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Progressive Application Decommissioning Models for U.S. Power and Research Reactors

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ABSTRACT

This paper presents progressive engineering techniques and experiences in decommissioning projects performed by Burns and Roe Enterprises within the last fifteen years. Specifically, engineering decommissioning technical methods and lessons learned are discussed related to the Trojan Large Component Removal Project, San Onofre Nuclear Generating Station (SONGS) Decommissioning Project and the Brookhaven Graphite Research Reactor (BGRR) Decommissioning Project Study.

The 25 years since the 1979 TMI accident and the events following 9/11 have driven the nuclear industry away from excessive, closed/elitist conservative methods towards more pragmatic results-oriented and open processes. This includes the essential recognition that codes, standards and regulatory procedures must be efficient, effective and fit for purpose. Financial and open-interactive stakeholder pressures also force adherence to aggressive risk reduction posture in the area of a safety, security and operations

The engineering methods and techniques applied to each project presented unique technical solutions. The decommissioning design for each project had to adopt existing design rules applicable to construction of new nuclear power plants and systems. It was found that the existing ASME, NRC, and DOE codes and regulations for deconstruction were, at best, limited or extremely conservative in their applicability to decommissioning. This paper also suggests some practical modification to design code rules in application for decommissioning and deconstruction. The representative decommissioning projects, Trojan, SONGS and Brookhaven, are discussed separately and the uniqueness of each project, in terms of engineering processes and individual deconstruction steps, is discussed.

<u>Trojan Decommissioning</u>. The project included removal of entire NSSS system. The engineering complexity was mainly related to the 1200 MW Reactor. The approach, process of removal, engineering method related to protect the worker against excessive radiation exposure, transportation, and satisfying applicable rules and regulations, were the major problems to overcome. The project’s successful completed earned a patent award.

SONGS Decommissioning. The reactor's spherical containment and weakened integrity was the scope of this decommissioning effort. The aspects of structure stability and method of deconstruction is the major part of the presentation. The economical process of deconstruction, aspects of structural stability, worker safety, and the protection of the surrounding environment from contamination is highlighted in this section.

BGRR Decommissioning Study. BREI was commissioned by Brookhaven National Laboratory (BNL) to evaluate and analyze the stability, and progressive decommissioning, and removal of BGRR components. This analysis took the form of several detailed decommissioning studies that range from disassembly and removal of the unit's graphite pile to the complete environmental restoration of the reactor site. While most of the facility's decommissioning effort is conventional, the graphite pile and its biological shield present the greatest challenge. The studies develop a unique method of removing high-activity waste trapped in the graphite joints.

INTRODUCTION

This paper discusses three decommissioning and deconstruction projects undertaken by Burns and Roe Enterprises, Inc (B&R, Oradell, NJ). The projects are the decommissioning of Trojan 1,200 MW nuclear power plant, deconstruction of the San Onofre Nuclear Generating (SONG) Station's spherical containment, and an engineering study to decommission the Brookhaven Graphite Research Reactor (BGRR).

TROJAN DECOMMISSIONING PROJECT

The Trojan Nuclear Plant was shut down for many years. In an earlier first phase of the project, B&R removed the steam generators, feed pumps, and the Pressurizer. The major task, however, was to remove the reactor vessel. A detailed study was initiated for the best removal method.

Reactor vessel removal was initiated by cutting off all external piping connections and fuel handling mechanisms. Utilizing a jacking device, the vessel was lifted above staged external shielding panels. The vessel was then lowered back down to the staged shielding structure. The steel panels provided shielding to the workers as well as a structural integrity boundary for transportation and handling. Fig. 1, Fig. 2 and Fig. 3 depict the shielding structure, the supporting and transport concept, and the final barge package.

Once the shielding was affixed to the vessel, the assembly was placed in a horizontal position, transported outside of the containment building, and lowered onto the transport cradles. The transport cradles were part of an overall transport frame that was designed for use with tractor-trailers or barge.

