The US Bombes, NCR, Joseph Desch, and 600 WAVES: The First Reunion of the US Naval Computing Machine Laboratory

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The code-breaking activities of the British Government Code & Cipher School at Bletchley Park have dominated our understanding of the secret war to infiltrate the message system of the German forces in Europe between 1939 and 1945. This is the story of the US Navy's response to the need to gain intelligence to win the Battle of the Atlantic in 1941 and 1942, the competitive development of mechanical code-breaking systems, and the contributions of NCR engineer Joseph Desch and 600 Navy WAVES.

In 1968, the British government revealed the story of the breaking of enciphered German messages during World War II. It permitted the first references, in spring 1974, to Ultra, which was the super-secret intelligence that the British gained from reading Germany's codes and ciphers, followed by F.W. Winterbotham's book entitled *The Ultra Secret*.[1] There followed a number of publications dealing with various aspects of the work of the code breakers of the Government Code & Cipher School (GC&CS) at Bletchley Park (BP) and the machines by which the decipherment was enhanced. From the point of view of computer history, the disclosure of the Colossus computer was a significant event, showing that the history of the electronic computer began earlier than ENIAC. While reference was made to the sharing of Ultra secrets with the United States and to the stationing of some US representatives at BP, the impression left was that there was little US involvement in the wartime breaking of codes. It was implied by omission that the US concentrated on the Japanese codes and otherwise was merely the recipient of Ultra intercepts.

Over the next decades, the existence of mechanized code-breaking activities and the development of US-built Bombes (huge, electomechanical devices designed to attack the German's Enigma enciphering machine) at the National Cash Register (NCR) plant in Dayton, Ohio, were unveiled, and the Smithsonian Institution put a US Bombe on display as part of its new Information Age exhibit in 1989. With the opening of the Cryptological Museum close to the National Security Agency headquarters at Fort George G. Meade, Maryland, the Bombe was moved to the new exhibit. By 1995, it was possible to organize a reunion of the WAVES (Women Appointed for Volunteer Emergency Service) who worked at the US Naval Computing Machine Laboratory (NCML), 50 years after the demobilization of most of them at the end of World War II. (See Figure 1, next page.) For the first time in 50 years, the WAVES were able, with some limitations, to tell their children what they did during World War II and to talk about their work with their colleagues. Reunion events were held at various sites around Dayton from 14 to 17 September 1995.

This article is based on the presentations at the reunion, supplemented by references to other sources.

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Figure 1. The entrance to the Naval Computing Machine Laboratory exhibit at the Carillon Historical Park, Dayton, Ohio.

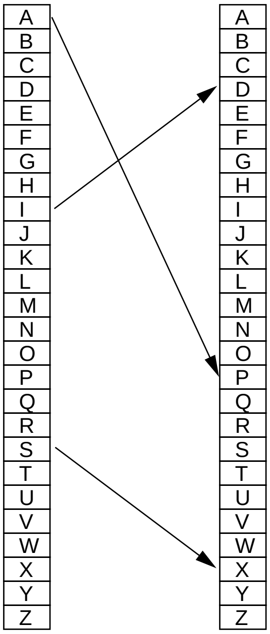

Figure 2. Character substitution by shifting.

Figure 3. The three-rotor Enigma.

Codes, ciphers, and Enigma

Messages have always been passed between partners in collusion. When there is a possibility that an adversary may intercept the message, there is the necessity of hiding the contents of the message through encryption. Up until the use of broadcast wireless for communications, messages could generally be restricted to one-to-one transmissions. While the capture or interception of a message may be unfortunate, it would be unlikely that a field unit would have the capability of decrypting a message within sufficient time to affect the outcome of any contained action. With the advent of multidirectional radio as the medium of communication, there became the possibility that the interceptor could receive the message at an off-battlefield location with extensive facilities for decryption. Consequently, it became necessary to increase the encryption complexity to extend the time to decryption beyond the effective lifetime of the message. At the same time, it was necessary to make message decryption by an approved recipient as simple as possible. Even if an encryption machine were available through capture or simulation, there should be sufficient variation in the encryption methods to still preserve the secrecy of the messages.

In the mid-1930s, the Nazi government chose the Enigma as an offline, automatic device for the encryption of communications between elements of the armed forces. The Nazi government commenced mass production of portable versions of the machines in a factory near Berlin.[2] At the same time, the Nazi government restricted the marketing of Enigma-type machines to military uses, cutting off commercial applications except when the organization was contributing to the national welfare. The German Enigma, used by various branches of the military, was an adaptation of a 1923 design by Arthur Scherbius of Berlin, itself an improvement of a 1917 design by Edward Hebern of the United States.[3] The Enigma is a character-substitution enciphering system that uses a keyboard as the entry device and a light display matrix as the output system. Conceptually, one can envisage the encipherment as a single-character substitution. Each character substitution is embedded in a single wire that completes the circuit between the keyboard and the light display and that shifts the representation by a fixed number of character positions (as shown in Figure 2).

By placing a set of shift wires on a rotor that is stepped one position after each character is encoded, then the substitution pattern for each successive character changes and, furthermore, is dependent on the starting position of the rotor. The Enigma employs three to four replaceable rotors (depending on the model). As each letter is entered into the keyboard, a circuit is completed through the sequence of rotors, through a mirroring commutator, and back through the rotors to the light display. In the three-rotor arrangement (see Figure 3) and the reflecting commutator, seven character transpositions occur, while in the four-rotor system, the number increases to nine. On release of the key after encoding a single character, the first rotor steps forward one character position. A complete revolution of a rotor then triggers a step motion in the contiguous rotor. Thus, each encipherment is different from the prior encoding. Because of the reflecting commutator, it is impossible for a character to be enciphered into itself. On the other hand, the reflective system also implies that for any given rotor setting, the encipherment and decipherment processes are totally reflexive. Thus, the same rotor settings implement both processes: encipherment and decipherment. Adding three complications—the ability to choose three or four rotors from a larger set, the order of placement of the rotors in the machine, and their angular starting positions—increases the number of encipherments even further.

The German version of the Enigma also had a "stecker" plug board added that provided an additional, but temporarily fixed substitution combination. Effectively, the stecker board was an additional "rotor" that remained in a fixed position during the operation of the Enigma. Along with the choice of rotors, the ordering of the rotors in the machines, and their angular positioning, the stecker board was also reset at least daily, sometimes as frequently as every eight hours. I.J. Good, a mathematician at BP, estimated that the three-rotor Enigma provided 10^{23} different encipherings, while the four-rotor system provided 10^{26}. Good's contributions to the BP effort appear in Lee.[4] Put another way, "brute-force" attempts at deciphering could require the application of over 10^{23} multicharacter transformations to reveal the clear text message. Miller computed the number of configurations as $3 \times 10{,}114$. This computation presumed that there existed a large number of rotors (26), corresponding to every potential wiring configuration. In fact, there were only six to eight different rotors used.

