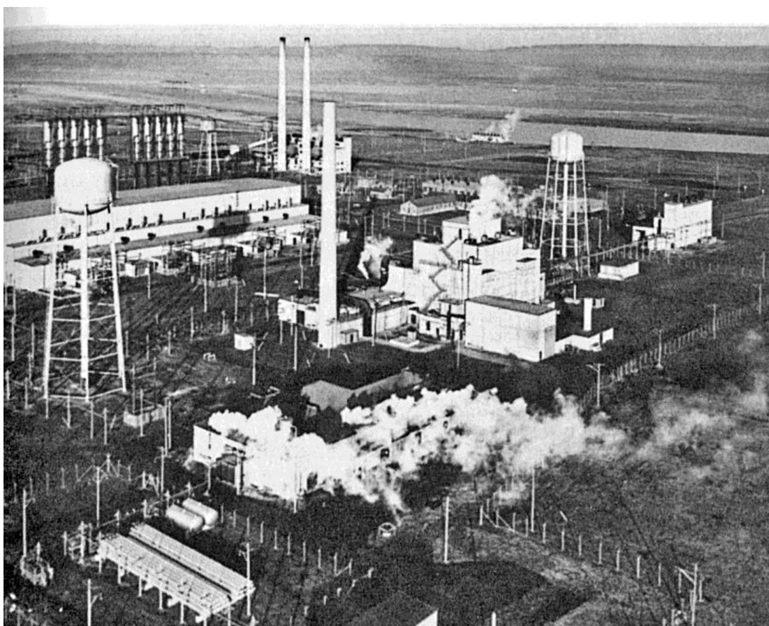
B REACTOR MUSEUM ASSOCIATION

Lost In The Telling

The DuPont Company
The Forgotten Producers of Plutonium



Assembled by the "DuPont Story" Committee of the B Reactor Museum Association
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FOREWORD

Like the world's tidal waters, the study of our national story sometimes leads us into historical eddies, rich in human interest content, that have been bypassed by the waves of words of the larger accounting of events.

Such is the case of the historical accounts of the Manhattan Project which tend to emphasize the triumphs of physicists, while engineering accomplishments, which were particularly important at the Hanford Site, have been brushed over and receive less recognition.

The scientific possibility of devising a weapon based on using the energy within the nucleus of the atom was known by physicists in both the United States and Germany before World War II began. After the start of hostilities, these physicists were directed by their respective governments to begin development of atomic bombs. The success of the American program, compared with the German program, was due largely to the extensive involvement in the U.S. Manhattan Project of large and experienced engineering firms whose staff worked with the physicists. The result was the successful production of weapons materials, in an amazingly short time considering the complexity of the program, which helped end World War II.

One view which effectively explains these two markedly different historical assessments of accomplishments, at least for Hanford, is noted in the literature with this quote. - ***"To my way of thinking it was one of the greatest interdisciplinary efforts ever mounted. . . but the physicists always want to pull the covers way over to their side of the bed.".****

As the country moves toward memorializing the Manhattan Project with a National Historical Park, the B Reactor Museum Association (BRMA) advocates that the history of the Hanford Site give appropriate credit to both the DuPont Company in its turnkey production of plutonium at Hanford, and to the physicists with whom they worked. Each complemented the other and, working together in very trying circumstances, ensured success of a program vital to the war effort.

The following expands the Hanford story with information about the contribution of the DuPont Company, much of which has heretofore been lost in the telling of the story of the Manhattan Project.

The BRMA "DuPont Story" Committee
Richard Romanelli
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* Interview in 1983 with Crawford Greenewalt, President of DuPont and former technical director of the DuPont work on the Manhattan Project at Hanford. Referenced in the book, ***Nylon and Bombs*** by P.A. Ndiaye. p 153

PREFACE

from

Ndiaye, P.A. ***Nylon and Bombs*** (Translated by Elborg Forster)
Johns Hopkins University Press, Baltimore 2007, 141-142

But what, after fifty years of basic research, made it possible to move from the first experimental reactor built in December 1942 to the bombs that exploded above Japanese cities less than 3 years later? What accounts for the success in getting tens of thousands of people to work together, of stamping giant factories out of the [desolate] desert in a few months, of mastering [totally] new technologies in rapid order?

The Manhattan Project was not only a matter of cutting-edge research in nuclear physics. It posed a [new] set of technical problems. It was an industrial program, and the necessary know-how did not appear out of nothing. It had been forged over a half-century of learning techniques of mass production in the high-pressure chemical industry, particularly at DuPont. . . .

My objective here is very different from writing a new general history of the Manhattan project. What I have set out to analyze is the manner in which DuPont’s engineers were able to impose their way of doing things and their organization on their military and scientific partners. This will offer a new prospective on the project, one that is not meant to invalidate the existing ones but to bring out hitherto neglected dimensions, . . . considering situations involving joint systems of science and large-scale technology operating under the aegis of the government. The difficulty is that [heretofore in historical accounts] the industrialists are placed in the background, as if they had been no more than secondary players in the service of the commissioning agency. As we shall see, [with DuPont] things went very differently.

Lost in the Telling

Perhaps you have previously seen a copy of the following account of a piece of history – a letter from the president of the Kiwanis Club of Pasco, WA, to the president of DuPont shortly after release of the news of the dropping of the atomic bombs and the role in that top-secret project of facilities at the Hanford Site in Washington State.[1] The news reported that the plutonium for the first atomic weapon test device and for the atomic bomb dropped on Nagasaki, Japan, on August 9, 1945, had been made at Hanford. The Japanese surrendered five days later, ending WWII. The news item had included a note of whimsy that DuPont had not received the entire contract-specified one dollar profit because a government accountant noted that the construction job had taken only two years, rather than the anticipated three.

