may have added a small amount, as we knew that MLW was struggling with costs overruns. The result was our best guess at MLW's bid price for the 500 MW Pickering A. Then, we did a comparison of the selling prices for our base bid to the specifications. Then we estimated the cost of our new, unique boiler design and added markups. The only decision then was to determine how much money we thought we could make or lose! Mort Robinson



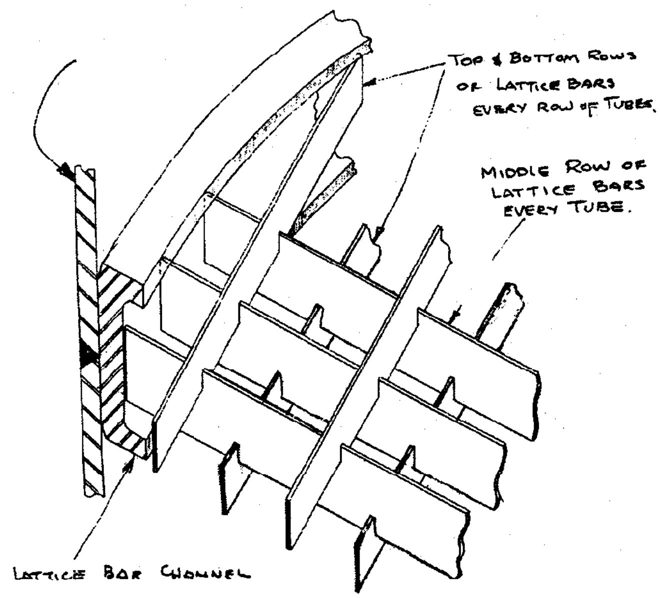
Pickering A— a Unique Design

said, "I want to get into the nuclear market. This is our only chance! Don't blow it!" He suggested that the customer always likes a low price. The commercial department under Don Rivers guidance set the selling price. We bid accordingly. BWC won the order with the alternate design and eventually won all the remaining orders for CANDU stations with the exception of one. As an aside, the only CANDU order BWC lost was the bid for the power plant for Wolsong I in Korea.

At the time, senior nuclear management staff had changed and different ideas prevailed. BWC lost its chance to win this order by refusing to negotiate on some important items the customer had requested regarding tougher inspection standards and techniques with no change in price. In the end, the contract was awarded to Foster Wheeler Ltd. who naturally agreed to do what AECL wanted with no change in price!

Returning to the Pickering contract, during the manufacturing stages, BWC received design 'sketches' of lattice bars, not drawings, as it was impossible to get copies of controlled drawings for security reasons because of the U.S. Navy restrictions. From these sketches, working drawings were made by BWC to fabricate the parts for the Pickering steam generators.

The short coming of this transfer of information was that the tube bundle of the Pickering design was larger than the navy boiler and the structure was not strong enough to support the weight of the heavier tube bundle. When the bundle was being handle in the shop and in the field, the heavier weight of the tubes bent some of the support bars. The retaining ring bent and the lattice bars popped out of the grooves. While this defect did not affect their performance in service, as was proven over time, it was a concern. Consequently, AECL and OH prohibited the use of lattice bars for all future contracts. What evolved, however, was the



Assembly of Lattice Bars

eventual use of lattice bars on the Darlington boilers. This changed BWC's place in the industry, The route to success was slow and painful with many human frailties to overcome or bury.

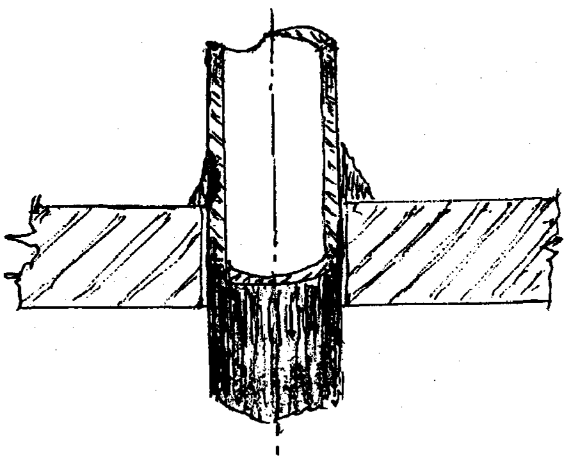
When Pickering A became a contract, Peter Collins was named project engineer, and Fred Eagle was manufacturing engineer. It became evident to management that the concept of full-time project management for future contracts would be a requirement of the industry, especially Ontario Hydro.

For that reason, more staff would be required. Thus, the department ballooned overnight. I was named Chief Engineer, Nuclear. This resulted from my discussions with Bob Harvey, then Vice President, when advising me of my appointment. He said what should we call the new position? I always wanted to be Chief Engineer of a Canadian company, which was a goal of mine, so it was done.

Achilles Heel: The Importance of Tube Supports

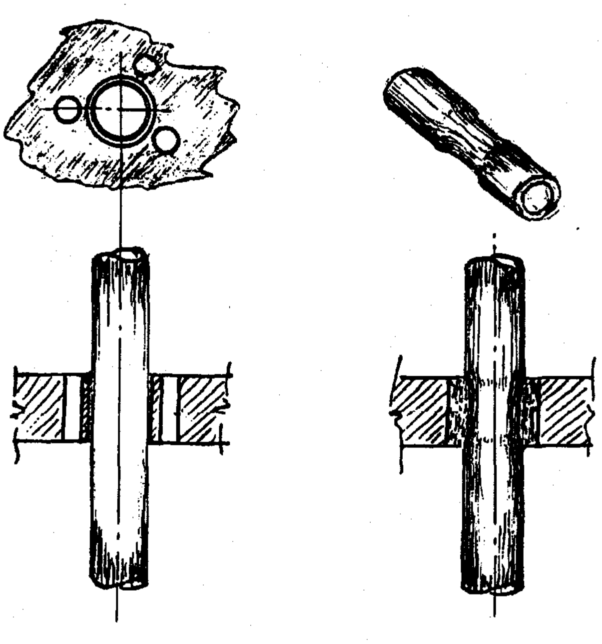
As nuclear steam generators came on line, everyone in the field followed their progress with interest. Nuclear steam generators were very large, pushing the design limits of heat exchangers and stretching the technology beyond the known limits. Because they were so big, it was impossible to duplicate the operating environment in a laboratory. It was important to know the field results to make progress from one generation to the next.