The history of the attempts to break the Enigma ciphers, starting from early work in Poland and continuing through the work at BP, has been documented in the pages of the *Annals* and in the open literature. While the Enigma is the most commonly cited encipherment method—and code breaking with respect to Enigma intercepts is frequently intimated to compose the whole intelligence that Winston Churchill labeled as "Ultra"—in fact, it was only a small part of the overall picture. German Enigma intercepts generally constituted the low-level operational traffic, while much more sophisticated online ciphering systems, generally collectively known as "fish," provided the more-strategic information. Fish traffic, as handled at BP, required the use of a series of machines known as the Robinsons and eventually the Colossus I and II electronic systems.

Enigma and the Battle of the Atlantic

Obviously, the best solution to the decryption problem was to capture the enemy codebooks that established the wheels to be used and the order of their placement in the Enigma machine. Given this information, mechanical analyzers were not necessary. At various periods throughout the war, there was access to captured codebooks for certain uses of the Enigma, but these rarely covered more than one aspect of operations, each chain of command having its own daily settings. David Kahn detailed the efforts to capture codebooks from the German submarine U-110 and the weather ship *Lauenberg* in his book *Seizing the Enigma*.[5] Both of those provided the code breakers with some temporary relief from their task, but when the codebooks became outdated, they were back to the problems of working in the dark.

The second assistance in reducing the number of possible encipherments to examine is knowledge of cribs. In English school systems, looking over another student's shoulder to get the answers to examination questions is known as cribbing and thus the information obtained is a crib. In the US, these were known as sillies. Code breakers sought cribs in order to get some clues to the clear message so that the polymorphic substitutions might be derived. Errors in operational procedures occasionally provided such cribs.

One major error occurred on 14 March 1942, when a message was sent to the German fleet announcing Karl Dönitz's promotion to the rank of admiral.[6] Fortunately for the code breakers, the message was sent to various elements of the fleet using different encipherings, several of which had been broken. This enabled the others to be broken also. This type of error occurred not infrequently and provided valuable cribs.

An intended complication turned out to be a crib. Rather than including the rotor angular positions in the codebook, operators were permitted to transmit this to the recipient as the first three characters in the message. To double-check, these three characters were repeated. Thus, if the settings were correct, then the second group of letters would be identical to the first. However, lazy operators would frequently use the same sequences of characters or sequences of three adjacent characters from the keyboard. Knowing the operator (from knowledge of the communication channel or from recognizing the Morse code "signature"), it was possible to guess at the first six characters of the message.

Finally, cribs could sometimes be derived from the German command's propensity to commence each message with a destination address and salutation. Thus, if it was known that the intercept was emanating from the field to go to the command headquarters, there

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would be a good chance that the commander would be addressed formally. Just as our e-mail messages today commence with "to:" and "cc:" addresses, so the Enigma messages contained well-formatted headers.

Starting even before the commencement of hostilities in September 1939, code breakers attacked Enigma intercepts using a variety of manual techniques. A transparent overlay method incorporating statistical and logical enhancements known as Banburismus was in common use at BP. It soon became evident that such manual techniques could not keep up with the density of intercepted traffic, so some more mechanical means of analysis was necessary. To this end, a series of machines known as Bombes was created.

A display card in the Cryptological Museum suggests that the name Bombe was given to these machines because they ticked like a time bomb. Rejewski[7] claimed Polish code breakers used the name Bomba for their early machines, and thus we must conclude that Bombe was a derivation therefrom. In his lecture at the reunion, Jeffrey Greenhut said that his favorite story of the origin of the name was that it came from two Polish engineers who liked to eat an ice-cream named bombe, and they simply used that name.

Their task was to compare the intercepts with known sequences of encoded character strings and, thus, to attempt to reveal the rotor selection and settings for the particular message. It was known that even such mechanical systems could not perform brute-force comparative analysis in a reasonable time (generally, the time between the receipt of the message and the implementation of its orders), and thus more intellectual techniques had to be applied to reduce the number of possible substitutions to be examined. Actual decoding of messages was not part of the task of the Bombes; once code breakers learned the settings of the Enigma (rotor selection, placement, and initial angular positioning), the solution was obtained by using captured Enigma machines or locally constructed analogs.

Using cribs, code breakers could set up the Bombes to look for particular sequences of characters—or, more precisely, to ignore certain patterns—so as to cut down drastically on the number of comparisons to be made to derive the rotors, their positions, and the initial settings.

While there were many nonmechanical aids to decryption, such was the background against which BP staff members used their Bombes. At the height of activity, 60 Bombes were in use at BP, though in the early years, the numbers were much less and their reliability was not good. During the period of the Battle of the Atlantic (1939–1943), the breaking of the German naval codes was sporadic, and there was a particularly disastrous period when the Allies were almost totally cut off from the communications affecting the command of the U-boats operating in the convoy lanes between North America and Great Britain. Until the US entered the war following the attack on Pearl Harbor on 7 December 1941, there had been little exchange of Enigma-based intelligence between the US and Britain. The amount of information the US community obtained was insufficient to formulate independent mechanical code-breaking activities. BP had such a lead in code breaking that it assumed there was no need to share anything beyond intercepts on a "need-to-know" basis. The British regarded the Atlantic as their domain of control, leaving the Pacific to the US forces. US land forces, initially in North Africa and later in Europe, could best be supported by intelligence garnered, analyzed, and distributed in Europe. Any code-breaking activities located within the US were regarded as being too far away from the action to be useful. Further, the US intelligence community was broken into several independent, apparently uncoordinated activities, whereas the whole of the British effort was in one location—BP. The British also were concerned about the possibility of leaks and the total compromise of the system if the German command were to suspect that its messages were being intercepted and deciphered. It was imperative to prevent the German command from adding complexity to the Enigma procedures.

