A SYSTEMS VIEW OF CANDU REACTOR RETUBING

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ABSTRACT

This paper attempts to give readers an overview of the various systems involved in the successful implementation of a CANDU reactor retubing program. The intent of the paper is to stress the importance of adopting a systems approach to minimize workers' dose and outage duration. The views presented are based on author's personal site experience during the retubing of four CANDU reactors at Ontario Hydro's Pickering "A" station. The paper deals with systems and site engineering aspects of retube work pertaining mainly to the fuel channel removal and installation phases of the outage.

INTRODUCTION

Retubing of a CANDU reactor is a complex and immense undertaking requiring the combined resources and concerted efforts of the owner utility, the reactor designers, engineering consultants, and numerous component, tool, and equipment manufacturers.

Complexity of the retube program stems from several factors. The **radioactive work environment** demands that the workers perform most tasks while dressed in air supplied plastic suits to prevent dose "uptake" from airborne contaminants. The work must be performed within the confines of a shielding cabinet and through sliding access doors, to protect workers from the radiation beams. The work assignments must be planned, and custom designed, shielded tooling must be used to ensure individual worker's quarterly and annual dose limits are not exceeded. The enormous financial incentives for the owner utility to complete the job in the shortest possible duration dictates that the retube activities are carried out by shift workers scheduled to work around the clock in a **production driven work environment**. On the other hand, tens of thousands of quality control checks and inspections that must be performed to ensure reliable operation of the reactor during its post-retube life favours a **quality driven work environment.**

Reconciliation of the production and quality related program objectives necessitates intensive and comprehensive training programs for all retube workers. The conflicts between the production and quality driven forces coupled with the radioactive work environment constraints make the creation of a ***"quality culture"*** and the adoption of a well organized, coordinated, and systematic approach essential.

Worker safety in retube, both radiological and conventional, is of paramount importance. Radiological incidents can cause major delays in the program, adversely affect worker confidence, and have serious ramifications for quality and productivity. All retube detailed work plans and training programs emphasize safety and stress the importance of a safe work environment. High (radiation) hazard work activities can not be carried out until all radiological safety issues are thoroughly examined and necessary protective measures taken. Retube workers receive extensive training in radiological and conventional safety. Integration of a carefully planned and well executed safety program and the adoption of a "no-compromise" safety philosophy is imperative to successful retube implementation.

WHAT IS RETUBING ?

The basic retubing program involves the replacement of 390 (Pickering "A" reactor) fuel channels. The original Pickering "A" fuel channel assembly is depicted in Figure 1. Rehabilitation and upgrading of other plants systems is carried out in parallel during the retube outage. **Pre-outage** activities entail system and process definition, equipment and component design, procurement, and site facilities preparation. Unit shutdown signals the start of **outage** activities that include defuelling of the reactor, decontamination (CANDECON) of the heat transport system, preparation of reactor vaults, removal of old reactor components, installation of new replacement fuel channels, refuelling, and recommissioning of rehabilitated plant systems. Unit start up marks the end of the retube outage and the beginning of **post-outage** activities towards full reactor power.

The complete life cycle of a retube program spans 6-8 years. Typically, the pre-outage phase requires 4-5 years and the outage and post-outage activities another 2-3 years. Ontario Hydro began work on the system definition phase of the planned retube outages on the first two units of its Bruce "A" station in 1989. The first retube outage at Bruce "A" is scheduled to start in 1994 and is expected to take 2-3 years to complete. The in-service date for the first two Bruce "A" units was September 1977. In other words, the retube life cycle for Bruce "A" units 1 and 2 began 12 years after the in-service date and the retube outage is scheduled to start 17 years after the in-service date.

A BRIEF HISTORIC PERSPECTIVE

Retube pioneers involved with the Pickering "A" units 1 and 2 Retube program were faced with an enormous task. Although substantial amount of preparatory work had been carried out prior to the forced shutdown of Unit 2 in the aftermath of the G16 Zircaloy-2 pressure tube failure on August 2, 1983, the ensuing decision to retube units 1 and 2 in parallel, brought forward the retube outage date well ahead of the original schedule.