Positioning of the vessel onto the cradles and providing the proper restraining system was a challenging effort. This was due to requirements of the vessel drop scenario. Design of impact limiters in case of a vessel drop was an essential part of the qualification. The theoretical procedure and mathematical approach for the impact limiters is detailed in Reference 1.

After placing the vessel package in the transport cradles, the impact limiters were installed. These were axi-symmetrical bodies (doughnut shaped) and segmented in four sections. The impact limiter material was selected based on its tested crushable physical properties.

A complex cable restraining system ensured that the entire assembly (known as the Reactor Vessel Package or RPV) was stable for transport.

The total transport weight was about 1,500 tons. The RPV weight without the restraining system and transport framing was about 900 tons.

Impact limiter design was another challenging effort. Considering the total RPV weight of 900 tons with Code application rules, it was not realistic to implement an originally conceived “hypothetical cask drop,” which required an analysis of a 30-foot drop onto an unyielding surface. With the technical and design argument, the drop scenario was changed to a “mechanistic event,” where a more realistic drop height was limited to actual possible drop from the transporter. Protection and dissipation of energy was achieved by special energy absorbing foam material. This foam material had tested force/displacement properties required for the design. Thus, the equilibrium between the impact kinetic energy was resisted by the strain deformation energy of the foam material. The design of the impact limiter is shown in Fig. 2. The analytical modeling of the impact limiter is presented in Ref. 1.

The entire process of the reactor vessel removal, preparation for transport, and satisfying all regulatory requirements, was completed on time and under budget. This project was awarded as well as patent for the unique method of the vessel removal (U.S. Patent # 6,414,211 B1, July 2, 2002).