The first failure of concern was the phosphate wastage of the tube walls. This resulted from using phosphate water-treatment chemicals, the same kind that were used in fossil boilers operating at about the same temperature and pressure. However the configuration



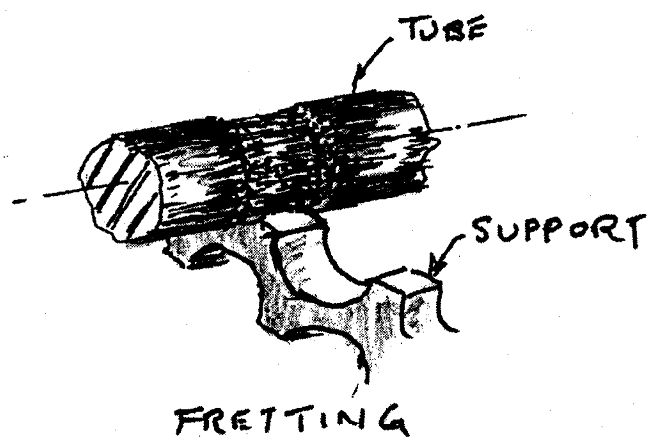
Tube Wall Wastage

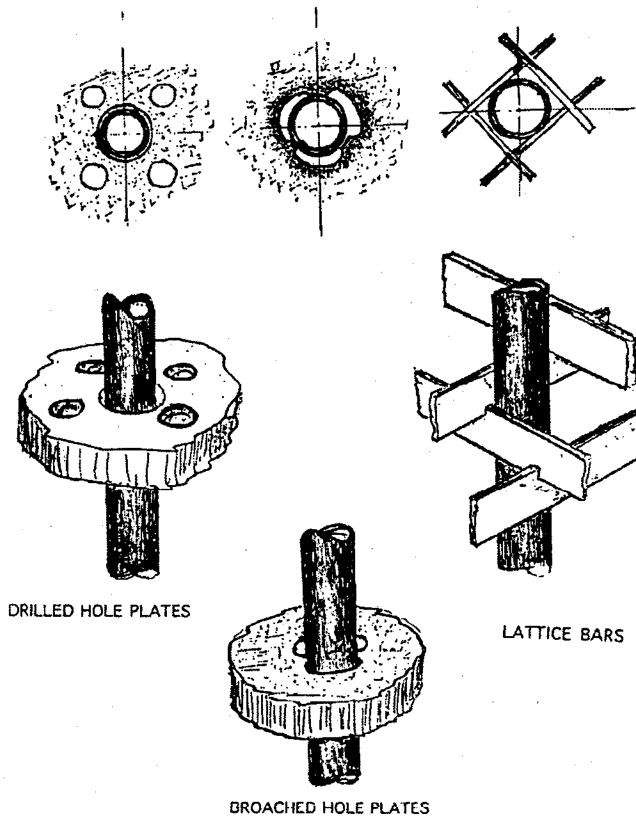
of the tube support system (i.e. drilled holes) tended to concentrate the residue in piles. In addition, under these piles, the tube wall was attacked by the percolation of acidic sludge created by the mixture adjacent to the tube wall and leaks occurred, thus shutting down the steam generator.



Classical Denting— Requires a Drilled Hole in a C.S. Baffle Plate – A.V.T. & Condenser Leak or Containments from B.O.P.

The next area of concern was stress corrosion cracking in the most highly stressed sections of the tubes—the innermost tubes at the top of the tube bundle were the ones that failed since these tubes were bent to a small radius. BWC did not have these failures, as I was aware that this could occur and designed a tube pattern that avoided the problem. This tight bend defect was corrected by others during manufacture in later designs. In general, most plants changed from phosphate-based chemicals to avoid phosphate attack, but the change in combination with All Volatile Chemical Treatment to avoid phosphate attack (by the sludge) caused denting. This change left the carbon steel ripe for attack, resulting in the formation of fast linear oxide forming in the tubes and the crevices of the support plates' holes. Eventually, these formed into an hourglass shape. The support plates were crushed and lost their strength, thus the units had to be shut down. This phenomenon plagued the whole industry. All boilers with drilled hole plates, scalloped bars, and broached hole plates suffered to varying degrees because each had a different effect on the rate of buildup and thus the time to failure varied. It, however, soon became evident that boilers fitted with lattice bars were not affected!





TUBE SUPPORTS

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BWC's first order in Canada was at Chalk River. The boiler was a clone of the U.S. submarine boiler, though it was built in Canada at BWC's plant in Cambridge (Galt). During its lifetime, it suffered phosphate wastage and major fretting problems but it was decommissioned before it had to be taken out of service. Because it had served its purpose in demonstrating that it could produce steam for a turbine to produce electrical power[1]. When it came to designing the steam generators for Pickering, I made sure that the new boiler would be free of these potential defects. Further, I knew that the tube walls required constant wetting to avoid attack. If this did not occur, the boiling of the water would form scale, similar to hard water deposits in a teakettle on the stove at home. I also thought I knew that the drilled hole support plate would need to be replaced, because 'dry out' would occur in the small clearances between the hole in the plate supporting the tubes.

Lattice bars were originally used in early U.S. submarines as tube supports in Nuclear Steam Generators. Lattice bars were replaced with a drilled hole design because lattice bars did not withstand the shock waves from depth charge attacks. Lattice bars were thought to be suitable for stationary plants (e.g.: Pickering A). Having been exposed to vibrating bars while designing the CAT Gear, I realized that lattice bars would perform well in the pool-boiling environment of the Nuclear Generator. I was anxious to offer the lattice bars in the Pickering bid. I knew that to avoid chemical attack failure, the tubes enclosed by the loose, lattice bar structure would dampen the abilities of the tube to vibrate (especially in the open spaces). More importantly, proper fretting would not occur. All these ideas were published in the technical press[2] in 1970.

The above activities were enhanced by responding to the service requirements of the Nuclear Power Demonstration boiler at Chalk River. The plant had been online for about 6 years (since 1965) and tube failures began to mature. As BWC had built the boiler, CRNL contacted BWC. We in turn involved Nuclear Labs (in the U.S.) to assist us in analyzing the functioning of nuclear boilers, and we became 'experts' in the field. We gave all of our findings to CRNL which they published in their *Yearly Report on Boiler Tube Failures in Plants—Worldwide*. All boiler manufacturers use this source of information to improve their designs. From this experience I made sure that Pickering A design features would not repeat the design conditions which caused the failures.

As noted elsewhere, Pickering lattice bars were not strong enough to support the larger tube bundle of the Pickering boiler, even though the Pickering boiler design was fashioned after a U.S. navy boiler. The bars failed and AECL/OH, who had originally opposed their use, ruled that the lattice bars were banned in all future OH boilers. This was an inauspicious beginning and was troublesome for me, as I had been a firm believer that the lattice bars would perform. In actual fact, no bench tests or other experimental work had been conducted. The only course we could take was to wait and see and watch Pickering's records over the years. After about five years it became clear to me that lattice bars did perform 'as advertised'. Pickering's record included the least number of leaks of any nuclear boilers on the continent. This was a great day for me, but not rewarding, since Pickering B and Bruce B had