BP had been unsuccessful at breaking the U-boat codes since February 1942, when the German navy added a fourth rotor to its Enigmas. The fourth rotor had to be constructed slightly differently from the other three in order to make it fit into the

Table 1. Allied shipping losses, 1939–1945.[9]

Year	Number: German U-boats sunk	Number: Allied shipping sunk	New construction (thousands of tons): US	British	Total	Net gain (or loss)
1939*	9	810	101	231	332	(478)
1940	22	4,407	439	780	1,219	(3,188)
1941	35	4,398	1,169	815	1,984	(2,414)
1942	**85**	**8,245**	**5,339**	**1,843**	**7,182**	**(1,063)**
1943	237	3,661	12,384	2,201	14,585	10,974
1944	241	1,422	11,639	1,710	13,349	11,927
1945**	152	458	3,551	283	3,834	3,378
Totals	782	23,351	34,622	7,863	42,485	19,134

* *Last four months.*
** *First four months.*

standard casing of an Enigma machine, and Thus the fourth rotor was not interchangeable with the other three. This shortcoming reduced the number of alternative wheels that could be put in this position, reducing the added complexity that could have been accomplished with a totally interchangeable rotor. BP had not upgraded its Bombes to account for the additional rotor, believing that the multiple use of Bombes could solve the problem. The result was disastrous. Convoys of equipment and supplies had been moving between North America and Britain for some time before the US entered the war, and while the losses due to U-boat action were not acceptable prior to February 1942, they were reduced to a minimum (averaging 400,000 tons per month) as a result of the intelligence BP provided. In 1942, however, losses were averaging about 700,000 tons per month.[8] Russell[9] has confirmed these general figures, as shown in Table 1 taken from King.[10]

These losses were simply not acceptable to the U.S. Navy, which was frustrated in the first place not to be in the driving seat to obtain firsthand intelligence about U-boat plans and activities and believing that the British were not paying enough attention to the problem.

Throughout 1942, there was an exchange of deputations between the two countries with a view to improving the exchange of intelligence, though the British view was that:

> while so much work remained to be done against the Japanese ciphers, [the United States] should not duplicate [BP's] work on the European, particular the Enigma, but should be content to receive copies of such decrypts as were required.[8]

Frustrated, the US was ready to develop its own versions of the Bombe. In late 1942, it was decided in the Holden Agreement[11] that the US Navy would get a Bombe to save the trouble of designing its own machine. But the year ended without the machine being delivered.

About the same time, the US Army was not having any better luck in its negotiations with the British. Starting in late 1942, the Army believed that the GC&CS was withholding a great deal of field traffic and the details of "high-speed analyses."[11] The latter referred to the BP work using Bombes. The Army, working at Arlington Hall near Washington, D.C., responded in February 1943 by producing "E solving machines" to attack Enigma messages. The British were concerned that the release of Enigma traffic outside the United Kingdom would compromise the Ultra secret. The US War Department was prepared to sever all ties with the GC&CS in March 1943, since its credibility was at a low point as a result of the realization that some of its own codes had been compromised. However, by June 1943, a seven-point agreement had been signed that allowed US personnel to learn about the Enigma solutions in the United Kingdom and for "formulas [to be] supplied for use on machine now at Arlington Hall."[11]

Comparatively, the US Navy negotiations through 1943 and 1944 were much less complicated, probably because, like the British, the Navy had concentrated all of its code-breaking activities in a single unit (OP-20-G). The Extension Agreement of July 1943 endowed the responsibility for machine ciphers (presumably the fish traffic) to GC&CS and in trade provided for the interchange of raw material between GC&CS and OP-20-G.[11]

OP-20-G

The US Navy branch for cryptanalysis dates back to World War I and was designated OP-20-G.[12] Although fairly dormant between the wars, the US Navy branch for cryptanalysis had kept a watchful eye on mechanical means of decryption. Most active in the 1930s was Vannevar Bush, who had built a series of analog machines (differential analyzers) for scientific use, but who had his eye on faster methods of computation. In the 1930s, Bush had begun to formulate his ideas that he would publish in a 1945 magazine article introducing the concept of Memex, an all-powerful desk computer that predates the modern workstation.[13] Among his ideas were a Rapid Arithmetical Machine for general computation, the Rapid Selector for data retrieval, and the Comparator for cryptanalytical work. He directed most of his efforts to the construction of the Rockefeller Analyzer, an advanced differential analyzer that the Rockefeller Foundation supported. Working out of the MIT Analysis Center, Bush looked for support from many of MIT's general supporters, such as IBM, General Electric, and Bell Telephone Laboratories, but they could not be enticed to support his work beyond the Rockefeller Analyzer.

OP-20-G was interested in the Rapid Selector, which Bush had initially envisaged to be a library system but that over time came to have more business-processing-like attributes. Eastman Kodak was also interested in the ideas with a view to being able to locate records in business microfilm archives. However, the concepts did not transfer well to practice, and by mid-1940, it was being admitted that the process could not be implemented. However, some of the ideas could be the basis for the other machine, the Comparator. This machine did get OP-20-G support and became the basis for the Navy Rapid Machines Program. Significantly, the Comparator was to combine electronics, microfilm, and digital processing to accomplish its task, ideas that were in advance of both the British Colossus and the University of Pennsylvania's ENIAC. Bush's appointment to chair the National Defense Research Committee (NDRC) in June 1940 was his opportunity to fund some of these projects in the interest of the war effort. The Navy was very concerned over the loss of control of some of its research interests because of the broad charter of NDRC, including radar and atomic energy. Both of these efforts, however, were recognized as needing advanced computational support. Fire control projects, obviously important to the war effort, would also benefit from computation, so NDRC sponsored work on digital electronics but gave little attention to the Navy's cryptological needs. On the other hand, the Navy's Rapid Machines Program eventually got support, which it used to continue the Comparator work.

Against this background, OP-20-G found itself, in early 1942, needing to build code-cracking machines and not being able to get the necessary information about the design and construction of Bombes from the British. Initially, the work was given to the M section of OP-20 led by Howard Engstrom, with the design being undertaken by a small group of academicians at MIT who were committed to an electronic solution. This group—known as OP-20-M, working in the dark, unable to get complete designs from BP, lacking the ability to reengineer a Bombe for the lack of an example in the US, not being fully appraised of the algorithms for finding the keys for decryption, and with little experience, but with a top-level concept of what was needed—produced a draft design document in early 1942.

Looking around for an experienced engineer to evaluate the design, the OP-20-M chose Joseph Desch, director of research of the NCR Electrical Research Laboratory since April 1938. Col. Edward Deeds, chairman of the board of NCR, had a strong working relationship with the MIT group and had provided regular support to MIT, including a $10,000 consulting position for Sam Caldwell, the director of the Rockefeller Analyzer project. It is likely that Bush asked Deeds to nominate an engineer to provide this review, and he recommended Desch. Desch had already made his mark on the war effort by constructing electronic counters capable of operating at 1 million counts per second, at least an order of magnitude better than previously attained. These counters were to be used in the Manhattan Project, though Desch was not aware of the application at the time.