Mr. Walter S. Carpenter, Jr., President, *August 11, 1945*
E. I. DuPont de Nemours Company,
Wilmington, Delaware.

Dear Mr. Carpenter:

At the last regular meeting of the Pasco Kiwanis Club a resolution was passed which reads as follows:

"An article in a local newspaper states that the DuPont Company received only One Dollar profit from the operations at the Hanford plant and that an expense item of thirty-two cents was not allowed by an accountant, leaving a balance of sixty-eight cents. Thirty-two members of this club are contributing one cent each to make up the difference and also placing their signatures to this letter."

We are very proud to be so closely situated to the Hanford project, and all of us feel very sincerely that we have had a part in this magnificent enterprise. We also hope that the Lord will see fit to direct the future efforts and achievements of this product into the right channel for the good of all mankind. (signed by Mel Swanson, president of the club together with 32 others).

Do you wonder what had caused the letter writer's pride and why so little of its source has been reflected in the recounting of accomplishments at Hanford in the numerous compilations of the history of the Manhattan Project?

Participants in the current local tours of B Reactor, offered to familiarize people with the role played by Hanford in the development of the atomic bomb, hear that the Army Corps of Engineers' organizational foresight, project scheduling and management skills, attention to construction details, and initiative resulted in the phenomenal Hanford success. As for DuPont, what was their role? Were they – *just a contractor?* The following information will help answer this question.

Ralph Waldo Emerson is quoted as saying "There is properly no history, only biography"[2]. Several writers have on occasion rearranged his thoughts into "All history is just biography"

One outgrowth of this idea is that the story of history is much more interesting and readable if it is built around the thoughts, words and actions of individuals, the more colorful the better. This approach is reinforced if the primary sources for documenting the stories are the writings of these same featured individuals. It would seem this approach is exemplified in the telling of the Manhattan Project. Many of the accounts accentuate the role of individual physicists and other scientists.

As a result, the history of the Manhattan Project as we have it today is primarily one of scientific breakthroughs, while the ability to translate that knowledge into the timely production of uniquely new materials and structures has lesser significance.

The Genesis of the Hanford Story

The United States became a combatant in World War II one day after the surprise Japanese military attack on Pearl Harbor, Hawaii, on December 7, 1941. Its major allies were Great Britain and the Soviet Union, and its enemies were Germany, Italy, and Japan. A massive national military effort, with the objective of ending the war as soon as possible, soon was under way throughout the United States.

One part of this effort involved developing ways to use scientific discoveries made earlier in the 20th Century to produce an entirely new class of weapons. The famous physicist Albert Einstein, at the request of fellow physicist Leo Szilard, had, in August 1939, sent a letter to U.S. President Franklin Roosevelt informing him that

> **"..it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.**
>
> **This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed."** [3]

By October of 1939, German aggression in Europe had increased to the point that President Roosevelt decided to create a Uranium Commission composed of scientists and military officers to coordinate scientific research in this area, with military objectives. This commission shortly became the Office of Scientific Research and Development (OSRD). Research coordinated by OSRD showed by 1941 that a potential nuclear weapon could be made using either the rare isotope of uranium, U^{235}, or the newly-created element plutonium. The OSRD decided to pursue the production of these so-called fissile materials by three different methods simultaneously; two of them were focused on isotope separation of U^{235} and the third, the production of plutonium. It was apparent that doing so would involve an immense construction effort, and Vannevar Bush, president of the OSRD, and James Conant, director of the National Defense Research Committee, (NDRC) recommended that the U.S. Army Corps of Engineers oversee the large-scale construction building projects. The Manhattan Engineer District was established for this purpose, and by autumn of 1942 it was headed by Brigadier General Leslie Groves.

The production of U^{235} by either of the selected approaches involved a very energy-intensive process of isotope separation which was relatively well understood on a laboratory scale but difficult to accomplish on a production scale. Very simply stated, both approaches involved uranium converted to a gaseous compound and subjected to a physical operation that affected the two isotopes differently. In the gaseous diffusion process the gas was pumped through a long series of porous filters, during which atoms of the lighter isotope U^{235} moved slightly faster through the filter than the much more prevalent U^{238} atoms. In electromagnetic separation, gaseous uranium was ionized, accelerated by an electric field, and then subjected to a strong magnetic field. The two isotopes have slightly different masses, and when processed through the magnetic field many, many times, the two uranium isotopes slowly concentrated into either groups of U^{235} or U^{238} atoms.

In contrast, plutonium can be produced by placing purified metallic uranium in a graphite reactor and bombarding it with low-energy neutrons generated by the uranium's natural radioactivity and the reactor's design. The neutrons interact with the uranium, causing some of its atoms to fission, or split, into lighter-weight elements, giving off tremendous amounts of energy but also two and sometimes three neutrons per fission. Under the right conditions of geometry and the presence of uranium and a moderator (graphite in the Hanford reactors), one can achieve a controlled chain reaction and create atoms of plutonium inside the uranium fuel. The task is then to separate the small amount of plutonium (about one part in 4000) from the highly radioactive irradiated uranium fuel and purify it to produce the raw material for an atomic bomb.