All work up to that point had been based on a fully remote retubing concept, driven by the assumption that radiation fields in the reactor vaults would be prohibitively high and would not allow the use of manual or semi-automatic tooling and equipment. It quickly became obvious that the fully remote concept would simply take too long to complete and that the adoption of a semi-remote retubing concept based on the use of manually operated or semi-automated tooling systems was unavoidable. Only the removal of high level waste category reactor components, such as pressure tubes and reactor shield plugs would require the use of fully remote tooling and equipment.

In parallel with the adoption of the semi-remote retubing concept, increased emphasis was placed on the development of an effective CANDECON system to bring the reactor vault radiation fields down to acceptable levels. High radiation levels in the reactor vaults could result in retube workers exceeding their quarterly dose limits prematurely. This would have dramatically increased the retube outage duration and manpower costs as larger numbers of workers would have to be trained. All known benefits of learning curves would be lost to the project and manpower management would become perilously more difficult.

All retube facilities, equipment, and tooling had to be designed, procured, commissioned, and integrated. With the units already shutdown, there was tremendous pressure to deviate from the processes, methods, and systems that had been established and followed until then. All temptations to opt for a "jump in and get the job done" philosophy were resisted and the systems approach adopted during the early days of the retube program was adhered to religiously until the end.

Pickering "A" units 1 and 2 were shutdown for retube at about the same time. Both units had Zircaloy-2 pressure tubes that had become suspect after the unit 2 - G16 pressure tube failure. Initially, it was felt that both units could be retubed in parallel. However, during early stages of the fuel channel removal phase, especially after the discovery of the Carbon-14 problem, a decision was made to continue retubing one unit at a time.

Today, first three retubed units of Pickering "A" are running at full power and unit 4 retube fuel channel installation phase is progressing extremely well towards its August 23, 1992 target completion date. The outage is several weeks ahead of its original schedule and is expected to be completed just over a year after the unit was shut down for its retube outage on August 14, 1991.

RETUBE SYSTEMS AND SITE ENGINEERING

The three phases of a CANDU reactor retube program and the major tasks involved in each phase are depicted in Figure 2.

Pre-outage Phase Systems Engineering

Systems engineers lead the retube pre-engineering work during the pre-outage phase of the program. They define the retubing process in detail and identify all activities involved in unit preparation, fuel channel removal, and fuel channel installation.

Systems engineers in consultation with designers prepare **Series Logic Diagrams** (SLD's) for each outage phase. SLD's break reactor face work into groups of activities that are called face or row series. A ***face series*** of activities involve work being carried out at all fuel channel sites before starting the next series of activities. A ***row series*** involves group of work activities performed across a row of fuel channels before proceeding with the next group of activities on that row. Most **fuel channel removal phase work** involves **face series** activities. Although the face series work strategies are generally more efficient from a production viewpoint, the more stringent quality control requirements of the **fuel channel installation phase** dictate the adoption of a **row series** based scenario.

During the next stages of the process, systems engineers identify all facilities, tooling, and equipment related requirements pertinent to successful implementation of retube work series activities. This includes definition of tool design concepts and assessment of tool quantities requirements.

In consultation with the site engineering and health physics staff, retube system engineers generate dose and duration estimates for all work activities. Dose and duration estimates contribute to the decision making process for the provision of self-shielding and automation features in tool and equipment designs. Process design refinements contemplated at this stage reflect and emphasize the dose and duration minimization objectives of the retube program every step of the way.

A START (acronym for Schedules, Tools, and Activities for ReTube) team comprising representatives from tool and equipment designer organizations, systems engineers, project engineers, and site experts convene to review, scrutinize, and validate the proposed process.

Systems and design engineers prepare systems requirements and interface control documents for specific facilities, tooling, and equipment. Interface control documents define interfaces to ensure that equipment designed by different groups and organizations can eventually be integrated and made to work efficiently and harmoniously.

Utility's supply and project engineering staff oversee the design, procurement, and commissioning activities for retube facilities, tooling, and equipment. Designers prepare and issue Tool Operating Procedures (TOP's)and training manuals for use by site personnel.

Outage Phase Site Engineering

There are two principal groups involved with the site work during the retube outage: Retube Construction and Retube Rehabilitation. Construction group carries out nearly all work pertaining to fuel channel removal and installation phases of the outage. They prepare detailed work plans for all work series activities, including hazard analyses for fuel channel removal phase high hazard work. They manage all aspects of site retube work including safety, quality, production, cost, and scheduling.