Desch reviewed MIT's proposed design and declared that it was not feasible. He estimated that the MIT design would require 20,000 tubes per Bombe being run at the limit of their capabilities. Of course, a similar number of tubes were used in the later University of Pennsylvania ENIAC project, which was completed in the final years of the war under slightly less pressure to succeed. In this case, J. Presper Eckert designed the circuits so that the load on the tubes was kept well within narrow tolerances. The MIT design for the electronic Bombe required that the tubes would run at voltages well outside this domain. Desch proposed that the US Bombe could be built using mechanical technology that he knew was in use in the British Bombe, which had been acquired in mid-1942.

The Navy already had an open-ended best-effort contract with NCR and Desch's group, and so the Navy basically took over Desch, his staff, and his laboratory and gave them the war assignment of creating the US Bombes. The NCR laboratory had become the workhorse of OP-20-G. The task was to create a machine that was capable of breaking the codes of the four-rotor Enigma, which would require a level of complexity at least one order of magnitude greater than that achieved by the British Bombes.

The US Navy parlayed the lack of BP progress on breaking the U-boat codes and the lack of four-rotor Bombes into getting an agreement to allow it to build up to 100 Bombes (though the Navy really planned to build 360). In return, the British would share in the intelligence derived and any resulting new technology. Eventually, the Navy built 120 Bombes and sent them to the Naval Communications Annex (Phil Bochicchio, private communication). To counter the British concern that broadening the membership of the assemblage that had knowledge of Ultra would compromise security, the US delegation promised to do everything possible to keep the secret. In October 1942, shortly after Desch had been recruited to build the Bombes, the British agreed to train Engstrom's M group to use hand methods of decryption and gave them instructions on how the existing (three-rotor) Bombes were set up.

In late 1942, Alan Turing made the first of several trips to the US, including a visit to Dayton to evaluate the NCR work. While Turing's evaluations were not totally positive, they were not sufficiently negative to derail Desch's work. Desch's preliminary design had been approved in September 1942, and he had plans to build the prototype before the end of the year. Many of Engstrom's M group moved to Dayton to help. Resources and funding, once the White House had been convinced of the efficacy of the work, flowed even more easily than those to the Manhattan Project. If OP-20-G had a problem, it was that of getting a larger share of the Navy resources without raising a red flag that might lead to questions that would compromise the Ultra secret.

At the beginning of 1943, the prototype was still not complete, and the Navy was beginning to wonder whether it had misplaced its trust in Desch's group. The promised support for breaking the U-boat codes had not been forthcoming. Fortunately, the British had a breakthrough by discovering some cribs that enabled them to use the existing three-rotor Bombes to decrypt the four-rotor Shark network of U-boat Enigma codes. But they knew that it was only a temporary reprieve, and on the next change of keys they would be in the dark again. Consequently, any hope for improvement could not be ignored; NCML continued its search for a solution. Improved plans for the prototype were approved in late January 1943, giving the Navy sufficient confidence to go ahead with the plans to provide accommodations for the work force of Navy enlisted men and WAVES to build the necessary Bombes. Two pilot models were to be constructed—Adam and Eve. At the same time, facilities in Washington, D.C., for the installation of the Bombes were needed at the Nebraska Avenue site. This facility, officially known as the Naval Communications Annex, had been the Mount Vernon Seminary and a girls school before the Navy took it over.

By midyear, the working Bombe was still not a practicality, but the Allies were beginning to win the Battle of the Atlantic by other means. One of those other means was an improvement in the security of Allied codes used in the convoys. In an attempt to prove the efficacy of the US Bombe program, it was decided to apply Adam and Eve to a number of intercepts. However, neither machine would run for more than a few hours without the rotor contacts burning off and the oil washing over the parts.

Joe Eachus, a US mathematician who had been assigned to BP in 1942, was seconded to Dayton to assist in the procedures for operating the Bombes. But Adam and Eve still did not perform up to specifications, and in the meantime, the British had completed their first four-rotor Bombe and had introduced a new series of machines (named the Robinsons) for fish traffic. There was a possibility that NCR would become the US manufacturer of British-designed Bombes. The past expenditures, however, justified staying with the program, and more pressure was brought on Desch to solve the problems besetting Adam and Eve. Moreover, there was a fear that the U-boat hiatus was only temporary, and thus there would be a future need for the US Bombes.

Desch reworked the wheels that were the analogs of the Enigma rotors to prevent distortion at high revolutions and instituted a regimen to improve the handling of the components and keep within the tolerances required during runs. Two new models, named Cain and Abel, were manufactured. By this time, the design involved the use of the

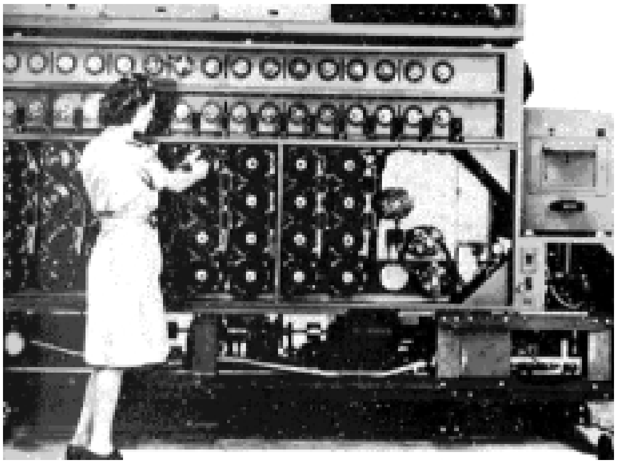

Figure 4. The US Bombe.

equivalent of 1,500 ordinary vacuum tubes using specially manufactured multipurpose tubes from the Desch plant. The main shaft turning 64 wheels operated at 2,000 rpm. Unforeseen problems of balancing wheels, which were replaced prior to each run, were being overcome, and an electronic technique to identify the rotary position of the wheels had replaced the much slower, relay-based methodology of the British Bombes. The electronic technique was essential to the recording of the positions of the wheels at the instant a hit was found, especially since, at high speeds, it was impossible to stop the machine instantly, and it was subsequently necessary to back up to the hit position. Printing the hit positions of the wheels was also solved, so that the US Bombes were 25 percent to 30 percent faster than the British machines. Hinsley[6] claimed that the US Bombe had an output capacity of only half that of the British machine. The four-wheel Bombe was hoped to be 26 times as fast as the three-wheel version, but double the speed was all that could be achieved. Despite that, the US Bombes were impressively productive. The hand methods of decryption averaged 600 hours per message at the beginning of 1943; by the end of the year, using the US Bombe (see Figure 4), the time was reduced to 18 hours—less than one day. Desch's seemingly simple modifications in mid-1943 had produced machines that were highly reliable once they had completed their shakedown. The Navy thinks of shakedown cruises for ships as the means to get out all the kinks and integrate the crew and the vessel; for computers, we now use the term "burn-in."