In summary, the production of plutonium avoided the need of isotope separation but involved the production and separation of an entirely new element. Neither of these steps had ever been done outside of the laboratory and plutonium had heretofore existed only in microgram amounts with little-known chemical properties and hazards

General Groves was a construction expert and he set about assessing which large U.S. construction firms had the capabilities needed to design and oversee construction of the large and complex facilities. His assessments continued during the autumn of 1942. For each of the two U^{235} isotope separation processes, he contracted with groups of firms to undertake the design, construction and operation of each of the two different approaches. For plutonium production, the OSRD had set up a government research organization, the Metallurgical Laboratory, to carry on the prerequisite research into all phases of the task of the formation and separation of this totally new material. But it was Groves' assessment that the task of taking that information generated by the Metallurgical Lab and designing, building, and operating a production facility could only be done through a turnkey contract with the DuPont Company.[4]

The corporate characteristics that led to that assessment included DuPont's practice of designing and building their own plants (i.e. with their own engineering department), their reputation for rapid insertion of new plants into the market, their heavy emphasis on corporate research in determining their product line, and the corporate safety culture, fostered by their depth of experience in producing explosives and munitions.[5]

On October 30, 1942, Willis Harrington, vice president at DuPont and a member of the company's Executive Committee, received a telephone call from General Groves asking him to come to see him "to discuss a matter of great military importance to the United States." The day after this telephone call, Harrington and Charles Stine, another vice president of DuPont, went to Washington to meet with Groves and Conant. The DuPont executives received a detailed briefing about the project, the status of the work by the Metallurgical Lab, the uncertainties involved, and the role envisioned for DuPont. Harrington and Stine responded that they would report on the matter to DuPont's Executive Committee.

DuPont's Board of Directors was hesitant to take on the project partly because it was such a huge commitment, but also because of the potential for a repeat of the difficulties the corporation had following WWI; it was accused of making huge profits from munitions and branded "merchants of death". DuPont requested, and got, a letter from President Roosevelt[6] requesting them to take on the project. The company refused any profits and agreed to sign the contract only on the condition that the company would be reimbursed for its expenses and receive one symbolic dollar. They also stipulated that within six months following cessation of hostilities they wished to be relieved of their contract. At that time, they had no corporate interest in being in the nuclear business. They also requested that an industrial production-oriented committee review the status of the other two processes for fissile fuel production, namely the isotope separation of U^{235} via gaseous diffusion and electromagnetic separation. The Lewis Committee, headed up by Warren Lewis, head of the department of chemical engineering at MIT and comprised of E.V.Murphree, director of research at Standard Oil Development Corp. plus three DuPont staff, met with Harold Urey and staff at Columbia University working on gaseous diffusion, Ernest Lawrence at the university of California working on electromagnetic separation, as well as Glen Seaborg working on plutonium. DuPont's caution and apparent skepticism of the chance of eventual success prompted Conant, head of the Metallurgical Lab, to tell Groves that DuPont's extremely cautious responses to many aspects of the project led him to feel they should talk to General Electric or Westinghouse about taking on the job – he felt they would be more optimistic in their outlook. Groves responded that it was his opinion that DuPont was the only organization that could do the job.

The period of negotiations and discussions ended on December 21, 1942, when a contract was signed between the U.S. Army and DuPont, stipulating that DuPont was in charge of designing, building and operating the future plutonium plant.[8] Crawford Greenewalt, who had been a student of Lewis while at MIT and a chemical engineer at DuPont, became the technical director of the DuPont effort. The corporation also was responsible for designing and building in Oak Ridge, Tennessee, a pilot plant for the plutonium production process, to be operated by the Metallurgical Lab scientists, in order to produce gram quantities of plutonium for studies of ways to purify the material and identify critical characteristics needed for designing the atomic bomb.

As an addendum to that contract, at a somewhat later date a "Memorandum Covering the Technical Basis for Work Under Contract W-7412 eng-1 between the United States of America and the E.I. du Pont de Nemours & Company" was drawn up and signed by both parties and the University of Chicago (the Metallurgical Laboratory) which spelled out the total approach for producing plutonium, the dearth of detailed information on the process, and the perceived chances of success[9].

Reading this memorandum provides an understanding of DuPont's reluctance to take on the task and an appreciation for the magnitude of the accomplishment of completing it successfully in so short a time.

A week before the contract signing, University of Chicago representatives had joined Corps of Engineers staff to meet with DuPont at their headquarters to agree with them on the criteria for the location of the plutonium production facilities[10]. A site search was undertaken in the western United States in late December 1942. The Hanford, Washington, site was selected in mid-January 1943 after a joint visit there by DuPont representatives A. Hall and Gilbert Church and a military staff member.

Construction of the camp out in the desert to house the required 45,000 workers, where only a small town of less than 470 people had lived, began almost immediately, together with the preparation of the ancillary facilities, roads, railroads and support buildings.

Missing from the Hanford Story

The list of reasons for the success of the Manhattan Project, including Hanford's success, legitimately starts with the global war situation. It resulted in

- the fear for national survival and its impact on the national commitment to the task, and the sense of urgency,

•organization of the total Manhattan Project under a single point of control with the highest priority, an open check book, and an iron-fisted boss,

• and a host of work-related procedures which minimized time–consuming activities at the expense of cost effectiveness, normal labor practices, and sequential scheduling of design and construction, but at an increased risk of costly do-overs and burn-out of personnel[11].

The first two are applicable for all phases of the Manhattan Project; the third tends to be more significant in the production phases of the project.

The rather obscure book, ***Management of the Hanford Engineering Works in World War II*** by Harry Thayer, provides a good discussion of an expanded list of the project attributes noted above that played a key role in the Manhattan Project success at Hanford[12]. It also discusses in some detail the construction practices used by DuPont which were of particular importance to that success.

However, less recognition has been given to the corporate capabilities and culture of the DuPont Company that were absolutely essential to the success of the project. These are discussed in a more recent book, ***Nylon and Bombs***, by the French professor of history Pap A. Ndiaye. The book has a lengthy chapter, *The Forgotten Engineers of the Bomb*[13].

The following information, based on these two accounts, is presented in sections introduced as questions concerning DuPont's unique contributions, and then amplified upon.

The selection of DuPont by General Groves to take on the plutonium production job was largely based on his assessment of the capabilities of the company with respect to in-house design and construction of plants, company research and the rapid deployment of research results into process integration, construction and operation, and a corporate culture emphasizing safety. How critical to the success of the Hanford project did these corporate characteristics prove to be?