Retube Rehabilitation group staffed by utility's nuclear operations personnel is responsible for miscellaneous unit preparation phase work such as defuelling and decontamination (CANDECON). They control all rehabilitative work on nuclear systems other than fuel channels and Primary Heat Transport (PHT) system feeders. Rehabilitation group has the responsibility of ensuring all conventional systems are properly laid up or rehabilitated during the retube outage. They manage all work related to refuelling, recommissioning, and restart activities.

MAJOR RETUBE SYSTEMS

Human Resources, Tooling and Equipment, Facilities, Reactor Components, and Information Management are among the major systems required during a retube outage. Each of these major systems comprise several subsystems or secondary systems. A Retube systems diagram is depicted in Figure 3.

Significant interfaces exist among the various systems and among their subsystems. Lack of careful interface definition and control can lead to inefficiencies, and ultimately to difficulties in achieving the overall retube program objectives on safety, quality, schedule, and cost.

Retube Human Resources System

Retube site organization pools the skills and talents of staff from the utility's design engineering, supply, construction, and operations departments and is supplemented with engineering and technical expertise from outside consultants such as AECL CANDU and GE-Canada. Some 300-400 construction tradespersons and 150 engineering and technical staff participate in the retube site work during the outage.

Design engineering and supply departments stationed at Ontario Hydro's head office have direct or project management responsibility for system and process definition, equipment and component design and procurement, and overall program coordination. A significant portion of the design and procurement work is undertaken by consultants such as **AECL CANDU** and GE-Canada under contract to Ontario Hydro. Construction engineering at site is responsible for tool and equipment testing and integration, reactor component preparation and quality control, work planning and scheduling, and cost monitoring. Construction trades carry out majority of the reactor face work with quality control support from site engineering.

Tooling and Equipment System

Tooling and equipment system comprises thousands of individual tools and equipment required for retubing work. Vast majority of tooling required for the retube program are designed, (usually prototyped), procured, tested, and shipped to site.

Upon delivery to site, tools are entered in the computerized Tool Monitoring System that keeps track of tool quantities, status, and locations. There are training and production quantities of all tools. As a matter of policy, training tools are always made identical with the production tools. This prevents breaches of safety and quality that may result from training tools becoming production spares in the rare instances where chronic tool break downs result in unavailability of production tools to continue reactor face work uninterrupted. Normally, training tools are kept in the training and mock up building and away from the radioactive work area where production tools are in use.

Many new tools are designed and built, and many existing tools are modified at site to keep pace with the rigours, demands, occasional surprises, and never-ending challenges of the retube work environment.

Retube Facilities

In multi unit stations such as Pickering, it is essential to have dedicated retube facilities for warehousing; equipment repair and maintenance; tool staging, storage, and decontamination; irradiated component handling; and new reactor components preparation. Training and mock up buildings, offices for retube support staff, and additional changerooms for retube workers are among other essential facilities that must be built and commissioned.

Irradiated Components Management System (ICMS) facility is used for transferring highly radioactive reactor components such as pressure tubes from in-station flasks to Dry Storage Modules (DSM's) that are used for interim storage of high level radioactive wastes at site.

Training of workers on reactor face activities, and tool proving and integration take place on the full scale reactor mockups in the Training and Mock-up Building (TMB) facility.

Reactor Components System

All baseline, contingency, and refurbished components required for the retube program form the reactor components system. All components arrive at site with proper history dockets containing material traceability information, and inspection and test reports supplied by the component manufacturers. Site engineering ensures all reactor components are stored according to strict storage requirements specified by the fuel channel component design authority. Systems must be put in place to maintain a running inventory of all components and to ensure availability of adequate reactor component spares throughout the retube outage.

Retube Information Management System

All documentation and electronic data used during the retube outage constitute the retube information management system. Efficient operation of retube systems would not be possible without the presence of a complementary information management system that is well designed and integrated. Implementation of several LAN based computerized retube information management systems along with an electronic mail system is an essential ingredient of a successful retube program. A brief description of some major retube information management systems is given below:

i) **Daily Work Log (DWL)** provides the reactor face crews with a facility for reporting significant events and occurrences related to safety, quality, production, tooling, and equipment.

ii) **Retube Quality Control** program helps monitor all reactor face activity progress with special emphasis on reporting and resolution of reactor components related discrepancies and deviations.

iii) **Retube Deficiency Reporting** (RDR) system provides a facility to record, and monitor to resolution all reported deficiencies.