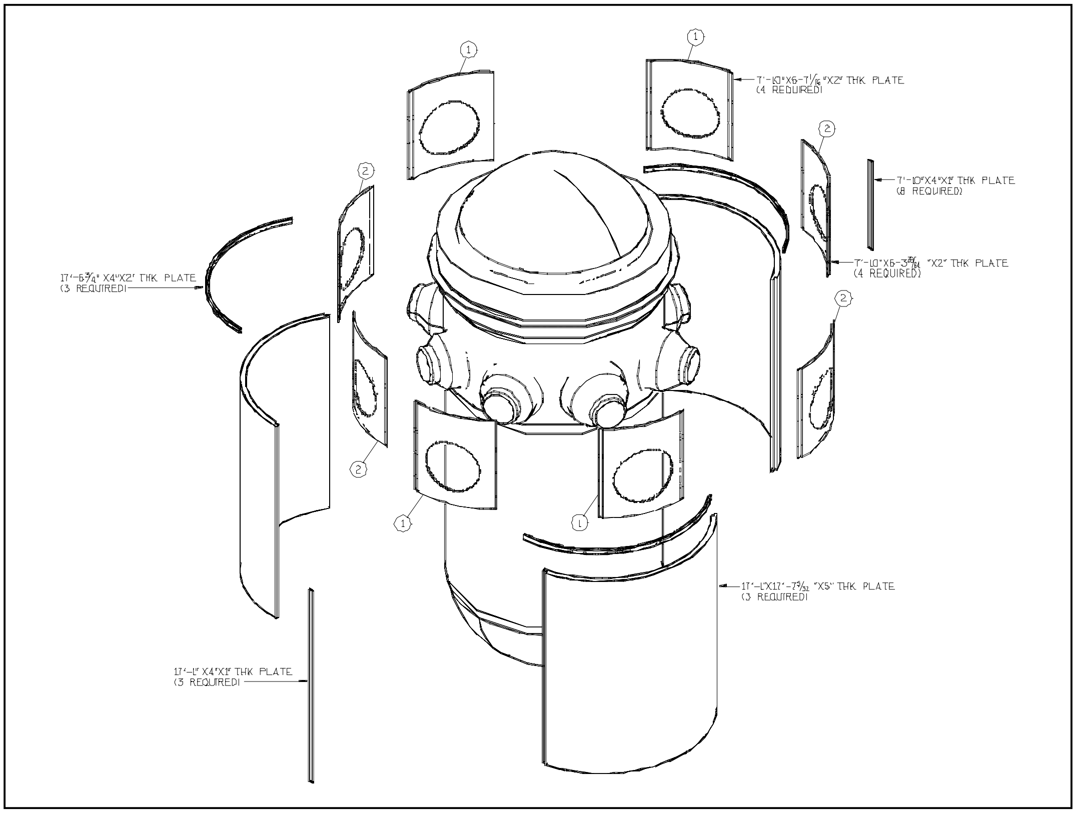

Fig. 1. Shielding concept for the Trojan reactor

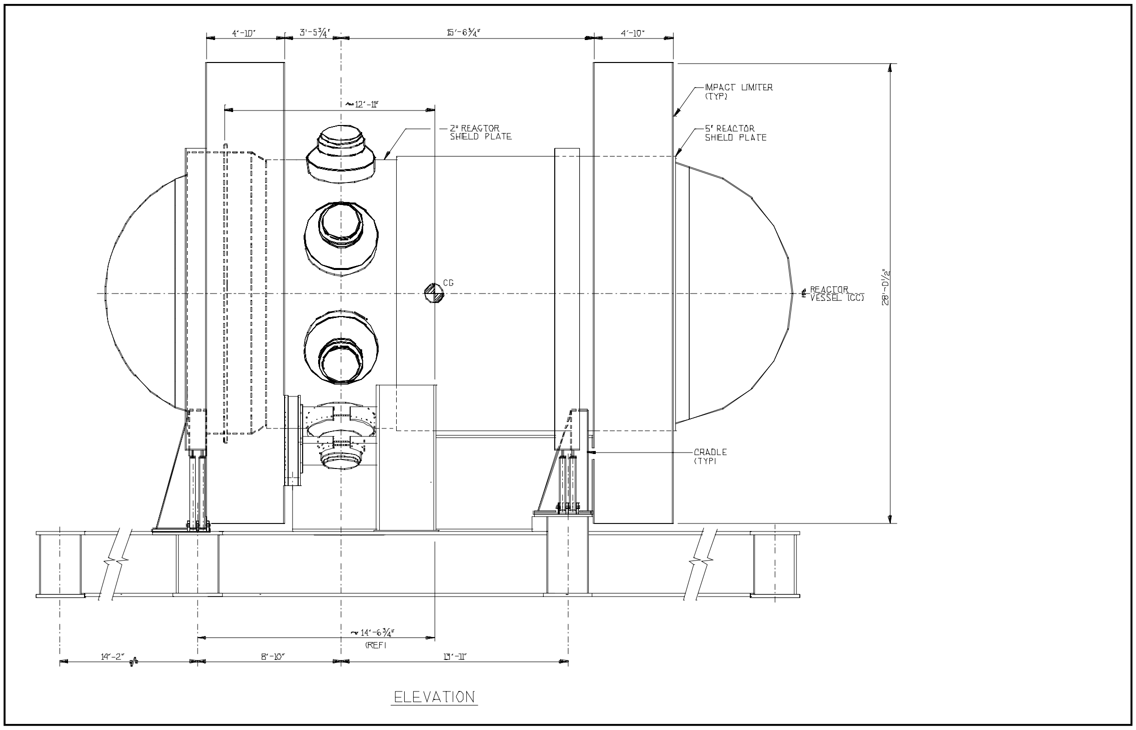

Fig. 2. Reactor transportation concept

Fig. 3. Final reactor barge transportation design

SAN ONOFRE 1 NUCLEAR GENERATING STATION DECOMMISSIONING PROJECT

Second project to be discussed is the “deconstruction” of the San Onofre Nuclear Generating Station (SONGS) containment vessel. This project, though different in nature, has similarities to the Trojan decommissioning effort.

SONGS Unit 1 had been shut down for several decades. The NSSS system had already been removed, and what was remained was the contaminated spherical steel containment and concrete structure. The task of this project was to remove and deconstruct the containment shell. Rubblizing the concrete structure was a relatively trivial problem; taking down the spherical shell was more complicated.

Fig. 4 is a graphical representation of the shell size, including all openings for rubble and shell segment removal.