The close integration of the design, construction and operation functions was absolutely essential to the success of the extremely compressed schedule achieved by the project. The ability of the construction and operations staff to be a party to the design assured both the successful integration of the uranium irradiation and subsequent plutonium separation, despite the paucity of detail about either operation, and the relative facility of startup of all phases. As will be further amplified in subsequent talking points, so little was understood about the nature of the intermediate products of the operation, that it was important for the operations staff to interject their need for operating conservatism throughout the design process in such areas (just as examples) as radiation protection and backup systems required in the event of process malfunction or power failures.

DuPont's practice of moving projects rapidly from research to production contributed to the relatively "quick study" of their staff to include the principals of nuclear physics and chemistry into their understanding of the design requirements and limitations inherent in the production operations of this completely new environment. This new environment involved at least four aspects they had never faced before; namely, (1) the "care and feeding" of neutrons, (2) heat removal requirements that were unprecedented and involved multiple back-up systems because of the dire consequences should the heat removal be compromised in any way[14], (3) the need for design of a separation process that had to be remotely operated and maintained, due to the high levels of radioactivity, and (4) protection of personnel and the environment from unknown levels of radiation. The total job had to be accomplished in a location that was far removed from suppliers of any sort (and also any place for the 45,000 workers to live), done in great secrecy (applied even to those performing the work) and done in great haste. The remarkable aspect of the whole situation is – it worked!

The ability to invoke the safety culture of the corporation is reflected in the very low fatalities (18 workers) from construction activities during DuPont's contract on the Manhattan Project. The rate of major injuries was 1 per 206,000 man hours, a factor of 2.64 time better than the national average for general construction industry[15].

Although DuPont was indeed very skeptical and cautious about accepting the responsibility of a total turnkey contract to deliver plutonium, having once become committed they accepted the project totally and committed their best staff to see it through. The president, Walter Carpenter, made sure the senior staff accepted that they held the total future of the company in their hands, that a poor performance in any respect would have very serious impact on the reputation of the company, and that anything they needed by way of support from the company would be delivered forthwith[16]! It was by far the largest project the company had ever undertaken.

But were the circumstance and results of the DuPont contract at Hanford so very different from the design – construct –operate contracts for the other two programs for fissile material production that brought success to the Manhattan Project at Oak Ridge? What sets DuPont apart from those firms and suggests that organization be particularly noted in the narratives of the National Park?

The talking points suggested here certainly do not imply that DuPont be recognized at the expense of recognition for the engineering effort at Oak Ridge. Indeed, one of the points that is offered here is that the total engineering accomplishments within the Manhattan Project have been undervalued, and that the side–by–side evaluation of the Manhattan Project and the failed German effort might conclude that the greater difference between the two lay in the engineering success of the Manhattan Project to obtain the raw materials for the bomb.

Having said that, the point is also made that there were very significant differences between the turnkey contract with DuPont at Hanford and the various contingent contracts for design, construction and operation that were used at Oak Ridge.

For the gaseous diffusion program, the concept had originated in the SAM laboratory at Columbia University; the engineering research and plant design was the responsibility of the Kellex Corp. Construction was the responsibility of J.A. Jones, and Union Carbide was the operating contractor[17].

For the electromagnetic separation program, the concept had originated in the Radiation Laboratory of the University of California. For the production effort, the design and construction of the buildings at Oak Ridge was done by the Stone and Webster Corp. while the extensive equipment contracts were with General Electric for the power supplies, Allis-Chalmers for the magnets, and Westinghouse for the process bins. Tennessee Eastman was the operating contractor. During the war, only the electromagnetic process was in a position to provide weapons-grade U^{235}, although for the final push to provide enough material for a single U^{235} bomb, both the gaseous diffusion and a third process, thermal diffusion, provided low enriched uranium as feed to the electromagnetic plant[18].

Thus, at Oak Ridge the situation was that of an industrial complex involving a considerable number of contractors. In contrast, the contracting situation at Hanford gave DuPont sole responsibility that started at the initial site selection, continued on to the erection and running of the construction camp which housed and fed up to 45,000 workers in a desert-isolated location, the designing of the facilities at their Wilmington, Delaware, headquarters (based on nuclear parameters provided by the Metallurgical Lab at the University of Chicago), building and managing the town of Richland for the operations personnel, operating the Hanford complex and delivering plutonium on schedule for a test device on July 16, 1945, and the Nagasaki bomb on August 9, 1945. When DuPont was initially contacted by General Groves, the general and Compton, who headed up the Metallurgical Lab, already felt that the scope of the task would make it necessary for DuPont to take over the plutonium production program in its entirety, and their opinion was endorsed by Bush and Conant who headed up the government oversight groups – the OSRD and the NDRC[19]. In addition DuPont designed and built the ”pilot plant” test reactor and separation lab at Oak Ridge to produce the first gram quantities of plutonium. Indicative of the unique nature of the turnkey contract with DuPont is the quote from Hewlett & Anderson, History of the Atomic energy Commission.

> *"As for operating policy, du Pont had from the first insisted upon complete control. In the months of negotiations with Groves, the company had refused to consider any sort of joint venture [with the Metallurgical Laboratory]. This approach appealed to both Groves and Compton. Du Pont's firm hand at the helm not only assured rapid progress toward the bomb but also relieved the two leaders from the many headaches of co-ordination and administration which plagued most joint enterprises between university research groups and industry[in other portions of the Manhattan Project]. Groves and Compton wanted*

action and they got it"[20].

Thus DuPont was the lynch pin of the plutonium program for the nation, and the corporation did not let the nation down.

> ***To what extent did DuPont staff contribute to the conceptual designs of Hanford facilities developed by the Metallurgical Lab organization? How detailed were the specifications DuPont received for these facilities (i,e. how much of Hanford was specifically of DuPont design vis-à-vis by the Met. Lab)?***

The first part of the response will deal with the Hanford reactors and the next part with the separation facilities.