Production of the remaining machines was set up so that each employee saw only a small component of each machine and thus was unable to identify the assembled product. This did not keep people from guessing however, and at least two people who worked on the project made an educated guess that they were working on a code-breaking machine. In each case, an infuriated supervisor (in one case, Desch) told them to stop guessing and keep their mouths shut. One young man was discovered to be an infiltrator and was quickly removed from the project. After a closed trial to keep the secret from the US public as well as the British, the man was found guilty and incarcerated until the end of the war (Burke, conference reunion presentation). Fortunately, no word got out into the community, and the secret of the code-breaking work was maintained for more than 50 years.

In the fall of 1943, staff members were being transferred from Dayton to Washington. Certain Navy officers—including Engstrom, who initially had an office at NCR—were the first to move, so as to set up the first machines in readiness for the task of productive code breaking. They were followed to Washington by a squad of WAVES who could be released from the manufacturing process and transferred to code breaking. Some officers and the NCR staff remained in Dayton to turn their attention to new problems, including the possibility of changes to the Bombe designs to accommodate any changes to the German encryption systems.

By the end of 1943, the Washington installation was on a par with the BP installation and equally capable of decrypting code traffic in anticipation of the run-up to the long-anticipated opening of a second front in Europe. The US Bombes were contributing to Ultra, and the longtime "operatives" in England could no longer ignore the contributions of their colonial "cousins." With the decrease in U-boat activities in the Atlantic, the Nebraska Avenue group turned to German Air Force messages, possibly in contravention of the interservice agreements with the Army group that William Friedman led. The Luftwaffe was still using three-rotor Enigmas. There was so much traffic from this source that the British were thankful for help from the US.

The OP-20-M group still resident in Dayton turned back to the Rapid Machines Project, including revisiting the Bush Comparator design. This group made advances in digital electronics and toward the end of the war were recognized as an asset that could not be allowed to be dispersed. From this realization, and with support from sources outside of the US Navy, this group became the core of the postwar company Engineering Research Associates (ERA). As an independent, private corporation, ERA continued the cryptographic machine development work of OP-20-M and eventually produced a series of general-purpose computers for commercial consumption. These machines were eventually incorporated into the Remington Rand line of machines when that company absorbed ERA.[14]

Desch spent the next few years conducting further research on high-speed tubes in a laboratory on the second floor of Building 20 in Dayton. Robert Mumma, who supervised the manufacture of the Bombes during the war, and the Electrical Research staff formed the basis of the Electrical Engineering Department at NCR. Relics of the project not shipped to Washington were assigned an ignominious end: A pit was dug in a deserted lot, across Dayton's Stewart Street from Building 26, and the spare parts were dumped and buried there. By the end of 1946, there was no trace of the NCML left at NCR.

The WAVES

The US Navy's OP-20-G used the need to win the U-boat war in the Atlantic as the impetus to create an independent mechanical solution to the code-breaking problem. Navy Admiral Stanford Caldwell Hooper and Joseph Wenger supported this approach and insisted that the US Navy should be able to participate as an equal partner in the code-breaking activity in Britain. It took the innovative concepts of NDRC director Bush, the staff of MIT who planned the Rapid Arithmetic Machines, and Desch's practical genius to bring these concepts to reality.

It also took the effort of 600 WAVES, 100 Navy officers and enlisted men, and a large civilian work force to build the first US Bombes in NCR's Building 26 in Dayton and about 3,000 workers to operate the machines at the US Navy facility on Nebraska Avenue in Washington. At its peak, it was estimated that BP employed 14,000 personnel.

In Dayton, the Sugar Camp resort, which had been NCR's sales force's training facility, had been turned into the dormitory facility for the WAVES. They were marched to NCR's Building 26 in three shifts to be the manufacturing force for the Bombes. At the reunion in Dayton in September 1995, several women described their daily activities, which consisted primarily of soldering and wiring, not knowing at that time what was the purpose. One of the wiring tasks was to recreate the Bombe wheels that emulated the Enigma rotors. Each Bombe required 64 wheels. To maintain secrecy, one WAVE was given the wiring diagram for one side of a wheel. Another WAVE soldered the other side.[15] When the WAVES were transferred to Washington, many of them saw the completed machines for the first time and saw how their work fitted into the whole plan.

In the later years of computer construction when the back planes of most machines were a mass of wires soldered to the pegs of connectors of plug-in modules, one of the major sources of unreliability was the quality of the soldered joints. The same was surely true of the NCR Bombes, and it is a credit to the WAVES that they were able to construct these machines in an era before automation of soldering had been conceived. It was eventually realized in mid-1943 that other problems associated with the unreliability of Adam and Eve were due to rotational distortions inherent in operating the Bombe wheels at 2,000 rpm.

Without the women in Building 26, it is doubtful that the schedule of manufacture, as late as it was because of the intricacies of the rapid cycle of development and design, could have been met. While the initial problem was the Battle of the Atlantic, the later support of the D-Day activities and the Pacific theater operations helped shorten the war. Unfortunately, the efforts of OP-20-G were not publicly recognized in the years immediately following the cessation of hostilities or even after the 1968 revelation of the work at BP or publication of *The Ultra Secret*[1] in 1974. The subsequent publications about the work of the Signal Intelligence Service and Friedman left the impression that the code-breaking efforts of World War II were almost totally in the hands of the British. Even on NCR's Web site (www3.ncr.com/history/ncr.htm), the references to World War II activities mention only rocket motors, analog computer bombsights, and the Chandler–Evans bombsight used in long-range B-29 bombers.