This project faced the following challenges. First, the integrity of the structure in its weakened state with the application of additional equipment, lifting devices, etc., needed to be assured. The “point” loads and question of the dynamic responses of these structures had to be addressed and investigated during the various deconstruction stages. The application of all applicable loads had to be considered as well. In addition, the cutting and economic removal of the contaminated pieces of the shell had to be addressed.

This project, as with the Trojan project, employed latest computational technology, used by industry today. A finite element analysis program, COSMOSM, modeled the containment shell. The structural integrity was compared to two Codes. Since the containment vessel falls in to the

ASME category, the allowable limits of ASME Code were implemented (see Reference 2). The AISC code at the time of construction (1956) also governed, so the AISC allowables were also checked.

B&R analyses and complete calculation process is available under the Calculation No. 2651-001-23-002 (Ref. 2). A sample of the stress results is shown in Fig. 5.

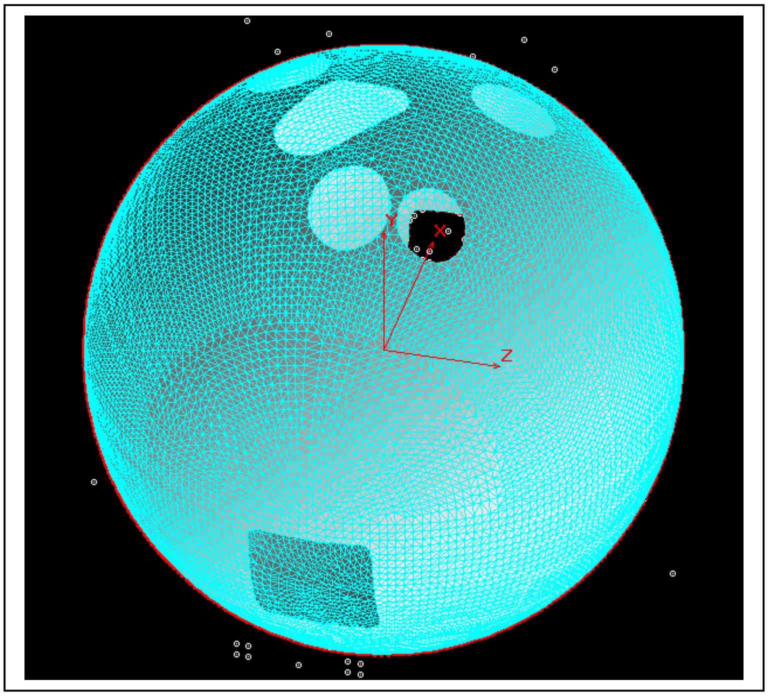

Fig. 4. Deconstruction mathematical model of SONGS Unit 1 spherical containment

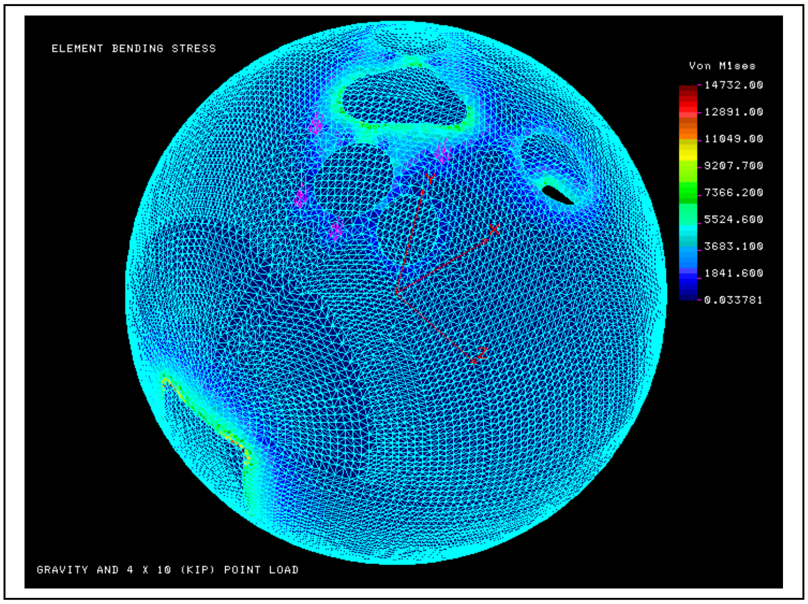

Fig. 5. Example of analytical stress results of SONGS Unit 1 spherical containment