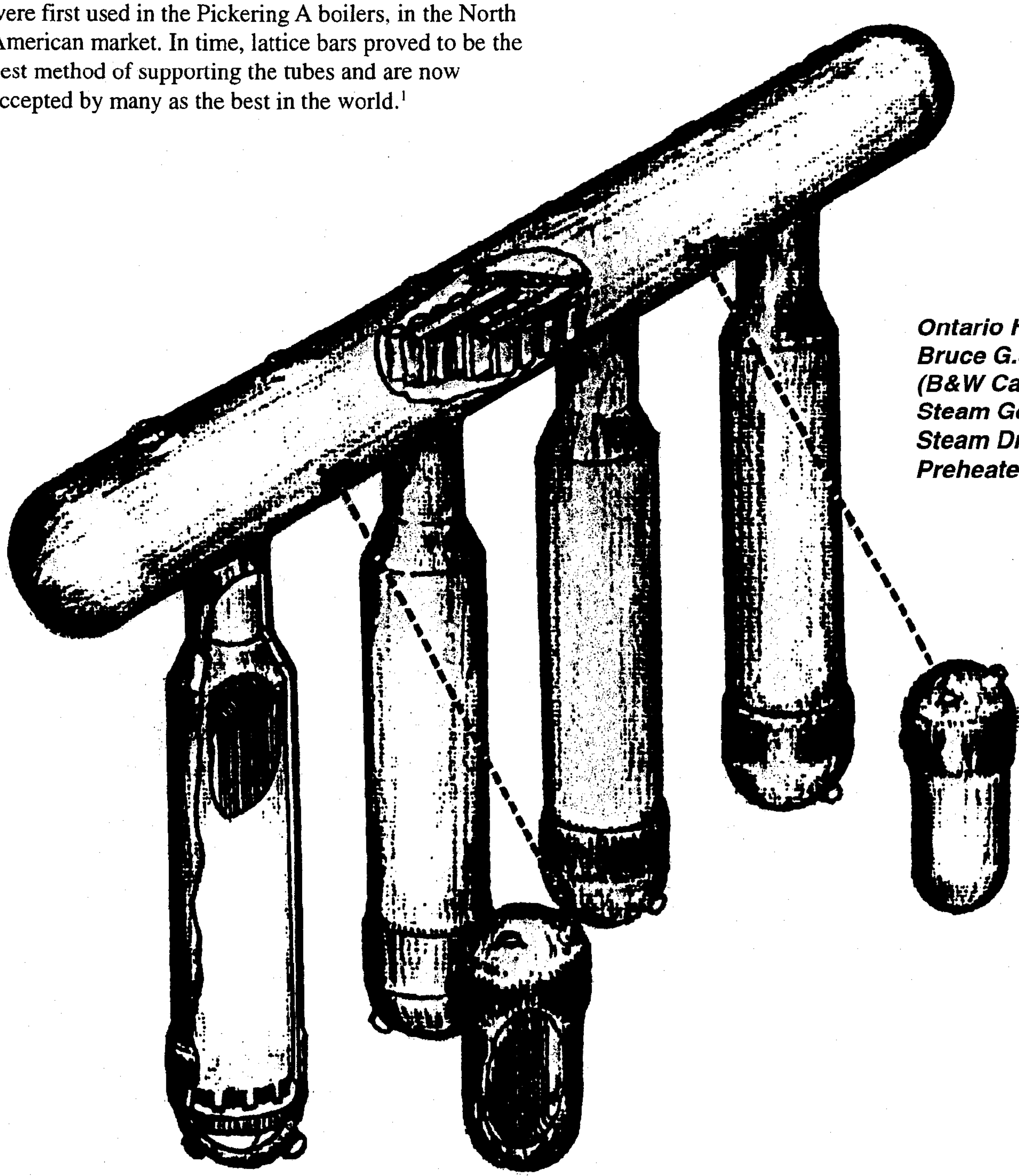
[1]The 20 MW plant was used to correct the power factor of the transmission line to the town of Chalk River. Thus the turbine drove a synchronous motor to accomplish this.

[2]My view on the superiority of the lattice bar supports was published in the Canadian Electrical Association Journal in March 1970.

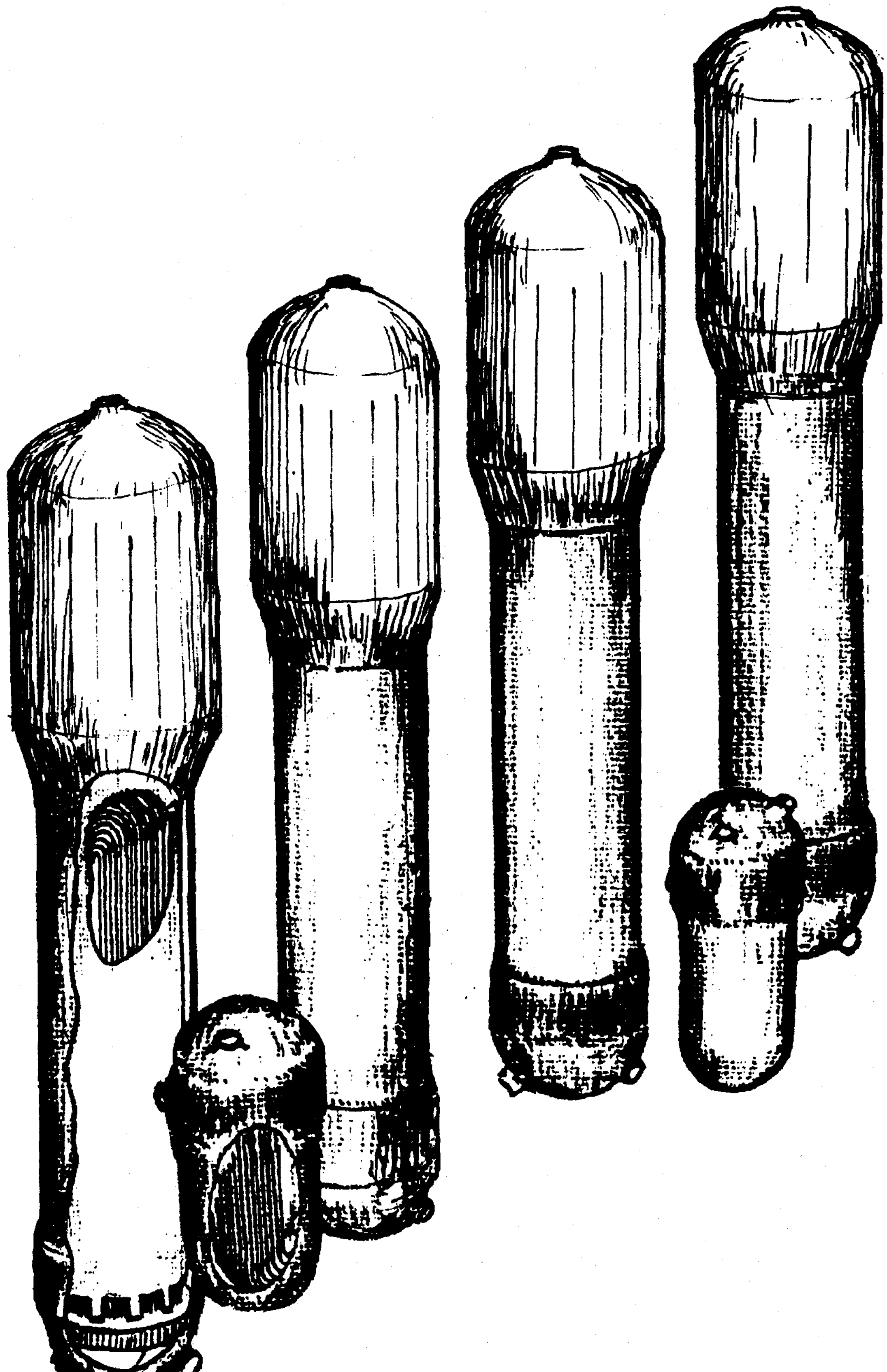
been built with broached hole plates and scalloped bars in the U-bends. This did not bode well for the service life of these plants. What's more, the Darlington order included the same details. I came to the conclusion that something had to be done. But what?