Desch's efforts were left in the dark as being subsidiary to the work at BP. The US Bombes, both in quality and quantity, were superior to the British versions and were able to take over the load while BP turned its attention to the higher-level ciphers known as fish and for which they developed the Robinsons and Colossus. It was not until the time of the reunion that the WAVES were also recognized by the collective presentation of Exceptional Service Awards. Bochicchio, who was one of the original Navy personnel at Nebraska Avenue, personally presented award certificates to Deborah (Desch) Anderson on behalf of her father, and to Robert E. Mumma, who supervised US Bombe construction at NCR and who was in the audience.

Figure 5. The photo exhibit.

Figure 6. The attendees at Sugar Camp.

NCML reunion

Anderson organized the first reunion of the staff of the NCML from 14 to 17 September 1995. The reunion was jointly sponsored by Carillon Historical Park, the US Air Force Museum, AT&T Global Information Systems (having then recently acquired NCR as a subsidiary and prior to its subsequent reemergence as an independent company in 1997), and the Dayton chapter of the IEEE. Funds granted by the History Committee of the Dayton chapter were vital to the reunion's organization. Attended by 75 WAVES, 18 Navy veterans, and 14 retired NCR employees and their families or guests, the reunion was the first opportunity for most of them to openly discuss their exploits.

The festivities began on the evening of 14 September with a reception, hosted by Anderson and her family, at the Dayton Marriott Hotel, where the group had accommodations. The hotel is located adjacent to NCR. Building 26, where the Bombes were built, still stands across from the hotel's entrance. Building 26 underwent renovation in the 1960s, and its front is covered by a facade, but the original brick outline is clearly visible in the back. The reception provided a chance for everyone to become acquainted.

The Carillon Historical Park hosted the reunion the morning of 15 September. Executive Director Mary Mathews greeted the attendees, who enjoyed coffee and donuts and received letters of greeting from Sen. John Glenn, the city of Dayton, and the Montgomery County Commission. They were then free to tour the park and see an exhibit of photographs, both posed and informal (many photographs were copies of originals borrowed from the WAVES), entitled "Dayton, Ohio: Home of the WAVES, 1943–1945" (see Figure 5). The pioneering spirit of the project was complemented by the fact that the exhibit was displayed in a building that is a replica of the Wright brothers' bicycle shop and that contained many artifacts. The park's printing shop exhibit produced special souvenir cards picturing the sleeve patch of the unit. This patch displayed a crossed feather and lightning bolt surmounted by an eagle—the symbol of the cryptographic service and known to the rest of the service as the "lightning fast chicken pluckers."

After the opening ceremonies, the group returned to a renovated Sugar Camp for lunch and a welcome by AT&T. One of the cabins that served as a commissary for the WAVES still stands, and the group assembled in front of it to have their photograph taken. (See Figure 6.)

On 16 September, the reunion moved to the US Air Force Museum at Wright Patterson Air Force Base for public lectures and the evening banquet. After a greeting by Col. Richard Uppstrom (USAF retired), Mathews introduced Greenhut, who is the director of the museum and the historian for the Naval Security Group Command. Greenhut gave the participants an overview of the history of codes and ciphers, finishing with a description of the Enigma ciphering machine, an example of which was available for viewing. For the majority of attendees, this was the first time that they had the opportunity to see the machine that was so central to their wartime work. He also noted that the fine work needed to construct the Bombes, such as the manufacture and wiring of the wheels, could be done better by women than by large-digited men. Their ability to produce finely crafted, yet rugged components was essential in the production of working systems.

Colin Burke then provided an overview of the WAVES' work in the context of the secret war between 1939 and 1945. He gave tremendous credit to Desch for his success in building a machine from very incomplete specifications, without a prior knowledge of cryptanalysis, and under tremendous pressure.

After lunch at the museum, attendees viewed the vast collection of aircraft on display, including World War II era planes. That evening, they reconvened for a banquet hosted by Col. Uppstrom and held in the dramatic setting of the Modern Flight Hangar. Tables were surrounded by a number of more-recent aircraft, including the Stealth fighter, a B-52, and an A-10. The keynote speaker was Margaret Fiehtner, assistant chief of staff of the Naval Security Group Command, who shared her view of the work of these pioneers and the impact their work had on the world. She pointed out that following the war, WAVES were shipped to many locations around the world to set up cryptographic stations to help in keeping the peace. Fiehtner expressed her pride in the fact that the Naval Security Group Command has always been extremely fair in its treatment of women and that today three of the major units are commanded by women captains, who are vying with each other to be the first female admiral in cryptography.

Fiehtner further complimented the attendees on their ability to keep the NCML secret for 50 years. The NCR program was perhaps the only program that was not compromised during the war. Even in the 50 years since then, though 25 spies have been identified, none successfully infiltrated this program. She posited that the women were chosen for the expectation that they could keep the secrets better than men, since they were much less likely go out on the town, get drunk, and possibly be subjected to external pressures to reveal their knowledge of their work. The style of the times, the early 1940s, gave the women much less liberty, even in a time when many women were replacing men in the factories and on the assembly line—as epitomized by the "Rosie the Riveter" characterization. The WAVES, closeted in Sugar Camp, were expected to not discuss their work outside of Building 26. Their liberties were orchestrated to minimize their outside contacts. Their lives, on the other hand, were not totally without recreation and relaxation. The Sugar Camp facility provided the venue for many leisure activities.

The Naval Security Group Command recently moved from Nebraska Avenue to Fort Meade to be integrated into the National Security Agency. As part of her presentation, Fiehtner showed a video clip of the farewell ceremonies that took place on 25 August 1995. Coincidentally, this ceremony took place in the same Navy chapel where many of the WAVES on arrival in Washington were told that just because they were women, they should not assume that they would not be shot for treason if they revealed the secret of which they were a part. The two speakers were Vice Admiral Michael Tunnel and Kahn, the author of *Seizing the Enigma*.[5] Both spoke of the WAVES' contributions in building the Bombes and running them afterward, contributions that were estimated to have reduced the length of the war by one to two years.

Figure 7. Joseph R. Desch.

The Dayton reunion closed with special commemorative services held at two churches frequented by many of the WAVES during the war: Westminster Presbyterian and Holy Angels. During the weekend, additional contributions had been made by Deborah Anderson, Darrell Anderson, AT&T Global Information Systems, Bochicchio, the Carey Company, the Center for Cryptographic Research, Dayton–Montgomery County Visitors and Convention Bureau, the Naval Security Group Command, and Evelyn Hodges Vogel.