BROOKHAVEN GRAPHITE RESEARCH REACTOR DECOMMISSIONING STUDY

When it became operational in 1950, the Brookhaven Graphite Research Reactor (BGRR) at Brookhaven National Laboratory (BNL, Upton, NY) was the first peacetime reactor built in the United States following World War II. Its primary mission was to produce neutrons for scientific research. Experiments at the reactor led directly to development of multigrade motor oils and Tc-99, an important medical diagnostic radioisotope. The facility was placed on standby in June 1968 and then closed permanently.

The purpose of the BGRR Decommissioning Project is to plan and implement a safe and cost-effective facility dismantlement to restore the site environmentally. BNL selected the team of Burns and Roe Enterprises, Inc. (Oradell, NJ), Babcock Services, Inc. (Richland, WA), and WMG, Inc. (Peekskill, NY) to perform detailed decommissioning studies that will be used by BNL in the decommissioning decision-making process.

The series of studies evaluated potential decommissioning alternatives that ranged from the disassembly and removal of the Pile to the total remediation of the site to a green field state. This section summarizes the decommissioning approach of the most critical and challenging component – the Graphite Pile. The Pile represents the major BGRR source term.

The Graphite Pile, or reactor core, consists of 63,000 interlocking graphite blocks in 2,600 different shapes (see Fig. 6). Designed to moderate neutron speed during operation, it forms a 700-ton, 25-foot cube split vertically through the middle by a 3-inch gap. Filtered cooling air was drawn down into this gap to provide cooling. Horizontal rows of round channels extend from the south face of the Pile to the north face. These channels housed the fuel rods. Of 1,369 channels, about half were used at any given time. An additional 29 square openings on the east and west faces were used for experiments. Reactions were controlled through 16 borated steel control rods inserted diagonally from two corners of the cube. The Pile rests on two 3-inch-thick steel bedplates that are supported on a set of steel I-beams (known as the *grillage*). Under the grillage is a foundation of four concrete buttresses, which are ultimately supported by a 3.75-ft-thick foundation mat.

The disassembly and removal of the BGRR Pile is a complex process. The 63,000 interlocking, irregularly shaped graphite blocks are not easily lifted or pulled apart. In addition, some surrounding structures need to be removed to access the graphite block. The most radioactive parts of the Pile are fuel channels that experienced fuel failures. The Pile itself is contained within a Biological Shield Wall, or Bioshield, which is a double steel walled confinement structure. It allows access to the Pile only through its roof, which complicates disassembly.

Six Pile decommissioning concepts were evaluated. The preferred concept, manual and remote disassembly after boring selected fuel channels, addresses the complexity of disassembly and removal. By isolating the high-activity waste stream, it vastly simplifies the entire decommissioning and waste removal process. The use of remotely operated equipment significantly limits potential worker exposures.

The first step in the preferred concept calls for boring out the fuel channels and vacuuming and isolating the shavings to separate the high-activity waste from the rest of the Pile. Radiological surveys and physical inspections of the Pile revealed that several fuel channels have very high activity contamination and/or debris within them. These fuel channels with documented high activity and/or high dose rates will be bored (reamed) to remove the contamination/debris, reducing the radiological risk of dismantling the bulk Pile graphite. The boring concept is depicted in Fig. 7.

An added benefit of boring is that separating high-activity waste from the bulk graphite waste will maximize disposal options and minimize waste transportation and disposal costs. Removing the most contaminated and active areas will significantly reduce airborne releases from the Pile during disassembly.

After boring, workers will manually create an opening in the center of the Bioshield roof. They will remove the Bioshield roof plugs, top aluminum airtight membrane, and any metal parts that limit access to the Pile. They will then remove the first five layers of graphite blocks and metal tie rods to create the space needed to use a remotely operated compact demolition machine. Dose rates at the top of the Pile and within the first five layers are expected to be relatively low and will permit such work.