iv) **Tool Monitoring System** (TMS) helps with tool identification and monitors tool quantities, status, and locations.

v) **Integrated Training System** (ITS) monitors training status of all retube workers on all retube work activities to ensure that only properly trained and qualified workers are allowed to perform reactor face activities. Integrated Training System facilitates orderly planning and scheduling of retube training activities.

vi) **Tool Processing System** (TPS) monitors tool repair, calibration, maintenance, storage, and disposal activities.

vii) **Electronic mail system** (E-Mail) facilitates rapid written communication among retube site engineering, systems engineering, design engineering, and other parts of the utility's Engineering and Construction Services organization. It provides effective communication links to fuel channel designers, outside consultants, and the utility's nuclear operations organization.

CONCLUSIONS

The complete life cycle of a Retube program spans 6-8 years. The pre-outage phase activities require 4-5 years and the outage and post-outage activities another 2-3 years.

During the pre-outage phase, systems engineers define the retubing process and identify all activities involved in unit preparation, fuel channel removal, and fuel channel installation. It is essential that a team of systems engineers, tool and equipment designers, project engineers, and site experts review, scrutinize, and validate the proposed retubing process. Adoption of a systems approach particularly during the pre-outage phase is crucial. Investments in pre-engineering activities pay handsome dividends through significant reductions in total outage duration and worker dose. Competent systems engineering can lead to a more practical and realistic retubing system by breaking down complicated processes into simpler and easier to manage chunks of work activities.

Production and quality related program objectives can only be realized through intensive and comprehensive training programs for all retube workers and continuous quality improvement initiatives. The use of the work series teams concept provided extremely encouraging results during the P4 Retube outage. The work series teams provided an excellent platform for soliciting ideas for process and tooling improvements by bringing together site engineers, technicians, and trades personnel. There is overwhelming evidence that the use of work series teams significantly contributed to the reductions in outage duration and dose during P4 Retube.

Unique challenges of retube programs can be met and successful implementation ascertained by paying meticulous attention to details, avoiding hasty decisions, and resisting the temptation to opt for "quick fix" solutions throughout all program phases. Lack of careful process definition and control can lead to inefficiencies, and ultimately to difficulties in achieving the overall retube program objectives on safety, quality, schedule, and cost.

Having a well trained, qualified, and experienced organization, able to operate in a "proactive" rather than "reactive" mode is critical to successful execution of retube site work. It is just as crucial to ensure that the retube site organization has the tools, facilities, training programs, and the competent engineering support needed to realize its program goals and objectives.

Quality problems that usually result from lack of adequate training or deficiencies in process definition or ambiguities in quality related requirements and guidelines can lead to diminished confidence and lower morale among retube workers. Any break downs in quality can have serious implications on radiological and conventional safety and productivity.

Success means more than just a retubed reactor, it generates enthusiasm, dedication, and a strong team spirit among workers. A well managed and systems oriented retube organization can provide the environment essential for retube workers to realize their inherent desire to be part of a winning endeavour. Retube is the major Plant Life Extension (PLEX) issue for CANDU Nuclear Power Plants. A well executed retube program can mean a reactor capable of producing power reliably throughout its post-retube design life.

