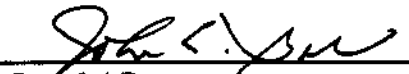



This course was originally developed for the use of Ontario Hydro employees. Reproduced on the CANTEACH web site with permission

NUCLEAR TRAINING DEPARTMENT
COURSE 41001
INTRODUCTION TO CANDU PROCESSES

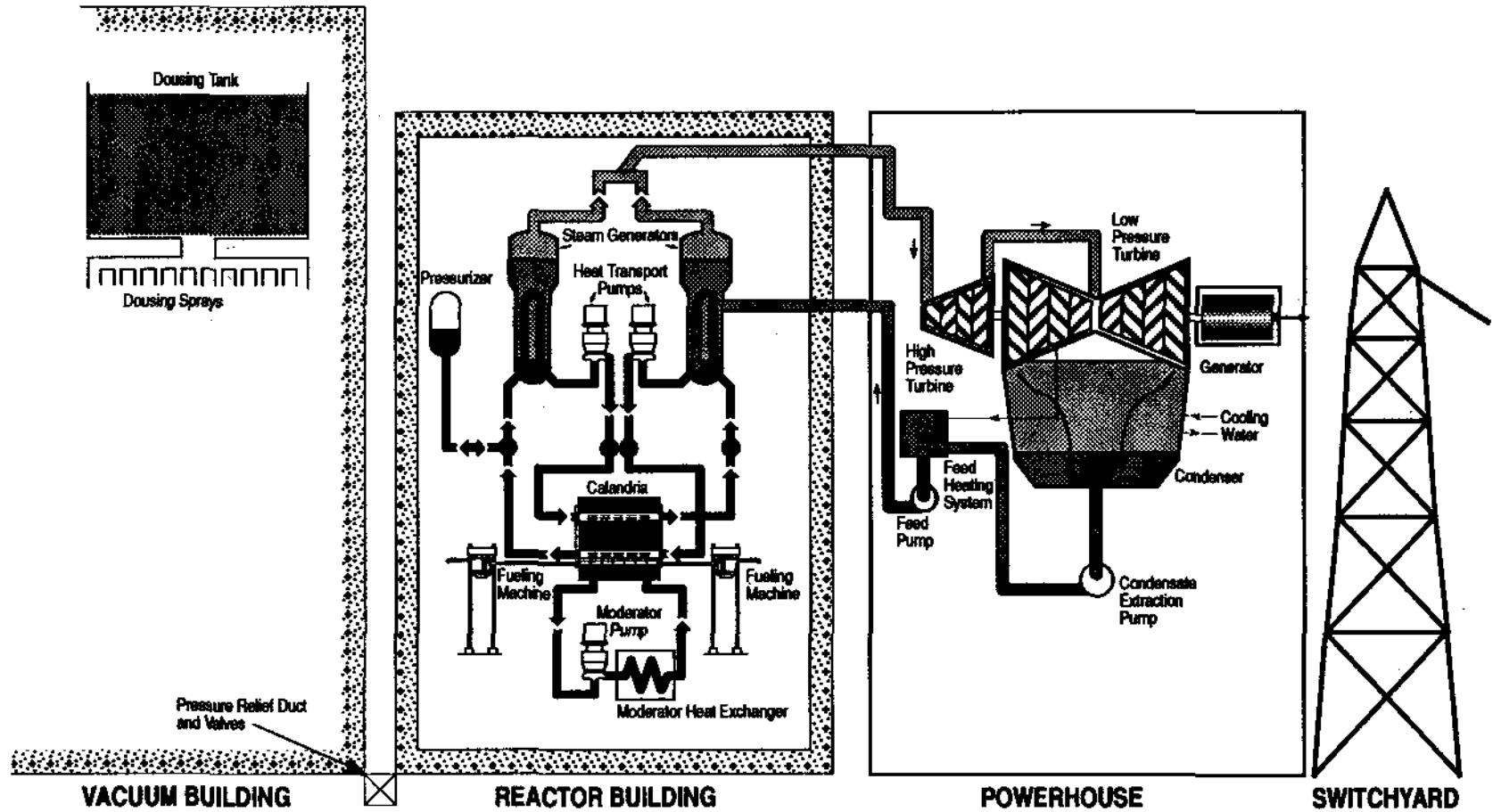
FOR ONTARIO HYDRO USE ONLY

R1 - 93.09.15

INTERIM APPROVAL FOR USE AT WNTD		
Prepared by:	Dioscoro Ejercito Graham Cooke Sam Austman	Date: 93.04.23
Revised by:	Sam Austman	Date: 93.09.15
Verified by:	 Level 4 Programme Coordinator	Date: 94.02.01
Approved by:	 Training Officer	Date: 94.02.01

Nuclear Generating Unit Schematic

CANDU Pressurized Heavy Water Reactor



 Heavy Water Moderator	 Steam
 Heavy Water Heat Transport System	 Water

PREFACE

This course will prepare you to use and understand the terminology and concepts of the CANDU Power Station. The course invites new staff to support Hydro's primary goal of providing abundant, competitively priced, safe and clean electrical and heat energy to Ontario's people and industries.