I was pleased. My work in the Canadian Navy designing the CAT Gear and observing vibrating bars led me to believe that lattice bars would perform very well in the boiler pool boiling environment. Lattice bars did not hold the tubes tightly, so they did not create conditions where deposits could occur. These lattice bars were first used in the Pickering A boilers, in the North American market. In time, lattice bars proved to be the best method of supporting the tubes and are now accepted by many as the best in the world.[1]

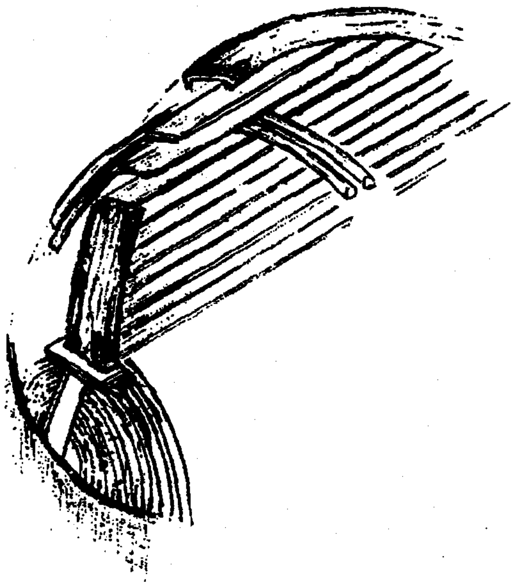
It is interesting to note that at the same time we started working on Pickering A, we bid and received a contract for the 120 MW Karachi Boilers for Pakistan. We did the proposal engineering and sales work necessary to get the job. It was all pro-rated from the Pickering A contract – complete with lattice bar supports and a revised tube sheet tube hole pattern to correct the U bend lattice bar orientation—and finished the sales details in about four weeks. When the order was received, the shop work was handled so that it didn't interfere with the Pickering A contract.



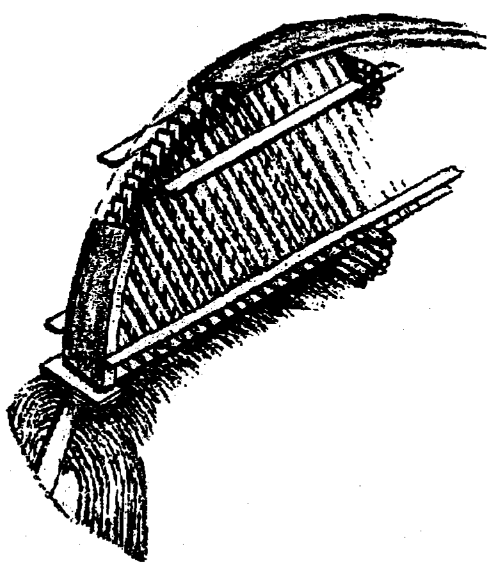
Ontario Hydro Bruce G.S. (B&W Canada Steam Generators, Steam Drum and Preheaters)



Ontario Hydro Bruce B



Karachi— U bends Supports Circa 1967



Pickering A— U Bend Tube Supports

The contract was run more like a ‘fossil’ boiler contract of the time, with no frills. We made quick decisions, and provided shop quality control and inspection by’ in house’ staff. The work went through the shop almost unnoticed. We proved to management that nuclear boilers were a viable product to pursue. At the time of this publication, BWC had received a request to review the Karachi design with others engineers. A problem was showing up in that the Karachi units were losing power.

What is most interesting is that the Karachi boilers have been on line for about 30 years—the design life of the CANDUs. I don’t know their history in any detail but, when last inspected, the boilers had the least number of leaks of any fitted with lattice bars. In fact, these boilers might have the best record in the world.

I remember receiving a report that they had only six leaks when inspected a few years ago. This is an amazing statistic, as the plant uses seawater for condenser cooling. Plants located near the sea are designed to use salt water to condense the steam in the condensers. This usually leads to many outages as condenser leaks, which allow seawater into the steam generator, cause severe damage to the tubes. In fact, most sea side plants have a poor in-service record. Karachi has not. It is one of the few seaside stations that we know with lattice bars tube supports! The latest information is that the boilers are being chemically cleaned to extend their life.

Bruce A

The need for power continued to grow. The situation was becoming critical as it took a very long time to bring a nuclear station on line to meet the expected demand in Ontario. Something had to be done to shorten the time to bring a nuclear plant into service. Thus, for the Bruce A contract, OH and BWC made an agreement that BWC would prepare the estimated cost of each set of steam generators for the future stations. Each station would then be reviewed in depth by a team of OH experts and BWC technical team, and cost adjustments would be negotiated by those around the table. From that, a selling price was set by the mutual consent of both companies management.

On the Bruce job, estimates were being prepared and checked at the same time as engineering discussions with AECL-OH and BWC to settle the details of these changes. Of concern, was the design of the cross-steam drum and the other was the tube support system. AECL wanted drilled hole supports plates, as promoted by Westinghouse, and copied by all other North American manufactures. I pushed for improved lattice bars. Finally, a compromise was reached and the contract was awarded on basis that we would supply broached hole plates, the U.S. B&W standard.

Though much time was lost on the Bruce A contract in sorting out these details, the overall schedule for the province’s needs was realized. In effect, BWC became OH’s sole source of nuclear steam generators.

When work began on Bruce A, Terry Seawright was appointed project manager from his position as planning engineer in the management group. He ran the project for about a year and then took a leave of absence to get his Master's degree in Business Administration. The company had to act quickly to avoid schedule slippage. I was asked to take over the position of project manager for Bruce A. I looked forward to the challenge. It was a long haul. Six years later, in July 1977, the contract was shipped on (revised) schedule.

When Terry left, I took over the work of redesigning to include broached hole plates and had to proceed post haste and make the changes quickly. It is my belief that all the modifications required, adapting from the flexibility of the lattice bars design of Pickering A, to the very strong and stiff broached hole plates weren't fully investigated. The temperature gradients, because of the new heat treating process, caused bending of the tubing. The tubes buckled. This buckling caused the tubes to catch the lobes of the broached hole plates. This bent the broached hole support plate into a dish configuration with more lobes catching more tubes in varying degrees. Subsequently, the tubes were scored by the sharp edges of the broached hole lobes. The broached hole lobes were locked into the tube circumference at discrete radii of the tube bundle. These very small but significant marks were evident in large numbers throughout the tube bundle. This problem was not addressed by the shop engineering group and resulted in the Recovery Program.

This was a major event in BWC's history. It triggered the critical decision to rebuild all the boilers. In all likelihood, the scratches would not have resulted in tube failures. However, once discovered a company with any integrity would never have recommended that these tubes be put into service in a brand new nuclear boiler. Consequently, the decision was taken to replace the tubes.