Desch biography

Desch (see Figure 7) came into the world at the right place and time to become an inventor—he was born in Dayton in 1907, just four years after the Wright brothers' historic flight and about a mile from their bicycle shop. He grew up at a time when Dayton was teeming with tinkerers and craftsmen. His grandfather, father, and uncles were wagon makers who were not only woodworkers and blacksmiths but also precision toolmakers and problem solvers. On his free days from school, he accompanied his father to the family wagonworks and was fascinated watching his father forge tools. Once Desch discovered radio at the age of 11, it was natural for him to assume that he would build his own equipment. He taught himself the necessary skills, and when he began experimenting with various components, he used tools he had designed and his father fabricated.

Desch attended the Catholic grade school of his family's German neighborhood parish, then he won a scholarship to the preparatory school of the University of Dayton. Later, while attending college at the University of Dayton, Desch worked evenings as an inspector at Day-Fan Electric in Dayton, supervising radio testing and production. After graduation from college, he got a job at General Motors Radio, where he supervised radio testing. He met two people there who were to play large roles in his life: his future wife—Dorothy Brockman, whom he married in 1935—and Mumma, who continued to be his colleague and friend for the next 50 years. After Desch supervised the liquidation of General Motors Radio in 1933, he conducted Teletype communications research for Telecom Laboratories, a basement laboratory in a residential area of Dayton that Charles Kettering financed. Two years later, Harry Williams hired him to be foreman of the Process Laboratory at the Frigidaire Division of General Motors, again in Dayton. He then followed Williams to NCR in 1938 to form the innovative Electrical Research Laboratory at the direction of Deeds, then president of NCR.

This was the opportunity Desch needed to establish himself in electronics research. At Deeds' direction, he conducted research to implement pioneering ideas in the use of tubes and circuitry in counting devices, with the idea of developing high-speed mathematical computing machines to augment or replace NCR's mechanical machines. The idea of applying electronic counting to calculating mechanisms occurred to him when reading of a thyratron (gas-filled tube) counting ring of five places (five digits, not five orders) developed by English scientist Wynn Williams. This particular counting ring was used to scale down impulses from the Geiger–Mueller tube used in radioactive emanation research.

Two kinds of counters were used:

> ...high vacuum counters using "trigger tubes" and gas tube counters using "thyratrons." The idea of using counters arranged in groups of ten, for division by ten, that is decimal counting, or scale of 10 counting, became evident to me in my search for ways and means to effect electrical arithmetical computings ... since gas tube counters required fewer tubes, could probably be made smaller, and were completely reliable, we decided to begin our research work on this type of counter.... A miniature gas tube or thyratron was developed which has proven completely satisfactory, enabling us to attain much higher operating speeds than the most optimistic contemporary investigators.[16]

Of the thyratron, he further wrote:

> This tube, later used in quantity in Navy equipment for purposes other than counting [In notes written for NCR archives in 1974, he wrote that over a quarter of a million were used during World War II.], was developed for production from our laboratory type by the Hygrade Sylvania Tube Co. ... Considerable time and effort were expended in perfecting this gas tube (thyratron) for counting use.[17]

Deeds was nationally known in scientific circles and had formed a relationship, both personal and professional, with Bush of MIT. This relationship irrevocably influenced the direction of the Electrical Research Laboratory. Simultaneous with the counter work at NCR, Bush and Caldwell conducted similar work at MIT under NCR sponsorship, working toward a "Rapid Arithmetical Machine." This longstanding professional exchange of ideas precipitated a crucial event in 1940, when the laboratory's work took a sudden turn:

> In the later summer of 1940 we were approached by George Harrison, Chairman of Section D3, Instruments, of the NDRC and requested to aid in the development of electronic counters for war, capable for very high speed counting. The research objective was the development of a counter capable for accurately counting impulses at the rate of one million or more per second. Presumably we became known to Dr. Harrison through Dr. Caldwell and Dr. Bush.[18]

The laboratory's initial work on the problem brought the top speed from 1,500 impulses per second to about 150,000 impulses per second. After Harrison's assistant saw that a new proposal Desch made involving a resetting-type binary counter was identical to a system that the University of Chicago had already developed, Harrison asked Desch to visit that university. The laboratory received a second six-month contract, and during this period, the work was moved to NCR, where the best reliable speed of this counter progressed from about 400,000 counts per second to a reliable in-field speed, at the time of the report, of 1 million impulses per second.[19] Unknown to Desch and the laboratory, the counter was for the Manhattan Project. The laboratory's success gave it entry into the electronic research community that included MIT, the University of Chicago, RCA, General Electric, and Eastman Kodak.

This was the first of many contracts between NCR and the Office of Strategic Research and

Development (OSRD) and NDRC. At that time, Desch referred to "the pressure of NDRC work." Eventually, the Navy's Bureau of Ships Department became interested in a counter printer development for the OSRD, and that work was finished under a Navy contract.

> After the Bureau of Ships received the counter printer [June 1942] they began to show interest in acquiring our services for other developments, resulting within a few months in the termination of our work for the OSRD, Army Signal Corps and Army Ordnance and the application of all of our energies to the development of special highly secret navy equipment.[20]

Ultimately, the Navy would ask the NCR laboratory to develop and build a US version of the British Bombe. But first, the laboratory's successes and Desch's leadership made him a prime candidate to evaluate the design for a totally electronic deciphering device a group of MIT academicians created. While not an expert in cryptanalysis, he gave the opinion that the implementation of the design was not possible, primarily because of the large number of tubes necessary. Believing that the US version of the Bombe could be built using mechanical and electronic components and recognizing NCR's past accomplishments, the Navy moved ahead. "They took us over," Desch said in 1973.[21] Captain Ralph Meader took over as head of the NCML, housed in Building 26 on NCR's large campus. Desch, serving as research director, moved his laboratory and staff from Building 10 to this isolated building, conveniently located immediately next to railroad tracks—ideal for nighttime shipments of equipment. Surrounding Building 26 with armed soldiers and taking over NCR's summertime educational barracks (Sugar Camp) to house incoming WAVES, the Navy began to build the machines that would regain Allied control of the Atlantic Ocean.

But first Desch had to gain security clearance for a project with restrictions as great as or greater than the atomic bomb and proximity fuse programs. He was taken to Naval Intelligence headquarters in Washington, D.C., to be interrogated. The Navy had thoroughly investigated his background and was especially concerned about members of his family still in Germany. His mother, who had immigrated to the US in the 1890s, still had relatives there. Desch jokingly claimed that they had found relatives of whom he had never heard. After several days, the interrogation became a dreadful experience, with the officers trying, through insults and accusations, to break him. When Desch decided he had had enough—that he wanted out—they told him he was in, that he was cleared and should return to Dayton to begin the task that was now his assignment.

