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CHARGED-PARTICLE BEAM: A SAFETY MANDATE

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CHARGED-PARTICLE BEAM: A SAFETY MANDATE*

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Abstract

The Advanced Test Accelerator (ATA) is a recent development in the field of charged-particle beam research at Lawrence Livermore National Laboratory. With this experimental apparatus, researchers will characterize intense pulses of electron beams propagated through air.

Inherent with the ATA concept was the potential for exposure to hazards, such as high radiation levels and hostile breathing atmospheres. The need for a comprehensive safety program was mandated; a formal-system safety program was implemented during the project's conceptual phase.

A project staff position was created for a safety analyst who would act as a liaison between the project staff and the safety department. Additionally, the safety analyst would be responsible for compiling various hazards analyses reports, which formed the basis of the project's Safety Analysis Report. Recommendations for safety features from the hazards analysis reports were incorporated as necessary at appropriate phases in project development rather than adding features afterwards.

The safety program established for the ATA project facilitated in controlling losses and in achieving a low-level of acceptable risk.

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Introduction

The Advanced Test Accelerator (ATA) is based upon a linear induction electron accelerator capable of rapid-repetition pulses of high-energy, high-current electron beams. The potential for safety problems, such as radiation exposure, high-voltage electricity, and other less "exotic" hazards, was recognized early in the conceptual phase of the ATA project. By integrating safety concepts into project planning, design, construction, and operation, the ATA is presently being operated as intended without safety issues slipping schedules, limiting designed performance specifications, or adversely increasing costs.

High-technology industries in the private sector, in addition to other government-funded research projects, are finding that an increasing public concern for safety of people and the environment is mandating safety programs to reduce risks to the lowest level practicable. The uncontrolled release of large amounts of energy could seriously restrict development of whole industries on a nationwide scale. We can no longer resolve safety problems with "band-aid" controls; a systematic approach of identification and mitigation of hazard potentials is prescribed.

I will capsulize the efforts of many people working with high energy systems having many interfaces transcending many disciplines. The first section of this paper will brief the reader on the machinery involved with the ATA. The second section will chronologically cover the specific system safety efforts and documentation that have contributed to the overall success of the ATA project.

Project

Lawrence Livermore National Laboratory (LLNL) has a historical involvement with induction linear accelerators dating back to 1963, when the Astron I accelerator was built to provide high electron-beam currents for fusion plasma studies using magnetic confinement. The majority of linear accelerators in operation today use a radio-frequency, traveling wave technology for accelerating the electrons. Radio-frequency accelerators, such as the Stanford Linear Accelerator (Palo Alto, California), are capable of accelerating electrons to billions of electron volts, but beam instabilities limit the electron currents to less than one hundred milliamps. As a comparison, the ATA is capable of accelerating electrons to fifty million electron volts, but at an electron current of ten thousand amps. The ATA beam is pulsed for a duration of seventy nanoseconds (70×10^{-9} sec) and is capable of a repetition rate (in burst mode of ten pulses) of 1000 Hz.

The ATA consists of essentially four major sections:

- The Injector. The injector consists of a cathode, an anode, and a focusing coil network. The electrons are emitted from the cathode and accelerated toward the anode to an intial energy level of 2.5

MeV. The anode, being open at the center, allows the beam of electrons to pass through into an evacuated beam tube surrounded by focusing coils. The beam diameter is reduced for entry into the accelerator section - at a velocity of 0.985 times the speed of light.

- The Accelerator. The electron beam passes now sequentially through 190 accelerator cells - each cell incrementally adding 0.25 MeV of energy to the electrons. The combined effect of the 190 cells is to increase the electron beam's energy to the desired 50 MeV. The beam velocity has increased to about 0.999 times the speed of light, and the effects of relativity have caused an increase in rest mass of the electrons - from six times rest mass at 2.5 MeV to about 100 times rest mass at 50 MeV.

- Beam Transport Section. Upon exiting the accelerator section, the electron beam enters the beam transport section. This section isolates the accelerator from the experimental area, permits space for diagnostic instruments to evaluate the beam's characteristics, and may in the future house a differential pumping unit for maintaining a pressure differential of up to one atmosphere between the accelerator and the experimental tank. At present, a thin foil separates vacuum from atmosphere.