Bruce B.

Jim Akeroyd was appointed senior project manager for all OH nuclear contracts at BWC. Jim worked closely with myself and Art Jackman of OH who was appointed in-house arbitrator to speed up decisions between the two companies.

I don't remember much about this contract. I do remember that much discussion arose because a choice had to be made. We needed to decide between building a repeat of Bruce A and its long drum style or considering a redesign, omitting the long drum and replacing it with four, separate 'light bulb' type steam generators.

The latter was considered necessary by a few to put the problems of building, the long drum in the first place and operating the plant with all the restrictions imposed on the plant because of the long drum characteristics, behind us, i.e. BWC and OH, forever. No one could make a decision! Time, again dragged on until the contract was running very late. AECL set out to make drawings for both arrangements, so that as soon as a decision was made the work could start immediately using the drawings that fitted the decision.

One day after a Bruce A job meeting, we were sitting around chatting. AECL reminded me that the AECB (Atomic Energy Control Board) was deciding how to set up the license for Bruce B. At lunchtime I received a phone call from Ottawa. A member of the board, a friend of long standing, said "John, we have a hung jury. The board is deliberating which way we should rule on the Bruce B Station. Should it be a repeat of the same design as A, or a redesign with four steam generators? Please give me your opinion, with specific reasons!" I gave him my opinions with reasons, the best I could conjure up over the phone in the short time allotted. The next day, AECL phoned from Mississauga and said 'AECB had ruled in favour of the redesign!' I said 'thanks,' and smiled to myself.

Darlington

The engineering for the Darlington station started in the mid-1970s with the question – 'How big is big?' OH & AECL wanted to know the maximum steam generator size we could build. So, the nuclear proposal engineering department got busy. They considered the ramifications of this greater size, providing a design that accommodated the parameters of the manufacturing processes, to the limitations of the available transportation systems. This additional work consumed a great deal of time in proposal engineering! But which was all part of marketing the nuclear business.

When the contract was awarded, Jim Akeroyd was named Project Manager. When problems were discovered with the Pickering B and Bruce B steam generators, Jim undertook a study for OH to show that the "solid" U bends with scalloped bars would not work. The flexibility of the U tubes was negated by the ridged structure. Again, I pushed for improved lattice bars.

In 1980, I left BWC and joined AECL. It was during this period that I became very concerned that the engineering department had not changed from scalloped bars to a new system of U-bend supports. They were not 'sold' on lattice bars in the first place and thus did only what they were told to do, with disasters results—despite the fact that all the evidence emanating from service results showed otherwise.

When I left BWC in 1980, Jim Akeroyd took over. Jim immediately tried to change Engineering's focus. He had been able to convince OH procurement personnel that something had to be done to convert all of BWC's tube bundle and U-bend support designs to lattice bar tube support systems. I was likewise concerned by the apathy in their thinking and I was compelled to bring pressure to bear from the outside—AECL or OH or both. My initial thrust through AECL failed. It seemed they were of the same mind!

As BWC's engineering department did not change their position, my loyalty to the company diminished. I thought that I should change tack and talk directly to our customer to influence them. At this same time, OH began to take more of an interest in boiler design details. Along with Jim Akeroyd, my talks with OH's commercial department landed on fertile ground through Art Jackman. They had been looking at world wide in-service experience and came to the conclusion that something had to be done to get BWC's engineering department and OH's own engineers out of the design 'rut' they were in.

At that time, vibration experts in Canada and the U.S. believed in drilled hole tube supports. As noted before, this was a Westinghouse design. In time, it was proven that drilled hole plates were a concentrating mechanism. Therefore, chemical attack created thousands of tube failures due to denting in each steam generator. Westinghouse and others whose designs included drilled holes eventually withdrew from the market.

Though I was at AECL, I continued my efforts, along with Jim Akeroyd and others at B&W to get OH to adopt lattice bars for Darlington. I did involve Dr. Dave Weaver, chair of Mechanical Engineering at McMaster University to set up a bench test, in his lab. Our goal was to prove that flat – or lattice – bars in the U-bends would stop the tubes from vibrating and thus stop fretting. Dr. Dave Weaver set a price for the bench test and Jim Akeroyd approved the work. BWC supplied all the parts necessary (i.e. bent tubes, flat bars) to conduct the experiment. McMaster University supplied wind tunnel, test rig, and instrumentation and technicians. The results of the bench test were positive, as reported in an ASME paper. This enabled OH and AECL, from an engineering standpoint, to approve their use.

With the results of the McMaster report accepted by OH and AECL, the engineering staff changed course to lattice bars. Thus, the Darlington steam generators were fitted with lattice bars and flat bars in the U bends.

Jim Akeroyd and others in Engineering made a tremendous effort to convince OH that lattice bars were the only way to go because of Pickering A's record. This move eventually paved the way for BWC's entry into the U.S. replacement steam generator market in the 1990s. The Company was the only one able to offer a guarantee that others could not match, based on the 20-year performance of the Pickering A boilers - the best record in North America.

The Recovery Program

At the outset of this tome, I recorded that the author of "The History of Babcock & Wilcox – 1844-1977" threw up his hands "when he reached the events of 1977" and concluded his history of BWC at that point in time. He wearied at the thought of attempting the task of writing the saga. I am about to attempt to do just that in the year 2001, as I was there in the thick of it all!

It is not possible for me to recall the exact timing of all the happenings between the various contracts, at this late date. Nevertheless, I'll tell the story of the memorable and dramatic events of the nuclear steam generator recovery program as I experienced them.

One Friday afternoon, before closing, I was sitting in my office musing that nothing was happening. I went along the hall to my boss, Howard Robinson's office. I sat down and chatted with him for a few minutes. Then I said that things were slow, nothing was happening. It seemed strange, I said, that things were proceeding so well. Howard sort of smiled and said, 'Just wait and see!' How right he was!

A few days later we heard through our contacts with OH that eddy current probes were jamming in the U-tubes when conducting a routine mapping and base eddy current inspection at Pickering. This raised many doubts in our collective minds, and we worried that something was amiss. We agreed to conduct a similar eddy current test on one boiler left in our shop. OH shop inspectors helped in the work and tests results were given to me in short order. I reviewed the information, made sketches of the damage and reported my findings to staff for discussion.