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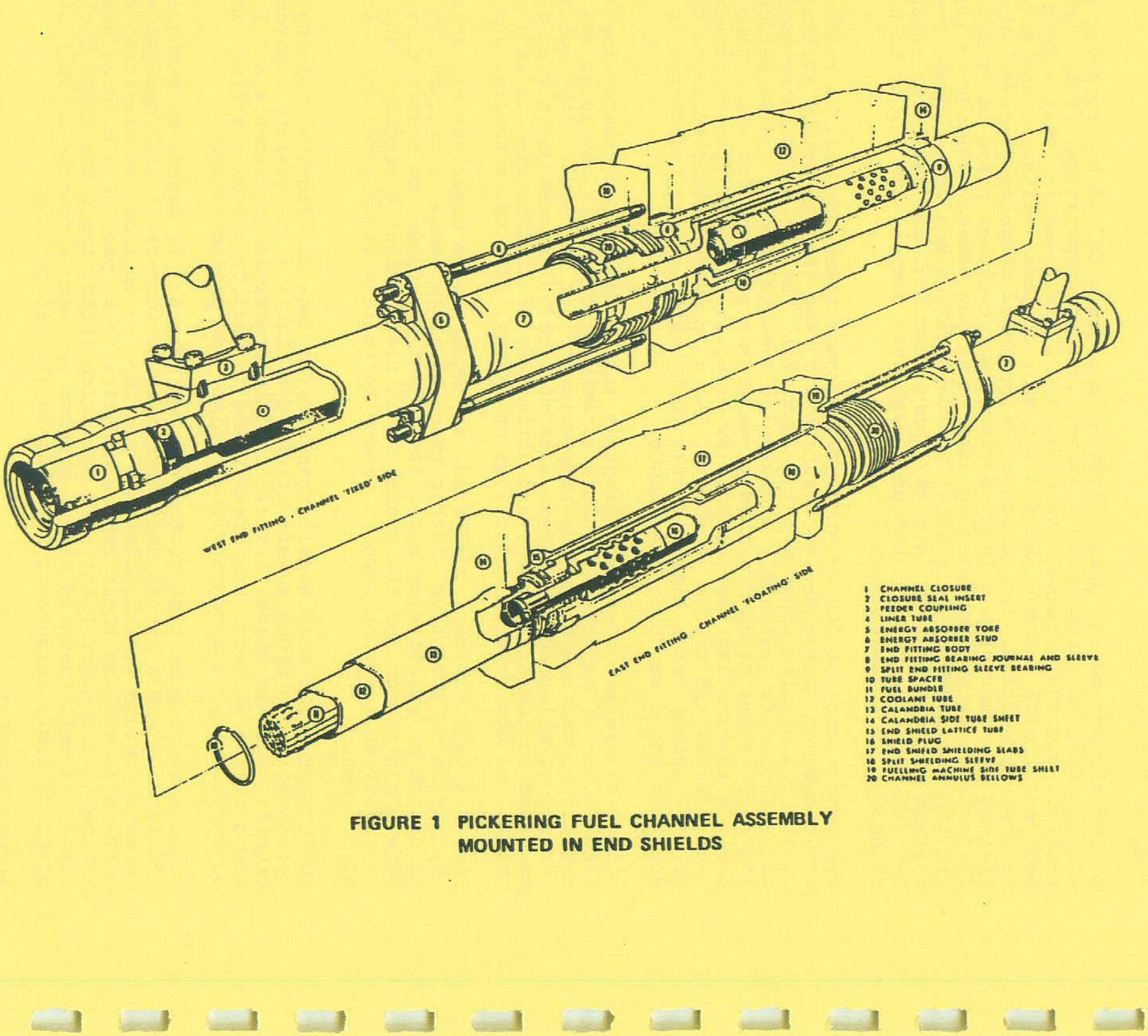