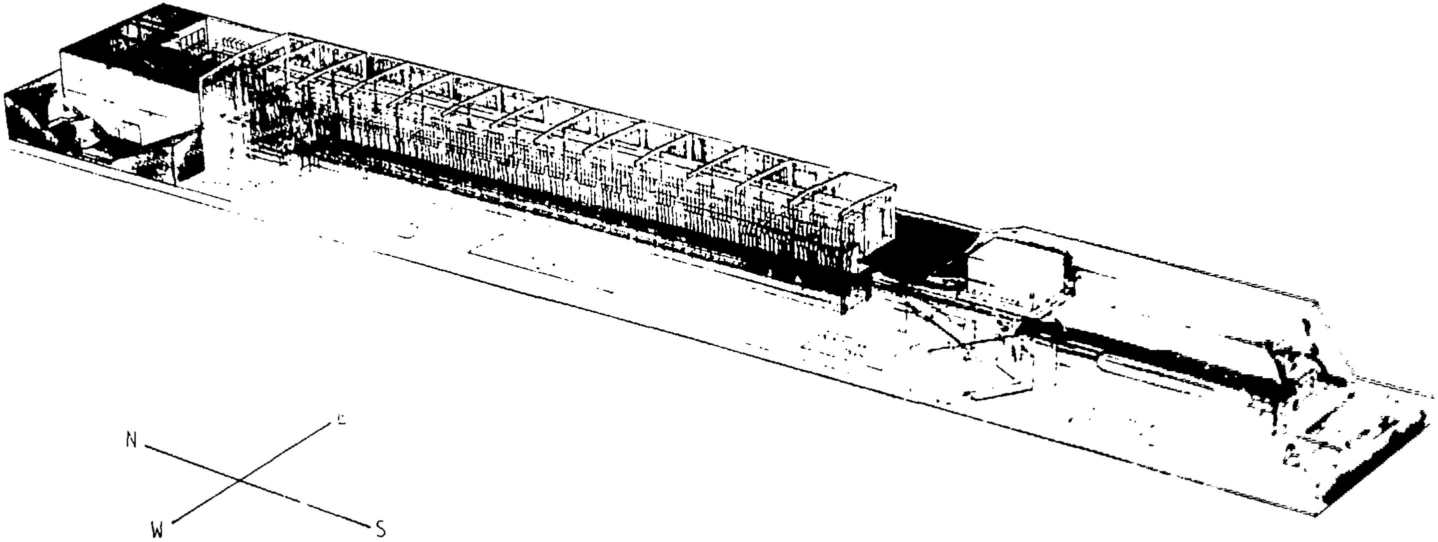
- Experimental Tank. Ultimately, the beam may be directed either into an experimental tank or out into the open atmosphere for testing.

The attached cut-away drawing shows these major sections in perspective. Considering the potential hazards inherent in this facility's operation, siting was chosen at the Laboratory's Site 300 test area -- a remote location some fifteen miles from Livermore, California. The beam is propagated in a southerly direction, away from occupied spaces. The control room for accelerator operations is located in the northern section (upper part of drawing) of the facility main structure. Support equipment, such as fluid systems and electrical switch gear, is located peripherally around the outside of the main structure. Offices, work spaces, and storage spaces are located north of the main facility.

Safety

The ATA is a composite of many advanced-technology components and requires specialized training to understand and operate the systems. In recognizing the many interfaces of the operating and control systems, the project team was formed in a matrixed manner. Thus, engineers, scientists, draftsmen, and technicians could contribute their specialized skills at the times when needed as the project progressed. Early in the conceptual phase of the project, a project staff position was created for a safety analyst. The analyst's function was to provide the focal point for line management to resolve any safety-related problems. Many of the potential problems associated with

ATA Advanced Test Accelerator



accelerator operations require safety discipline specialists (such as health physicists or industrial hygienists). The Hazards Control department at LLNL is organized with such safety discipline groups; thus, the safety analyst was also to be the focal point for enabling the safety disciplines to deal with project scientists and engineers.

Interface Control Documents (ICDs) were generated to assure that information effecting more than one specific work group was promulgated. For example, maximum accelerator output would determine the location of occupied spaces and the amount of shielding material to be used to assure personnel safety. This kind of information would be written on an ICD form which would be routed through the different groups for concurrence or changes. The groups needing to approve the ICD before action would be taken are Controls, Software, Electrical, Mechanical, Physics, Diagnostics, Project, and Safety.

The safety efforts of the ATA project paralleled the distinct (but overlapping) phases of development. The following discussion relates the involvement of the safety analyst and discipline specialists during each phase.

Conceptual. This is the stage of the project during which the physicists confer with the engineers and safety specialists and agree on exactly what can realistically be built. As a result of this process, System Requirements (SRs) are established which define the parameters required of the system - be it the accelerator in general, or an issue as specific as cooling water flow rates through a heat exchanger. The outcome of many of these SR's provides enough information so that the safety analyst, along with the safety discipline specialists, can perform a Preliminary Hazards Analysis (PHA). It is the PHA that initially addresses the potential hazards - providing input to the engineers and designers on the need for safety-specific structures such as radiation shielding or ventilation systems. The PHA is used to determine the initial risk assessment, establish the relative hazard level of the ATA, and provide the framework for all subsequent hazards analyses.