Hanford Reactors

DuPont had no background in nuclear physics and deferred completely to the Chicago physicists in so far as the nuclear parameters of both the Oak Ridge pilot plant and the Hanford reactors. Eugene Wigner, a Hungarian physicist who was one of the original proponents for the Manhattan Project, is often credited as being the "designer" of the Hanford piles because he championed cooling the piles not with helium, as originally proposed by the co-workers of Enrico Fermi, but by water. Alvin Weinberg, one of the co-authors of Wigner's report, has stated

> *". . . the Hanford design [effort at the Metallurgical Labs] culminated in a report CE-407 titled* ***Preliminary Process Design of Liquid Cooled Power Plant Producing 500 MW*** *dated January 9, 1943. It was probably the second-most important report of the Manhattan Project, the first being the report on the first chain reaction."*[21]

Miles Leverett, another of the co-authors of that report, has expressed quite a different opinion. His view was that the Chicago physicists had written that report "not because they thought it was inherently better [to have the reactors water-cooled rather than helium cooled] but to have a second string to the bow", and that the final decision was made by DuPont after they evaluated both approaches.[22] In any event the Hanford reactors have the essential nuclear parameters of the CE-407 report, i.e. the diameter of the fuel rods, lattice configuration within the graphite moderator, number and dimensions of the process tubes, and water coolant dimensions.

But in most other respects of the detailed mechanical/civil engineering design of the Hanford reactors there is little similarity to the CE-407 report. The preliminary design included two possible orientations of the reactor core, either vertical or horizontal. The Hanford reactors are oriented horizontally. Looking back 73 years, one can imagine many of the design changes were to better shield the reactor, integrate the reactor operation with the subsequent handling of the irradiated fuel elements for reprocessing, and for better operability and greater conservatism in the design.

In the beginning, the relationship between the physicists at the Chicago Metallurgical Lab and DuPont's engineers included a considerable amount of resentment[23]. This was largely because DuPont was brought in to be "in charge of" the plutonium production facility, i.e. designing, building and operating, not simply as an A&E/Constructor. The two organizations sparred over control of the program. There also was a clash of cultures. They spoke different languages. The physicists either put a great deal of faith in the results (precision) of their calculations, wherever they could develop the mathematical model of the situation, or they felt at liberty to "build it and see if it works." Enrico Fermi, when he chafed under DuPont's insistence on the Met Lab's approval of all construction drawings, expressed his view on how the project should have proceeded with the construction of the piles,

"*What you should do is build a pile just as quickly as you can, cut corners, do anything possible to get it done quickly. Then you will run it, and it won't work. Then you find out why it doesn't work and you build another one that does.*[24]"

In contrast, although the DuPont engineers were in the forefront of the developing trend to understand many aspects of their discipline in terms of mathematical models (e.g. the so-called transport phenomena of heat transfer and fluid flow), they realized those mathematical models contained simplifying assumptions and hence the results were often approximate and conservatism should be included when using them for design to accommodate unforeseen factors. Furthermore, the concept of "build one and see if it works" was not part of their culture. To get a working reactor in the shortest possible time, the design had to be the best known representation of the final facility and "frozen" relatively early in the process.

For DuPont to take the preliminary design CE-407 and accept just the nuclear parameters of the design but not the total mechanical design did not set well with a number of the authors of that report. Quoting again from the Hewlett and Anderson, History of the Atomic Energy Commission,

"Young, Ohlinger, and Weinberg enthusiastically joined Wigner in completing the basic design of the water-cooled pile. The favorable reception of their report in Wilmington was encouraging, but in the following weeks Greenewalt made no move to invite Wigner or his associates to join the du Pont design group. Although Greenewalt consulted Chicago on isolated theoretical problems, Wigner realized that du Pont had no intention of giving the Metallurgical Laboratory a free hand in designing the Oak Ridge or Hanford piles."[25]

"Whether the Chicago scientists liked it or not, the Metallurgical Laboratory had become a vital, but distinctly subordinate affiliate of the DuPont organization. More than any other event, that shift in authority engendered the undertones of discontent which pervaded the laboratory until the end of the war. . . . . In part, it was the realization that the exciting quest for the atomic weapon had moved to Oak Ridge, Hanford, and Los Alamos, leaving

the laboratory with little direct part in the war effort"[26].

This was a contributing element in the "revolt" of a number of them in mid-summer 1943[27]. They wrote a letter to Eleanor Roosevelt and contacted Bernard Baruch, a close friend of President Roosevelt, claiming DuPont was trying to sabotage the whole project. Eugene Wigner, quoted forty years later in S.L Sanger's book, ***Working on the Bomb***, retained much of his resentment for being "ignored" and claims the reactors could have been built much faster if DuPont had followed his design[28]

Major changes were made in the neutron shielding of the reactor, the materials handling (arrangements of charging and discharging uranium fuel to and from the reactor), cooling water treatment, and backup systems. Several aspects of that design would have had serious consequences had not DuPont's eventual design been built – a design that was essentially repeated in a total of eight production reactors (five of them built after DuPont terminated their Hanford contract) which provided the majority of fissile material for the nation's nuclear weapons arsenal for most of the Cold War. This is in contrast to a rather "minimalist" design in the CE-407 report focused on the immediate projected need for the war-time situation – as evidenced by the statement that the designers felt reasonably confident that "the estimated pile lifetime based on available corrosion tests is considerably more than 100 days even without exchanging all central [fuel] rods."[29] Throughout the DuPont design period, during which the physicists had to sign-off on each of the DuPont drawings before they were approved for construction, they frequently complained that DuPont was too concerned with questions of safety and conservative design. Incidentally, Wigner had also proposed that the reactors be built at the mouth of the Potomac River where it flows into Chesapeake Bay.