Worker will then position a Brokk Model 330 or similar remotely operated, compact demolition machine on the north or south side of the Bioshield roof. This will give it access to the exposed Pile. Using an excavating bucket, grapple or other demolition end effectors, the Brokk will continue to pull apart the Pile and place the rubble in containers. It has enough reach to remove more than 50% of the Pile from this position. The unit will be lowered into the Pile pit to remove the rest. Remote operation will eliminate the need for extensive work within the confines of the Bioshield and keep worker exposures as low as reasonably achievable (ALARA). It will also reduce the possibility of heat stress and workplace injuries.

In addition to graphite boring and remote equipment, this decommissioning model also employs other critical technology concepts, such as a contamination confinement enclosure, temporary ventilation units, and contamination fixative.

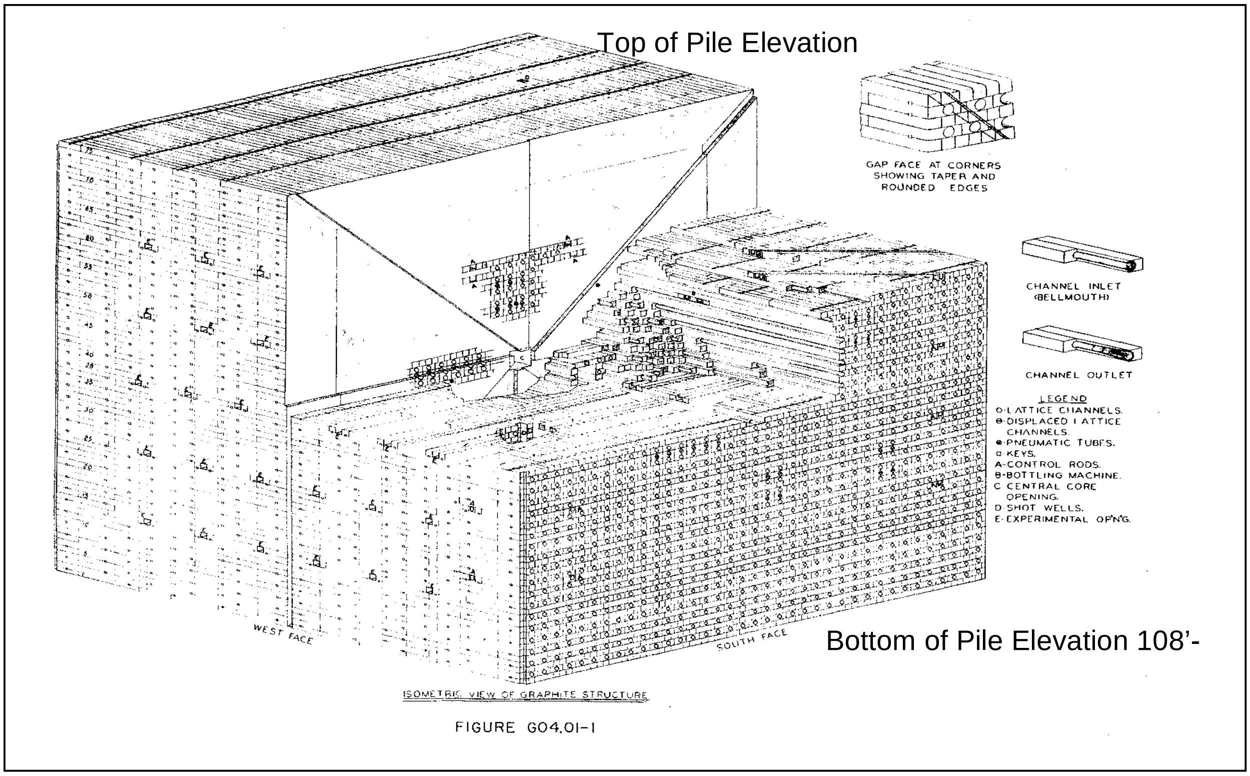

Fig. 6. Brookhaven graphite pile

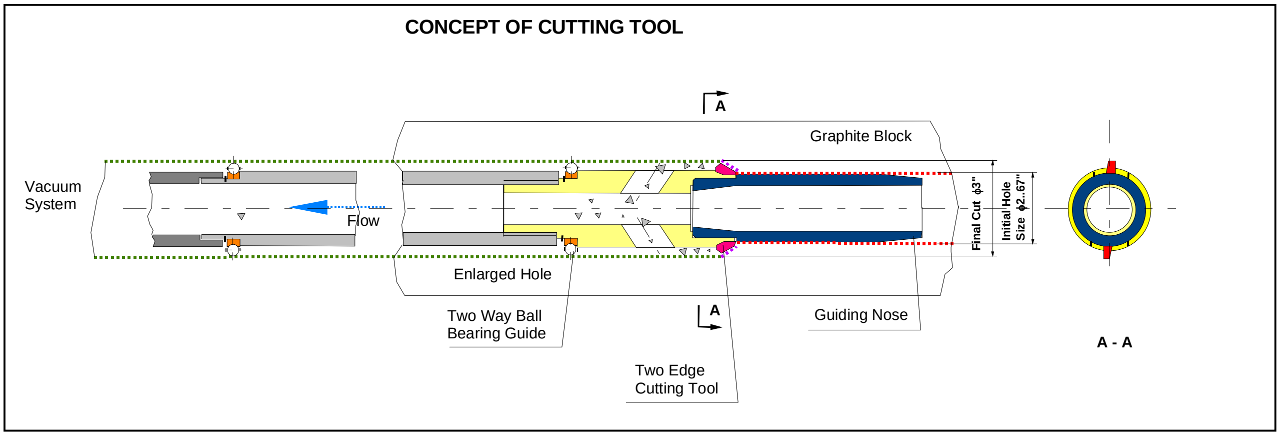

Fig. 7. Cutting tool concept

CONCLUSION

Even though each preceding project was unique, there were common activities. These are:

- Planning of the decommissioning effort and preparation of the concepts,
- Application of the regulatory rules,
- Application of the design codes, and
- Use of engineering analytical methods and solutions.

The major lesson learned throughout the execution of these projects is the need of specific codes related to decommissioning. It must be clearly understood by the regulating bodies that decommissioning is not a design effort for longevity and operability. In many cases on these projects, Burns and Roe grappled with long-term design rules versus short-term design rules. Unnecessary conservatism was required by the regulatory agencies that increased cost. For example, in the Trojan Decommissioning Project, Burns and Roe was originally required to design the transportation package to withstand a 10 g deceleration force. We had to demonstrate that it would not be credible for the transportation package to experience this type of loading.