The PHA was performed by examining the systems contained in the work-breakdown-structure of the ATA Project Management Plan. Specific hazard potentials were evaluated for pertinent systems, such as the potential for a radiation exposure problem with the Accelerator Focusing and Steering system. A qualitative determination of the severity and probability of the occurrence of an accident was evaluated if no corrective actions were taken. From this information, control requirements were developed which would reduce the risk of each particular accident to an acceptable level. This information was kept in a "Hazard Catalog" under the cognizance of the project safety analyst. The published PHA report condensed this information into a matrix for ease of review and interpretation.

The ATA as evaluated by the PHA was determined to be a moderate hazard facility - meaning that there is a potential for on-site safety impacts, but negligible off-site effects. The choosing of the site location at the Laboratory's remote experimental facility near Tracy, California, allows for even greater reduction of the risk to on-site personnel and structures as well as to the general public. However, designation as a moderate hazard facility indicated that further analyses were to be performed on the ATA.

The Master Safety Plan (MSP) was the next document from the safety analyst. The MSP defined the Safety Policy (consistent with the Laboratory's Safety Policy); delineated responsibilities of engineers, managers, and staff; and specified system safety criteria - what would be acceptable as well as unacceptable conditions (such as design limitations or single-point failure). The stage was also set for future analyses.

Design. The Integrated Hazards Analysis (IHA) expanded upon the controls of the hazards associated with specific systems examined in the PHA. As a refinement, the specific controls were evaluated for each of the systems and associated hazards. The residual risk was qualitatively determined, and mitigating features thought to be necessary were recommended and incorporated to reduce the level of accepted risk.

Due to compressed, overlapping phases in the project schedule, the IHA was still in the compilation stage when project construction was underway This practice of overlapping can be advantageous for evaluating the adequacy of specific safety features. If a new situation arises that needs to be addressed, or more advanced technology allows for incorporation of better control features, changes may be designed and implemented with a minimum of disruption to the schedule. The need to build a project within budget all but prohibits the expense of retrofit.

Construction. There is no specific analysis effort associated with the construction phase. Safety problems of the construction phase are generally those encountered for all projects and were therefore handled by already existing procedures and management systems. But due to schedule compression as mentioned earlier, the IHA report was completed during this phase, and the next analysis effort was commenced. The Operational Hazards Analysis (OHA) was the final analysis in the sequence. Previous analyses were concerned with design features and equipment installation; the OHA, however, considered the interaction of procedures, equipment, and personnel. The OHA examined operations and modes of the ATA; considered residual hazards to determine the need for further control, and examined management policies, procedures, and programs with respect to safe operations. The OHA was to form a basis for the Operational Safety Procedure by which the ATA would be operated. Included in the Operational Safety Procedure are the schedules for performance of safety systems checks to assure proper operation of these systems. This analysis would also be the last evaluation performed on safety-related items - a final check to appraise management of their assumed risk. During the end of the construction phase, acceptance testing and limited operations began.

Operation. The hazards analyses delineated in the MSP as needing to be completed prior to operation have been performed. Residual risks have been determined by management to be acceptable - as long as the facility is operated within the scope of its present design limitations. In the event that specific operational parameters are changed, added, or deleted, a formal Change Analysis is recommended to determine the need to alter any safety features for continuing safety of operations. Because the ATA is intended for experimental operations, changes in scope of operation are anticipated, and will be preceded by a formal change analysis.

Conclusions

The individual hazards analyses are being collectively termed the Safety Analysis Report (SAR). In summary, the SAR is composed of the Preliminary Hazards Analysis (PHA), the Master Safety Plan (MSP), the Integrated Hazards Analysis (IHA), and the Operational Hazards Analysis (OHA). Project management has supported these safety efforts and incorporated the recommendations from each hazard analysis needed for continued safe operations. As one of the first major projects at LLNL to apply this formal system safety program and to integrate safety into appropriate phases of the project, this effort will be reflected in projects yet to come.

In these days of tightly-controlled budgets and multi-million dollar costs, the loss figures for a project or industry with inadequate safety considerations could be staggering. Accounting for money saved directly due to the safety program is not possible; however, a safety program such as the ATA Project developed is essential for reducing the risk of loss to a minimum.

The potential for a large dollar loss from a single incident when coupled with regulatory pressure brought on by a concerned public could severly restrict or shut down discreet sectors of any high-technology industry. This possibility mandates an integrated system safety approach for resolving safety problems.

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