The most publicized change introduced by DuPont was the augmenting of the total number of process tubes from about 1500 tubes to 2004 by "filling in the corners" of the cylindrical arrangement of tubes within the reactor core.[30] The physicists' original calculations of the reactivity of the core had not included the effect of xenon gas, which is a strong neutron absorber, formed as a daughter of one of the products of the fission of U^{235}. During construction, John Wheeler, one of the physicists on the DuPont staff, had become concerned about the possibilities of impurities incorporated in the construction of the reactor cutting into the reactivity of the core. He advised George Graves, Crawford Greenewalt's assistant director, that DuPont should take action to offset this "growing encroachment" on the reactivity of the core and increase the margin of safety in the design by adding process tubes to the corners of the reactor. The Chicago physicists objected strenuously because of the delay and extra uranium involved in the change (and because it deviated from their "elegant" design). They complained that it was yet another example of the tendency for the production organization to become overly concerned with safety and reliability of the plant. When the startup problem of xenon poisoning manifested itself, the extra reactivity made available by adding uranium to those extra process tubes was just enough to override the difficulty and make it possible for the reactor to eventually operate at full power.

The physicists eventually passed off the design change as "more from luck than foresight," but in actuality it was emblematic of the difference in mindset between that of the experimenter who has observed an event once or twice in the laboratory and is sure he can reproduce it precisely time and time again to produce a product, having little or no idea of what is involved in bringing a new concept into commercial production; and the mindset of the engineer who, charged to make that happen and wondering what other things he is not aware of could go wrong as the result of tremendously scaling up the task, seeks ways to build a prudent amount of conservatism into the design.

In the case of the early Hanford reactors, without that conservatism, the delivery of plutonium would have been set back by at least ten months and the end of the war considerably delayed[31]. Would it have been historically noted as an engineering blunder, or more appropriately noted as an example of naive overconfidence on the part of the physicists?

Separation Facilities

DuPont had initially been approached to take on just the design and construction of the separation facilities. But this became an integral part of their total contract --to build and operate the plutonium production part of the Manhattan Project. Still it was a very new experience – the first time to design a chemical plant in which the processing had to be operated and maintained totally remotely. Moreover, during much of the design phase the process for separation/purification of the plutonium had not been set and almost nothing was known about the physical aspects of the compounds and very little was known about their chemical aspects, since the material had been obtained only in microgram quantities. Thus the required equipment and instrumentation was understood only on a very rudimentary level[32]. Yet, because of DuPont's unique capabilities and total contractual involvement, they were able to accommodate this situation on a very tight schedule.

DuPont devised an ingenious design of a process cell, essentially a remote chemical-laboratory "kitchen", which included great flexibility of equipment that could be installed using crane-operated impact wrenches, operated remotely, and viewed by the operator through a periscope while shielded by a thick concrete wall[33]. A series of different standard cell designs were developed having a variety of process-line, power, and instrument outlets on the walls of the cells. The walls were lined with welded stainless-steel sheets over the thick concrete. A heavy concrete covering plug isolated the highly radioactive equipment within the cells. Specially designed jumpers provided connection of these process, power, and instrument lines to whatever pieces of equipment were needed to carry out the selected chemical operations. All equipment and jumpers had to be designed with a lifting rig that would maintain the hanging equipment in just the right orientation to allow it to be lifted or lowered into the cell and mate with the desired jumper or wall connection.

Perhaps the most ingenious aspect of the design and construction of these remote facilities was DuPont's practice of first mocking-up each unique cell design in their Wilmington shop, but then, rather than using craftsmen to install the individual cells in the huge 800 foot Hanford concrete canyon separations facilities, they had the operations and maintenance staff do the installation – REMOTELY[34]. In so doing, they assured the operability and maintainability of the integrated process line from startup. The scientists at the Metallurgical Lab organization were astounded at the ease with which operations startup was accomplished.

Did DuPont bring to the project any distinctly new approach to the management and scheduling of large projects that had a critical impact on the efficiency of their operations?

Yes, they did. DuPont had developed a system of laying out the total scope of a complex program into discreet self-contained jobs for which could be identified the required input of information, materials, circumstances etc. and the resultant products of information, materials etc., to be used by subsequent jobs within the program[35]. These were jobs for which reliable estimates of time duration and manpower requirements could be developed, with each of these jobs arranged into a web of activities such that each job was placed in the appropriate sequence of inputs and products and none was arranged to occur before the required inputs had been achieved from prior jobs. This web showed the required amount of time to go from start to finish by each of the branches of the web. The route through the web that showed the longest time requirement was identified as the critical path of the project, i.e. the series of tasks that had to be completed in sequence that required the longest time. Thus, all other sequences of required tasks could be done in a shorter period of time. The critical path defined the minimum time required to complete the project, provided manpower was not an issue in the accomplishment of all the other tasks not on the critical path. A similar assessment of the manpower and type of crafts needed in each job, and the period during which all the tasks had to be performed, would indicate the staffing needed of each particular type to maintain the critical path, or possibly identify another set of tasks which could become the critical path. At frequent intervals, this chart would be updated to reflect actual times required for accomplished tasks and new estimates for forthcoming tasks. It also identified those parts of the project which would most benefit the overall project from close control and efforts to improve the rate of progress. In a real sense, it was a “living plan”.

DuPont had first developed this scheme, which was called the Critical Path Method (CPM) system, in 1940 a couple of years before being asked to take on the plutonium production job. It remained an unshared company treasure for more than 15 years before its disclosure in the late 1950s. At that time it was shared with the U.S. Navy where it was refined and called the PERT (Program Evaluation and Review Technique) and claimed as a U.S. Navy development[36].