Lacking complete information on how the British devices worked and not having received the promised prototype, Desch's group had to complete its own design under tremendous pressure. After several false starts and redesigns, his group delivered the first US Bombes to the Navy in 1943. For the next two years, Desch and Mumma continued to improve the devices and deliver machines on a regular schedule to the Naval Communication Annex on Nebraska Avenue in Washington, D.C.

The secrecy surrounding the NCML extended into Desch's personal life. His home became a secure facility, and Meader became a permanent house guest. When not at home or in Building 26, Desch was always within sight of a Navy guard, though the Navy never officially acknowledged this watchman. Desch cheerfully recalled years later the wild-goose chases on which he would take the plainclothes drivers when he left NCR for home, leading them miles out of the way without a destination only to turn around and drive home. When he finally pulled into his driveway, the men who had followed him would pause nonchalantly in front of the house, watch him enter, and then drive away. The next morning, he might wave to the guards parked in their unmarked car waiting for him to leave, but they never acknowledged his greeting.

The Navy also used the Desch home, because it was secure, for house guests visiting the project. Since the house had only two bedrooms with Meader using the second bedroom, everyone from "admirals in the Navy to Lords of Parliament" slept on the living-room floor.[21] Pictures that Desch took show guests as varied as Capt. Wenger and a commodore from BP. Years later, Desch also mentioned that Turing was among those who "had to sleep on the floor." The Desch household was also a home away from home for the WAVES, whose visits were later described by not only Desch's wife but also his sister-in-law, brother-in-law, and their families.

An aunt and uncle living in Cleveland got a surprise weekend visit from the Desches and a WAVES softball team visiting Cleveland for a tournament. The group descended on them without warning, brought in their own food and drink, slept on the floor, and had a wonderful time.

As the work on the design of the Bombes came to fruition in early 1943, hundreds of

Further information

National Cash Register records, including laboratory notebooks and other research materials, have been transferred to the Montgomery County (Ohio) Historical Society. The society is currently cataloging the materials. For a summary of this material, see http://www.daytonhistory.org.

people began arriving at NCR. While the original laboratory staff consisted of 10 to 20 people, the complement grew to over 1,000 by 1944. Enlisted Navy personnel came as early as February 1943, followed by trainloads of WAVES in April. At its height, the laboratory included 100 officers and enlisted men, 600 WAVES, and a large civilian contingent.[21] Living at Sugar Camp, the WAVES marched to and from Building 26. None of these people, however, knew the purpose of the equipment they were building. Only a handful of NCR engineers and the Navy officers had full knowledge of the project.

Following the successful completion of the Bombes, Desch moved his efforts to applying the technology gained to building machines to tackle the Japanese codes. Using Bush's Comparator concept, Desch's group built an electronic code-breaking machine known as the Copperhead and a series of electronic analogs of the Japanese encryption machines. These machines (known as Vipers and Pythons) were steps on the road to building the electronic versions of the Bombes that had been proposed in 1942 and resulted in a machine named the Rattler, which was a significant engineering achievement. His group also continued work on German codes in response to special requests to build modifications to the Bombes by adding electronics and very sophisticated logic to produce sophisticated electronic machines known as Duenna and Bulldog.

Three years of intense war work left Desch drained. At the completion of the Navy contracts, the president of NCR, Stanley C. Allyn, no longer wished to pursue government work, so Meader joined Navy colleagues William Norris and Engstrom in the founding of Engineering Research Associates in Minneapolis, Minnesota. Desch remained in Dayton, seeking some restoration of his energies in continuing research on the use of gas-filled tubes in counter work. NCR moved its Electronics Laboratory from Building 26 to 20, and Desch worked alone, hoping to prove tubes more reliable than the semiconductors of which he was hearing news in correspondence with fellow researchers. However, his work did not produce any clear results, and NCR asked him in 1952 to cease operations of the laboratory and become supervisor of electrical engineering. At this point, the elaborate tube-blowing laboratory on the second floor of Building 20 was locked and left undisturbed until 1972, when the building was scheduled for demolition, hence the name "The Lost Lab."

In 1946, Desch filed an application for a patent on an electronic calculator he had designed with Mumma as part of an application initiated in March 1940. This brought about three interferences filed in the US Patent Office between their application and one by Arthur Dickinson of IBM. Eventually, these were settled in favor of Desch, in part because he proved Dickinson's design was unworkable. This gave Desch and Mumma the first patent on a modern digital computer.[22]

His career after this point was noteworthy, and he was especially proud in later years of his work with Mumma in the development of the NCR 304, the first completely solid-state computer. It was, of course, an immense relief to have projects that he could talk about openly once again.

In the next 20 years, his contracts included the NEAM-class computer, the Post-Tronic-class calculator, check-sorting equipment, magnetic character printing equipment, and computer peripherals (including magnetic tape units, high-speed printers, and numerous types of equipment for the government) while directing the Military Division's command and control aircraft equipment, thermal printers (including equipment on the Apollo spaceflights), radio rescue beacons for downed pilots, Facer–Canceller machines, zip-code readers, and parcel post routing systems for the US Post Office.

Desch retired from NCR in January 1972, shortly after the death of his wife Dorothy. Much to the frustration of his daughter, he discouraged historians from investigating his early electronics work, fearing it would lead to investigations of his wartime activities. He expressed sizable indignation when the British permitted publication of *The Ultra Secret*.[1] The safest topics in his home were his grandsons.

A source of pride for him, despite the fact he could not discuss it, was the Medal of Merit he received from President Harry Truman in 1947. It recognized "such civilians of the nations prosecuting the war ... as have distinguished themselves by exceptionally meritorious conduct in the performance of outstanding services in the furtherance of the prosecution of the war." He died at the age of 80, on 3 August 1987.

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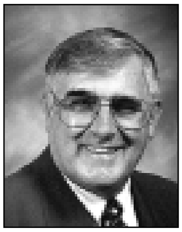

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Deborah Anderson, born after World War II and the only child of Joseph and Dorothy Desch, received a BA in 1971 from the University of Dayton. She pursued graduate work at Ohio State in medieval and renaissance literature but fortunately had sufficient scientific background to realize the significance of documents and correspondence she found in her father's home after 1987. Unfortunately, that was too late to ask him the many questions that those documents raised. She initiated the 1995 Reunion of the Naval Computing Machine Laboratory in Dayton, Ohio.

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