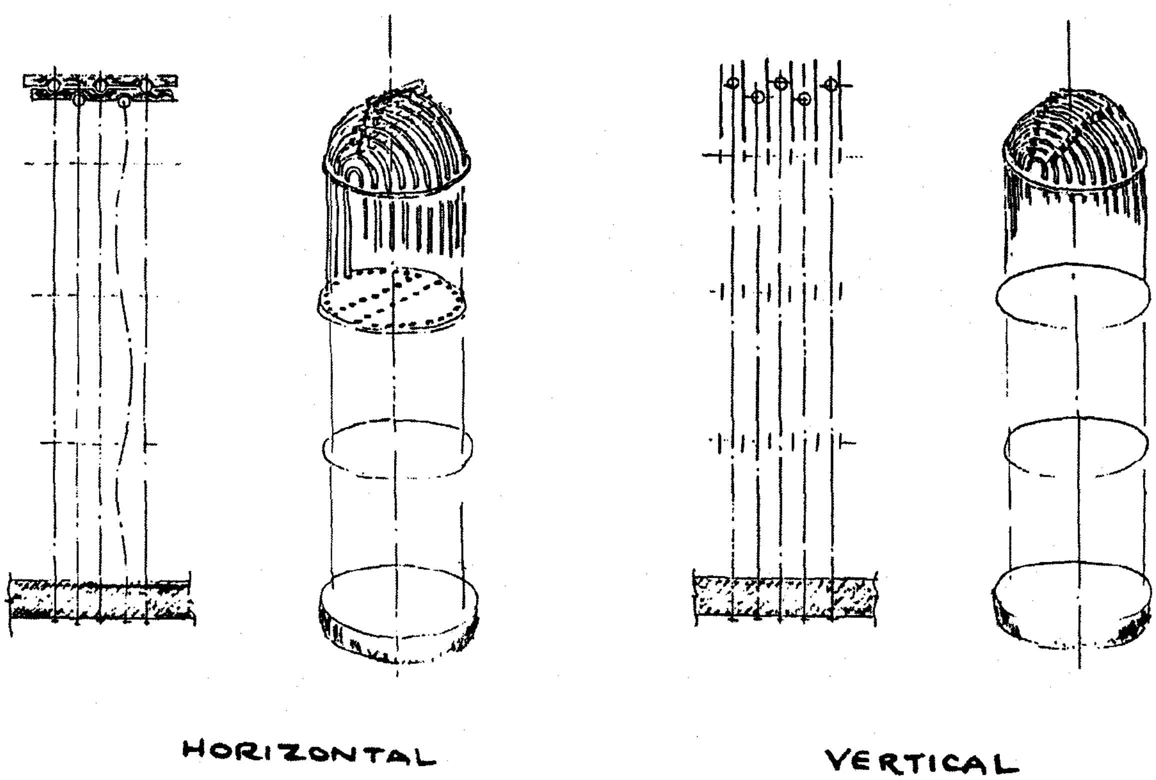
As the first full-vessel heat treatment for the 600 MW contracts was to take place within a few days, Jim Akeroyd arranged to personally witness the procedure. The morning after, at 8 o'clock sharp, he came into my office. He reported that he heard strange 'snapping' sounds on the heat-up cycle and similar sounds on the cool-down ramp. He believed that there was something terribly wrong. This was his job and something had to be done about it. "It's now in your hands, John!" he said. "Yes," I replied, but I would have to think about it. We had also observed a restraining clamp on a previous vessel had bent, and it was cut to allow it to be free. I thought this was only a temporary fix. It freed the clamp from being a restraint in one ramp only, up or down, of the heat treatment cycle. We should be very cautious and continue to assess all the evidence that became known.

As I learned more, I was beginning to put everything together into one terrible conclusion. The ball was now in my court. Jim's ultimatum was, "Get on with it, Dyke." As the day wore on, I became more distressed. I walked out into the shops, then circled back through the office building, and came back to my office. I sat down, stood up, wrote notes to myself. I got up and walked the route again many times, trying to get the knots out of my stomach. I thought about the costs of field repairs. I worried about our reputation and the staff who worked here. As the sole supplier of steam generators to Ontario Hydro, what would they think of us? What would others Canadians think of us? What would the industry worldwide think of us? These thoughts went through my mind, again and again!

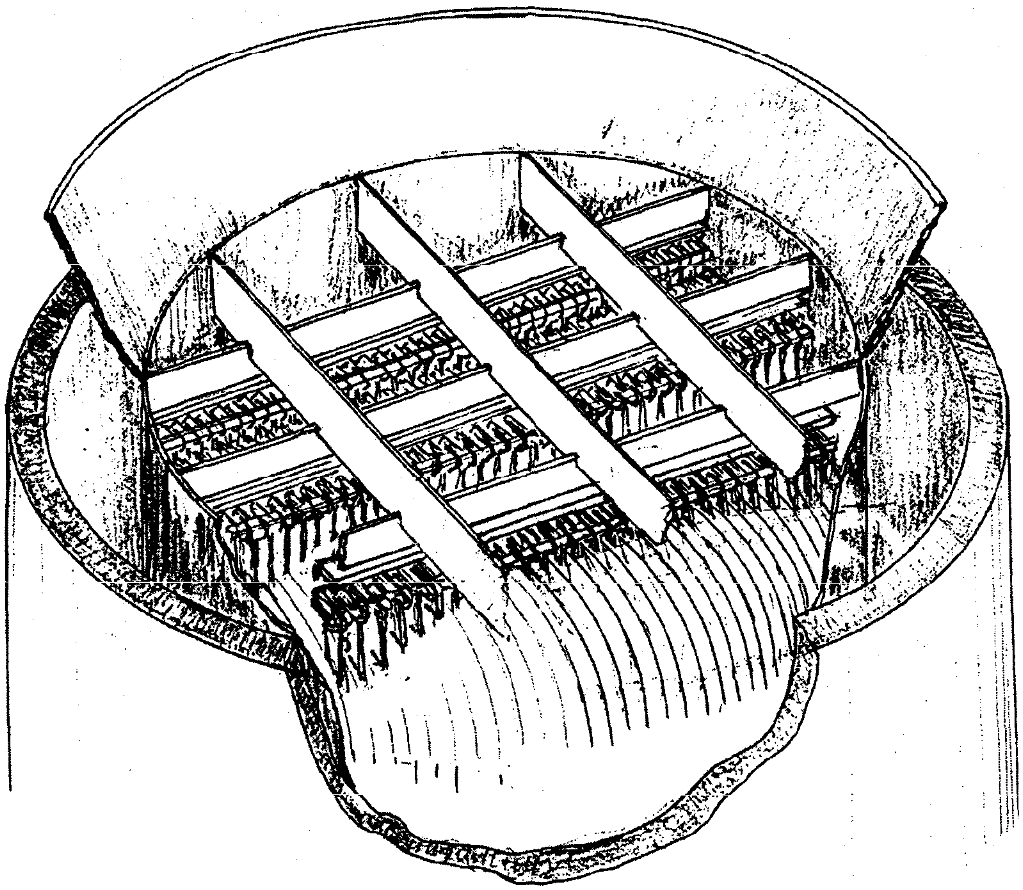
Finally I decided to talk to Howard Robinson and set in motion a request to see Tom Campbell, the president. Howard came back and the meeting was set with Tom in a few days hence. So I sweated bullets, night and day. Finally, the time came and Tom asked me to sit down. I revealed the story, as best I could, and finally he asked how much did I think it would cost. I was ready. I gave him my best guess of the shop costs and the field costs. My best guess of the total cost was a whopping $75 million! His face went white.

The next day after the meeting with Tom, Don Stelliga called a meeting of all the nuclear engineers and sat us down to advise us of the total situation as he saw it! I was completely frustrated with his methods and conclusions. I was so upset that I left the meeting and went straight to my family doctor's office for a checkup, for him to judge my state of health. Though I got a clean bill of health, the stress and the frustration continued.