However, with the benefit of lessons learned since the 1979 TMI-2 accident, and especially post 9/11 cost profiles and risk tolerance features have been dramatically altered. This certainly applies to funding decommissioning projects. Resources are now required for improved communication with stakeholders and a more robust physical security profile at all nuclear facilities. Certainly, one of the “bill payers” can be a sharper more appropriate technical approach that avoids wasting any funds. This also improves the progressive integrated approach to implement prudent engineered solutions for projects, both operations and decontamination/decommissioning projects, with protective force/physical security objectives to optimize risk profile. This new approach will also open up public-stakeholder involvement to the maximum extent practicable to improve confidence and ensure buy-in from the real “bill payers” (investors, stockholders, and voting citizens) along the way (see Ref. 2).

With respect to the three projects, the following conclusions are noted:

1. It is essential to seek early concurrence from the regulatory agencies. These agencies need to be flexible and adapt to change.
2. Implement the latest engineering computational methodologies. Apply finite element analysis to the greatest extent possible.
3. Apply codes and regulations properly and judiciously by realizing that decommissioning is not a design effort for longevity and operability. Update – improve codes in a proactive manner.
4. Scrutinize requirements for hypothetical accidents. Demonstrate and present analyses for credible design conditions rather than incredible ones.
5. Resources expended versus risk profile must be both perceived and actually be favorable to allow sponsors to be confident – particularly post 9/11 relating to safety and security.

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