Several of the chroniclers of the Manhattan project have noted that work at Hanford was slow in getting under way. Perhaps what they overlooked was that DuPont did indeed start from ground zero; first picking the site, where essentially nothing existed from which to start any sort of industrial project, and building that location into a construction project employing between 39,500 and 45,000 workers (depending on the source one uses) and employing approximately 120,000 over the course of the total program.

Although Compton and staff at the Metallurgical Lab had estimated in December of 1942 that a bomb could be ready in 1944 (roughly 24 months) and that production could then be at the rate of a bomb per month in 1945, it was an estimate for which Greenewalt could find no basis[37] – other than hope. DuPont, at that same time, estimated that it would take to the middle of 1945[38] (roughly 30 months) before a bomb could be ready and that production would be about as predicted by Conant. The DuPont contract in December 1942 called for a construction phase of 36 months. However, their internal schedule for constructing B reactor (the 105B building) indicated a (Critical Path Method - CPM) scheduled time of 43 week; they were only 2 weeks behind meeting that schedule[39].

Thayer, in his book on the management of Hanford during the war, analyzed the "rational" war-time scheduling of projects[40] which followed the prudent sequencing of scientific conceptual design, semi-works study of the production scheme, design, construction and operations, ***each step being of the duration experienced on the plutonium project,*** and concluded the first bomb would have reasonably been expected to be available in mid-1948 – three years later. Without the ability of keeping on top of the complex tasks at Hanford, through such capabilities as the CPM method, the compression of the schedule that combined design, construction and operation under one organization would probably have been unmanageable and the Hanford success impossible. In all probability, the ending of the war would have been markedly different.

Were there any aspects to DuPont's methods of managing the day-to-day design and construction activities that had a unique impact on the efficiency of their operations?

DuPont's underlying approach to the management of design and construction procedures were not particularly unusual except to the extent that, in the eyes of the contract manager Col. Matthias, their policy was not to spare good design or total and constant attention to detail in order to save time. Quoting the same source, "their drawings were very complete with drawn out details leaving nothing to uncertainty, and checked thoroughly by a separate organization."[41] (This contrasts with Wigner's petulant remark 40 years later, recalling the Metallurgical Lab's review and approval of all DuPont drawings – "many[of their drawing] had serious failings. They did not understand why we designed [the reactor] in a certain way")[42].

Where DuPont construction methods were unique was in the interface between the engineering and the construction organization, i.e. the field management. Thayer, in his discussion of the management of the Hanford project, wrote:

Hanford's $4 billion [1995 dollars] processing plant, comprised of totally unprecedented components, was brought in a year ahead of schedule, with a nearly flawless startup and with cost overrun limited to 11%. How did DuPont do this? The explanation encompassed:

• A massive and time-tested field organization [~1200 engineering-related positions],

staffed with men long-experienced in process-plant construction who had worked amicably together for years
*• Scheduling by the DuPont-invented Critical Path Method [**15 years before it was known to the industry**]*
•Day-to-day close supervision of crafts by DuPont's Assistant Division Engineers
*•An effective Quality Assurance program [**a generation prior to the coining of that phrase].***

Col Matthias was much impressed by DuPont engineer supervision of crafts.

"The engineer would lay out every task for a day ahead. Then the engineer would supervise it. The workers and the foreman were told just what to do by the engineer. I think this close supervision of the crafts by the engineers is what made the [great] difference in the efficiency"[43]

In this engineer-managed system, each supervising engineer had about five foremen. For the relatively short span of time during actual construction it was an exhausting job, as the crafts worked two nine hour shifts (with an hour overlap) but the supervising engineer was there for both shifts, six days a week – a "killer" schedule[44].

They were aided by the fact that during design, the construction organization was anticipating the unique aspects of the required construction and preparing procedures for many of the particular jobs requiring detailed instructions. For example, in the laying of the graphite, it was estimated that more than 200 separate procedures[45], averaging 10 pages each, were written. Many of these were construction-Quality Assurance (QA) procedures which were carried on concurrently with the construction operations. As a DuPont supervisor later reported, "We had QA. We didn't call it QA, but we had it[46].

Finally, it is not surprising that the American National Standards Institute's Nuclear Quality Assurance-1 (ANSI NQA-1) program resembles DuPont's Hanford program because 35 years later, ANSI and the American Institute of Mechanical Engineers (ASME) canvassed all who had been major players in nuclear engineering and construction[47].

Thayer notes that the quality of DuPont work existed because[48]

• DuPont had a background in quality work in their previous munitions and chemical plants,

• DuPont was motivated toward the highest quality at Hanford because of the fear of catastrophic failure was uppermost on the minds of DuPont's Board of Directors,

• Hanford construction and QA was in the hands of the best engineers and construction managers in DuPont.

Are there any Measures of Management Success that can be identified?

Three measures of the exemplary quality of the total Hanford project can be noted.[49]

•The product of the Hanford Engineering Works worked – with a nearly flawless start (after the implementation of the work around of added process tubes in B reactor because of incomplete physics data for the preliminary design. from the Metallurgical Lab).

• HEW delivered the plutonium product on time – June 1945 – for a test device on July 16 and the second bomb on August 9 of that year,

• A third intangible measure was provided by an engineer in DOE's current Hanford Site Infrastructure Office. He noted in 1993 that whenever he has to go into the now-abandoned B Reactor, he is impressed with the quality of the workmanship there.

Was the impact of DuPont's corporate culture limited to design/construction aspects of the Hanford project, or did it also have a lasting influence on operations as well?

The DuPont corporate culture had a lasting influence on the safety culture of the Hanford Project through the establishment of programs to ensure adequate radiation safeguards for workers and increased understanding of the impacts of radiation on the environment. However, unlike the previously noted unique corporate contributions in the areas of project control and construction efficiency that had a make-or-break effect on the remarkable record of design / construction /successful startup, DuPont's role in radiation safety was undertaken in cooperation with scientists from the Metallurgical Lab and with the involvement of General Groves.