As I mentioned before, although no one could be sure that the boilers were a safety risk, the decision was made to rebuild them. Since the Canadian company could not absorb the costs of the recovery program, a top-level meeting was called between OH, AECL, BWC and the U.S. parent of BWC to solve the financial crisis.



U Bend Supports



Advanced U Bend Supports

As management struggled with the problems and the repair strategy, they set up a Board of Inquiry to determine how to avoid making similar mistakes in the future. This felt like an inquest to me, and disturbed me greatly. The investigators would interrogate different people at different times, alone or together in groups, with or without their bosses present, to see how their answers would vary under different circumstances! I answered all the questions put to me honestly and thoroughly. I never read the final report but my best friends, who did read it, told me that I came out untouched. Others at my level and above were asked to leave the company when it was determined that they were part of the problem by not responding to the early warning signs of the disaster.

Although I had contributed much to the design in the early stages, i.e. Pickering and Karachi. When I was moved to Project Management, I still did not agree with the tube support system selected by engineering. My views were set aside. I fought the changes with all the power that I could exert as a project manager, and ensured that it was 'on the record'. This may have 'saved' my job at that time. However, the memories of my determined involvement in the steam generator design over the years probably led to the popular belief that it was my actions that caused the defect that led to the mess the company was in. This myth was probably fueled by the fact that I was demoted in rank to staff assistant to Bill Missell, Manager of Manufacturing, while Eric Dahlin was put in charge of the 600 MW field rebuild program. *This undeserved reputation has haunted me throughout my entire career, and it is my hope that this memoir will finally set the record straight.*

As the rebuild program got underway, an engineering design review committee was convened which consisted of BWC staff and B&W U.S. staff, representing both commercial and naval departments. As you may recall, the CANDU boiler design had some design relationship to the U.S. Navy submarine boiler. The U.S. engineers needed to ensure that any revisions adopted by the committee did not negate any details of design used in the existing naval boilers. As the U.S. Navy was B&W's best customer, it was also important to demonstrate that security had not been breached.

At the same time, the dismantling work to repair the Pickering and Bruce units in the shop began. It started by cutting the boiler shell above the tube sheet, leaving enough of the tube showing so that the tube 'pullers'—in theory—could grasp it and extract the tube from the hole in the tube sheet. However, when it came to putting this procedure into practice, *it didn't work!* The operation ground to a halt. No matter what the foremen tried, it was impossible to release the tubes from the holes in the tube sheet. If the tubes or parts of the tubes did not break clean as they were pulled out, the tube holes became 'scored' or scratched almost beyond repair. The site managers were at a loss how to proceed and it became the topic of the day. Everyone was concerned.

I was in a plane returning from a meeting at the company's labs in Lynchburg, Virginia. One of the engineers from Hydro Quebec who attended the meeting said to me, "I wonder if they are trying to extract the tubes using the right tools in the correct order." I began to think about this statement, and it still went through my mind as I went to bed that evening and tried to sleep. In the middle of the night I got up, wrote a few notes to myself and fell back into a deep sleep.

In the morning I spoke to Eric Dahlin and told him of my idea. We discussed a plan to pull on the tube first while it was still held in-situ. This would stretch the tube walls through the tension of the puller, while it was still attached to the tube sheet by the seal weld. Thus the tube walls would be elongated and thinned by the metal flowing under the applied stress. To compensate for the change, the tube would collapse slightly in the tube hole. When the trepanning tool cut the seal weld, the tube fell out of the hole without scratching the surface of the hole in the tube sheet. Now they could get on with the job. We would not over run the allotted time to complete the tube pulling operation!

As the recovery program continued, it became apparent to me that some important aspects of the remaining items of the design were not fully addressed. In my opinion, the design review committee had a strong influence in the changes made which fell short of the best available solution to the problem for the Canadian designs. While changes were made to the shroud and its many facets to loosen it up, these design changes were not repeated for the U-bend supports. Their idea was to tighten the structure up to keep it from vibrating. The theories of how lattice bars work was not applied. The essential principle is that flexibility—not rigidity—was the rule. Consequently, these designs attempted to stop fretting by ensuring that the whole structure was held tightly. The top of the tube bundle was supported by a very strong and secure structural steel array. To meet the failure analysis, this array had to be joined to the shroud of the heat exchanger section to prevent it from being swept away in case of a burst pipe. In addition, the fan bars were held in place by 'J' bars attached to the tubes. I demonstrated in bench tests that if one row of tubes was held tightly by restraints, that the adjacent tube row would vibrate violently. Thus, the design resulted in two features that caused vibrations and fretting. There is evidence that this is still occurring. At this early stage of the rebuilds, in the year 2001, damage seems to be slight. There is a concern that it could be a major problem in time. In addition, the 'J' bars could become plugged with chemical deposits, similar to the scalloped bars in Bruce A & B, and chemical attack could take place.

Under the guidance of the design review committee, the Pickering B and Bruce B steam generators were rebuilt mostly as is, as far as tube supports are concerned. They followed the basic theories of the boilers built by the engineering dept. with scallop bars and stiff U bend supports. The boilers went back into service mainly as they originally designed.

The rebuild program took all the energy and time that anyone doing the work could muster. I sat in my office pondering the changes I heard were being applied to fix the generators. I wondered if the cost of the work was being tracked as they normally would. Therefore, I undertook a summary of what I thought the costs overruns would be. My calculations revealed that these were huge amounts of money, in the range of $5-6 million dollars, and I sent a note to management preparing them for this shock. A couple of months later, BWC's controller Ron Jack came rushing into my office and asked desperately if I could see him. After telling me that then-president Joe Stewart had torn a strip off him for not advising management of this terrible overrun. I said, "Look up my memo of 10 weeks ago. In that memo, which you both received, you were advised that this overrun was probable." "Thanks," was all Ron said.

As the rebuild program was ending, I felt that my influence had failed. As I mentioned before, in 1980 I thought it was time to move on to other endeavours. I accepted a position with Atomic Energy of Canada Limited (AECL) at Sheridan Park as Manager of Heat Transfer Equipment. I stayed with AECL less than a year, as I was not assigned any meaningful work. Instead, I spent my time writing position papers on any nuclear topics where I thought I had an understanding and a solution to offer the problems plaguing the industry.

In December 1980, I left AECL to take a job back in the fossil boiler field, with Gothenburg Energy Systems in Cambridge, Ontario, as Manager of Wood-Fired Boilers. Going back into the fossil side of the energy industry after so many years in nuclear work, I felt out of step for a while. I felt like the sailor who, going ashore for the last time, carried a pair of oars on his shoulders. As he walked inland someone stopped him and asked, "What are those funny things you're carrying?" That's where he settled down. I had such a poor feeling about the nuclear industry at that time that I didn't want to think about it anymore. It was time to put down my oars. And I did – for a while.