FIGURE 1 PICKERING FUEL CHANNEL ASSEMBLY MOUNTED IN END SHIELDS

FIGURE 2 - RETUBE PROGRAM PHASES AND MAJOR TASKS

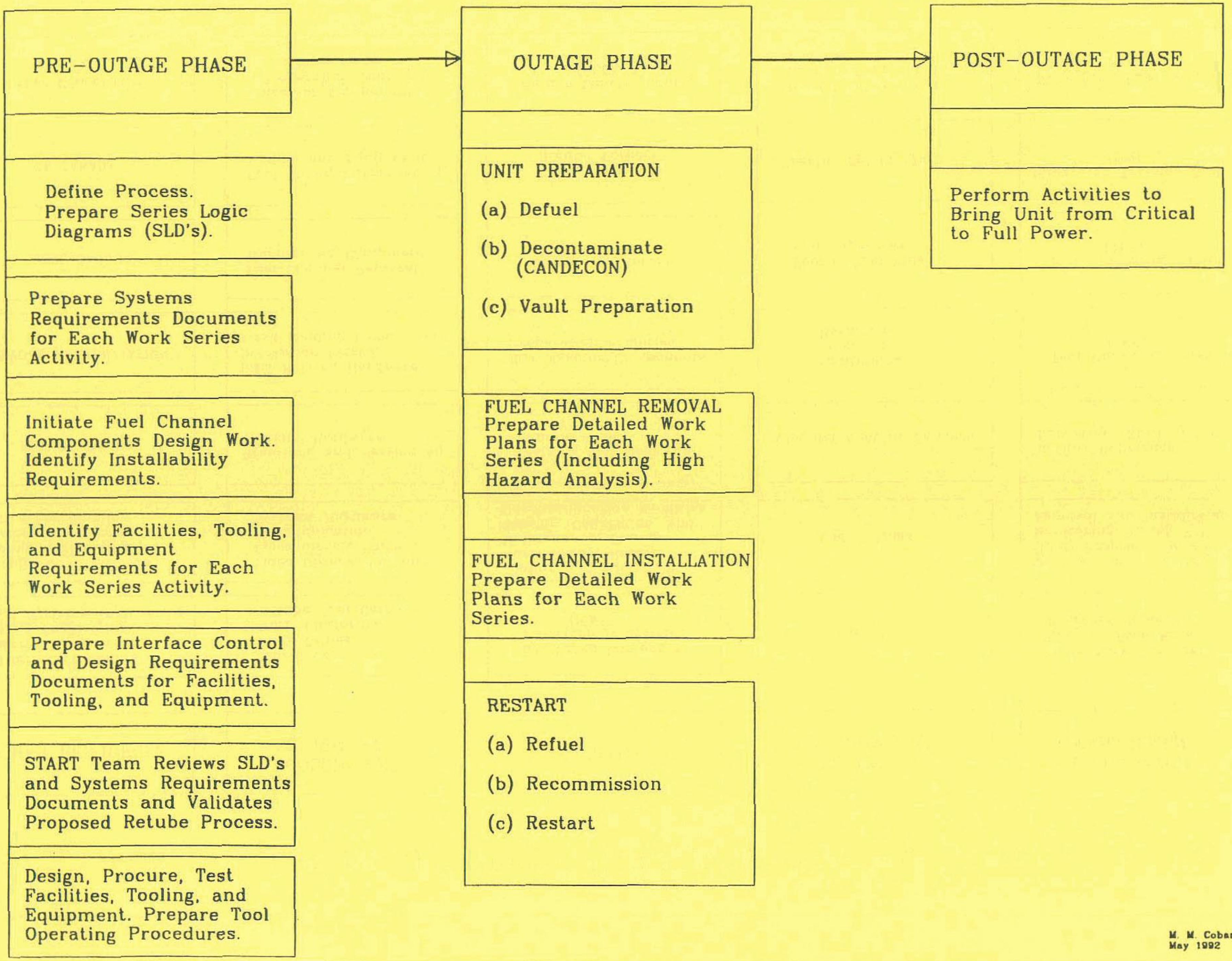

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FIGURE 3 – RETUBE SYSTEMS DIAGRAM

HUMAN RESOURCES	TOOLING AND EQUIPMENT	FACILITIES	REACTOR COMPONENTS	INFORMATION MANAGEMENT
RETUBE ENGINEERING Systems Engineering Tooling Engineering Plant Systems Engineering	Shield Cabinets, Work Tables, Work Platforms, Retube Tool Carriers	Irradiated Components Management System (ICMS)	Pressure Tubes	Daily Work Log (DWL): Reactor Face Work Progress Reporting
RETUBE CONSTRUCTION Tooling Engineering Reactor Engineering Series Coordination	Video Observation and Close Circuit Voice Communication Systems Hardware	Tooling and Equipment Warehousing, Repair, Maintenance, Storage, Staging, Calibration, and Decontamination Facilities	End Fittings	Quality Control Retube (QCR) Program: QA Activity Monitoring During F/C Removal and Installation
RETUBE TRADES	Breathing and Service Air Systems Hardware	Training and Mock-up Building (TMB)	Channel Annulus Spacers	Retube Deficiency Reporting (RDR) System
RETUBE REHABILITATION	ICMS Related Hardware In-Station Flasks, Flask Loading Devices, etc.	New Reactor Components Preparation Facilities	Positioning Assembly Hardware	Tool Monitoring System (TMS)
AECL CANDU	Fuel Channel Removal Tooling and Equipment	Offices for Retube Support Staff	Feeder Seal Rings and Capscrews	Tool Processing System (TPS)
GE CANADA	Fuel Channel Installation Tooling and Equipment	Changerooms for Retube Workers	Reactor Shield Plugs	Integrated Training System (ITS)
Other Consultants	Reactor Components Preparation Tooling and Equipment	Retube Control Centre (RCC)	Miscellaneous Other Reactor Components and Parts	Networked Electronic Mail (E-Mail) System

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