As reported by Ellis[50], early in the design phase of the project Greenewalt met with General Groves, Safford Warren, a noted radiobiologist of the Met Lab, and Robert Stone, director of the newly established Health Division of the Met Lab, to discuss the outlines of a radiation biology research program tailored to the unique problems posed by Hanford's reactors and separation facilities. According to the recollections of Herbert Parker, a radiation physicist in Stone's division and later (the following year) head of Hanford's Health Instruments division, concern for aquatic life in the Columbia River was "due to Greenewalt's insistence that we do not open this place until we are sure of possible radiation effects". However, DuPont's desire for a rudimentary radio-biology research program was also supported within the Corps (General Groves) and by Stafford Warren, chief of the Manhattan Project's Medical section, who was keenly interested in the biological effects of radiation, and had published important research in radiation biology during the 1930s. The result was a contract with University of Washington fisheries biologist Lauren Donaldson to study the mortality rates and developmental effects of X-rays on salmon and trout. As soon as construction of the three reactors at Hanford was complete, DuPont constructed an aquatic biology laboratory at the most downstream of the three reactors, (F Reactor) and this work was moved onsite. It might be said this was the first instance of research at Hanford and was the precursor of what became the Hanford Laboratories and eventually today's Pacific Northwest National Laboratory.

As significant as salmon in the Columbia River are, they were not the only living creatures for which the effects of radiation were critical. Although DuPont was not intimately familiar with the hazards of ionizing radiation, Greenewalt quickly became aware that the production of plutonium entailed safety problems, including potential exposure of workers to high levels of both fission products, most of which are intensely radioactive, and neutrons, which are particularly damaging to living tissues. He responded vigorously to the needs, pointed out by the Met Lab scientists, for an active program of monitoring the radiation exposure experienced by operators and maintenance workers in both the reactors and separations plants. DuPont established a Health Instruments division, under Herbert Parker, a British-born health physicist who had spent short stints at Chicago and Oak Ridge. The division's responsibility was to establish standards of allowable exposure and monitor actual exposure of essentially all Hanford operating personnel, as well as monitoring environmental impacts of Hanford operations on aquatic and terrestrial plants and animals near the Hanford site. The scope of the radiological monitoring program was truly unparalleled. Through the first eight months of 1945, with production fully under way, the division processed over 1.5 million worker measurements.

This program, still in effect at the Hanford site, has led to an enviable safety record there through the years with respect to avoidance of serious radiological incidents.

If DuPont's contribution was so significant, why has it not been given more recognition in the numerous accounts of the Manhattan Project, even in the few specifically emphasizing the program at Hanford? Why should it be of concern now?

Several factors have contributed to that lack of recognition of the corporate contribution of DuPont. For one, history is more interesting if it is centered about individuals that are interesting. DuPont's contribution arose from people working together and involves the utilization of unique work culture to accomplish that effectively. In DuPont's case, one source of their success was that many of the leaders were so used to working together and trusting each other that work proceeded without the need for extensive written communication[51] – not particularly interesting reading. Moreover, DuPont staff were told not to keep a diary[52] – they were potential sources of breaches in security. Hence when security slackened 40 years or so after the Manhattan Project, accounts were written primarily by those who could refer to diaries for interesting details – primarily written by the physicists and U.S. Army Corp of Engineers personnel.

Another reason is that, as noted earlier, between the physicists of the Metallurgical Lab and the DuPont engineers there was a level of tension because the later had been designated as being in charge of the production of plutonium, a move deeply resented by some of members of the Metallurgical Lab. Moreover, there was a distinct difference in the culture of the two disciplines. The most significant example of that tension centered on the fact that the reactor design at Hanford did not hue directly to the preliminary design laid out by Eugene Wigner's group. These tensions subsided as the reactors were built and it became obvious what a huge job it was to put the designs of the physicists into a production plant[53]. However, many years later, when the opportunity arose to recollect and recount experiences, those tensions seem to have been reinforced and what gets reported focuses almost entirely on the contributions of their colleagues. It is unfortunate that the histories that have been written about the Manhattan Project all come out with the Hanford development as a triumph for the physicists. Quoting Greenewalt, *"To my way of thinking it was one of the greatest interdisciplinary efforts ever mounted. . . but the physicists always want to pull the covers way over to their side of the bed"*[54]

A third reason is that although shortly after the war and DuPont's completion of their Hanford contract, great pride in the accomplishments of the corporation at Hanford was voiced within company publications, there nevertheless seemed to be some reservation in broadcasting this feeling outside of the company[55]. An ambivalence existed about their participation in the Hanford project because of the destruction produced by use of the bombs, and the corporation was much more interested in being remembered for nylon and ladies' stockings. And so as time went on and security permitted the more detailed accounts of the Manhattan Project, DuPont left it to the diary duplicators to tell the story.

The few histories that have focused on Hanford's role in the Manhattan Project have relied on the same primary sources, so details of the DuPont work have not been featured even there. It has been **Lost In The Telling.**

So, what is the importance in telling the DuPont story at this time? The National Park Service – ***The Nation's Storytellers*** – is focused on having an interesting story for its visitors. And most of those visitors will have the same attitude toward history – "tell me something interesting – and make it short". But for those who will sense the disconnect between a handful of physicists listening to the click of a counter before a stack of graphite under Stagg Field in Chicago, signifying the accomplishment of a chain reaction, and the production of a totally new element in a huge industrial complex in the desert of eastern Washington, it is quite likely **The Nation's Storytellers** will want to be ready to ***Tell the rest of the story which has heretofore been lost in the telling***.

BRMA invites your comments. Please join us for an opportunity to discuss history where it was made.

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