The lucrative replacement steam generator market

Around 1985, the demand for nuclear power plants decreased drastically as public opinion grew against the production of power from the atom. But, at the same time, the existing steam generators began to fail. To address the serious reduction of power to the grids over the whole of the United States, replacement nuclear steam generators had to be designed and orders placed. BWC got into the race by offering a modified Darlington design to meet the U.S. steam generator requirements. The Darlington design with lattice bars in the tube bundle and flat bars in the U bends following Pickering's lead as built in 1967. BWC was in a unique position to be able to offer a guarantee for the rebuilds, that no others could provide, based on the record of performance at Pickering A.

In February 1988, BWC received an order from Northeast Utilities of Connecticut to rebuild the nuclear steam generators at its Millstone Plant. A Canadian-designed boiler was modified to suit the PWR conditions at Millstone. This opened the floodgates, and BWC began a long period of successes in replacement steam generator market for the U.S. utilities.

B&W Canada's proven steam generator design boasts the lowest tube failure rate and the best operating record in the industry, with a high circulation ratio, and the best design details and manufacturing processes to reduce stress corrosion cracking. This experience has helped the Company dominate the replacement nuclear steam generator market in the U.S., replacing units originally manufactured by other suppliers. A wealth of experience in servicing the nuclear industry and the development of computer-controlled robotic tooling allow them to provide unique responses to the nuclear industry's stringent service and safety requirements.

What have we learned, in retrospect

As an engineer, I am proud of my affiliation with the nuclear power industry and with the part that Babcock & Wilcox Canada played. Their contribution to the nuclear steam generator field is significant and historic, even with all its shortcomings. The magnitude of Babcock & Wilcox Canada's innovation and ultimate success in this field is not generally acknowledged. That pioneering spirit is rare, but when it happens - that's progress! As engineers, we must continue to challenge assumptions and learn from our mistakes.

Epilogue: A lifetime of learning

In May 1983, after being at AECL and then Gothenburg Energy Systems (GES), I was asked to retire from the best job of my career – as site manager at Nova Scotia Pulp and Paper Ltd.'s Port Hawesbury Paper Mill. GES had received a 'turnkey' order to build a wood-fired boiler for Nova Scotia Pulp – probably the first of its kind, in Canada for a boiler Company. The work included all trades, excavations, foundations, plumbing, concrete work, building steel structure, walls roofs piping and boilers and stoker and pressure piping. A large contract and a very interesting project!

I started out in the office and as the job proceeded, I moved to the site each month for job meetings. However, as the work got into full swing, we were shocked when several contractors went bankrupt. The site work came to almost a full stop. The site manager asked for help and management suggested that I take over. I was in complete control with no other goal than to get the job done. As there was a hefty penalty clause for not meeting the closing date, urgency to complete the job increased. We came close but we were two weeks late and had to pay the penalty.

I returned to Cambridge. The depression of 1983 had set in and contracts were rare. I was the most senior of the company and they offered a 'golden handshake,' saying that the younger members of the company would benefit if I left!

It was a Tuesday. I asked for time to think about retiring as I wished to discuss it with my wife. When I did, she said, "What are you waiting for?" So, on Thursday I was at home wondering what had happened to me. No phone calls, no meetings to call, and none to attend! It seemed that I had entered a vacuum. It was a difficult transition. As the site manager, I had lots of action every day. The buck stopped at my door and I thrived on it! Now keeping busy was going to be very important.

For a few weeks, my wife and I made lists of things to do around the house. No matter how hard I tried to work off the list, it never got shorter. Then one day, in 1989, I received a call from Steve Premock of BWC who asked me to come in and discuss a possible project with the company. I was delighted to get the call.

Steve told me that Westinghouse, whose boilers were failing, were being sued by a group of U.S. utilities. To defend itself, Westinghouse took the position that U.S. B&W had as much trouble with their designs as Westinghouse had. They claimed that the problems they encountered were industry-wide. Since BWC had designed and built a recirculating steam generator similar to Westinghouse, it was only logical that BWC, as a subsidiary of B&W, should defend the charges against the parent company.

Newly appointed president Malcolm Cox gave the task to the project management team. As fossil boiler work had dominated BWC's order book for the past few years, only a few people in project management had any nuclear experience, and no one had the time to dedicate to this legal project. Steve asked me if I would do the work. I would have to cull through the files for 'discovery' and write counter arguments to the specific charges contained in the subpoena. U.S. management suggested that it would consume about 6 person-years in both divisions to do the work. So I began.

I worked through the files for about three months, recording notes of 'discovery'. Then, BWC received a request to submit a summary, "white paper" of our findings within a week's time to U.S. management. A couple of weeks later Westinghouse agreed to settle out of court! I was thrilled to have played legal researcher for a few months, and even more pleased that we won!

One day soon after that I received a phone call from Phil Hennings, who introduced himself as a friend of John Wright, an old family friend of ours. He said that John had been in a terrible car accident and wouldn't be able to complete a construction job for him on an old farmhouse that Phil had purchased. The crew was idle at the site waiting for instructions. Would I help? This phone call got me started on a 6-year adventure in the construction of light industrial buildings, sewage systems, layouts, building permits renovating homes, etc. I finally dropped out as the pressure of meeting construction schedules reminded me that I had retired from this rat race once before. Why was I doing it again?

Nevertheless, my lifelong habit of learning didn't stop there. I heard rumors about fretting in the Darlington boilers. My engineering curiosity got the better of me and I set up experiments to examine vibrations in the U-bends. I took video tapes, some in slow motion, to illustrate how lattice bars worked. Over time, these tapes were shown to engineers at an ASME student branch meeting at McMaster University. Some BWC engineers attended, including Don Stelliga. I also loaned the tapes to my old friend Dr. Dave Weaver for him to study and involve his students. I hoped that some student might do a thesis on the subject to get the information into the technical press.

Finally, in 1999, after a few more attempts, I gave a short presentation to a group of BWC design engineers at the request of Dennis Dueck. Because of this presentation and discussions, I am now constructing two more models. They provide an air-activated wind tunnel test to show how model lattice bars would act under earth quake or burst pipe conditions. Despite several meetings with key individuals, there was no appetite for this research. Again, I gave up.

I know now that I will never stop thinking about how a nuclear steam generator works. For nearly 40 years, I have been involved in this engineering innovation. More remarkable still is that my wife, Pat, is still with me! For the best part of her married life—55 years—she has lived with the development of the recirculating steam generator with an integral steam drum and an internal economizer! I thank her for her indulgence and forbearance over the years. But, most of all I want to thank her for remaining by my side to give me the encouragement to continue!

Therefore, while my learning will continue, this memoir must now end. I have stashed the test rigs in my basement and closed the door. Another chapter in this story will evolve, written by some one else.

It is my hope that Canadian engineers will gain something from reading about my experiences. As an engineer, I am proud of my affiliation with the nuclear power industry and with Babcock & Wilcox Canada and of my involvement in developing the design of the best Nuclear Steam Generator (certainly in North America and perhaps beyond). This achievement could not have been accomplished without the help and support of many others. Moreover, I hope that all readers will understand that it is only by making mistakes that one can learn. Keep an open mind. Have the guts to say, "We've made a mistake, but here's the solution. Let's get on with it!" Above all, challenge your assumptions. Remember: to engineer is human. To learn from it, divine!

J.M.D.