After the course, you will be able to convey the following ideas to your colleagues, families and friends:

- CANDU Reactors are a Canadian invention, with construction and operation of commercial reactors pioneered by Ontario Hydro early on in the history of worldwide nuclear power generation.
- Ontario Hydro is the major user of CANDU technology, deriving over half the province's power from these systems. CANDUs are also operating in Quebec and New Brunswick, and have been purchased by five other countries.
- The CANDU design, using heavy water for cooling and moderation, differs significantly from reactors such as those used in the USA and most other nations.
- The CANDU design is *more* expensive to build and refurbish but provides *safer* and *less expensive* operation because it uses natural Uranium and has on-power refueling capability.
- The use of a heavy water moderator to sustain a nuclear reaction makes the precise geometry of the reactor vital to continuing the reaction. Any serious damage to the reactor core stops the nuclear reaction.
- Ontario Hydro's Nuclear Operations Branch (NOB) has developed an organizational structure intent on supporting an Operating Philosophy based on staff and public safety as well as reliable and economic power generation.

In summary, CANDU remains a valid, modern technology, based on its inherent economy of operation, safety and reliability.

REVISION SUMMARY

R1 93.09.15

- table of contents added
- course pages renumbered sequentially
- minor changes/additions throughout to clarify/correct text and correction of typos in response to comments received from EAST class in June 1993, from ENTD, and from WNTD instructor
- major rewrite of Module 1 section E to reflect reorganisation of Nuclear during summer of 1993

TABLE OF CONTENTS

PREFACE	III
REVISION SUMMARY	IV
TABLE OF CONTENTS	V
INTRODUCTION	XI
BRIEF HISTORY OF CANDU	XI
ADMINISTRATION	XI
COURSE OBJECTIVE	XI
AUDIENCE	XII
PROGRAMME STANDARD	XII
COURSE STRUCTURE	XIII
LOOKING FORWARD	XIV
OPERATING PHILOSOPHY	1
INTRODUCTION	1
A. EMPLOYEE AND PUBLIC SAFETY	3
MAJOR HAZARDS ASSOCIATED WITH OUR NUCLEAR FACILITIES	4
RADIATION	4
HYDROGEN SULPHIDE	7
ALARA - OUR PHILOSOPHY TOWARDS HAZARDS	7
A SAFE WORKING ENVIRONMENT	7
SAFETY STANDARDS	8
ASSIGNMENT	9
B. REACTOR SAFETY	11
BASIC RELIABILITY CONCEPTS	12
DEFINITIONS	13
CONCEPTS	13
ASSIGNMENT	16
DEFENCE IN DEPTH	17
EFFECTIVENESS OF DEFENCE IN DEPTH	21
ASSIGNMENT	21
DOCUMENTATION	22
ASSIGNMENT	24

C. ENVIRONMENTAL LIMITS	25
NUCLEAR STATION RADIOACTIVE EMISSIONS	26
EMISSIONS FROM THE BRUCE HEAVY WATER PLANT.....	27
ASSIGNMENT	27
D. ECONOMICS OF CANDU	28
TOTAL UNIT ENERGY COST	28
ASSIGNMENT	31
E. HOW WE CONDUCT OUR BUSINESS	33
ORGANISATION.....	34
THE ROLE OF LICENCED POSITIONS WITHIN THE NUCLEAR STATION	37
THE JOB FAMILIES THAT MAKE UP THE STATION STAFF	39
PLANNING AND THE DEFICIENCY REPORT PROCESS	41
WRAPUP AND SELF-CHECKING.....	43
ASSIGNMENT	44
REFERENCES	46
THE REACTOR SIDE OF THE STATION.....	47
INTRODUCTION	47
A. PRINCIPLE OF REACTOR OPERATION	48
ATOMIC STRUCTURE.....	48
FISSION	50
CHAIN REACTION	51
CRITICALITY AND NEUTRON MULTIPLICATION	52
THE REACTOR CORE.....	54
FUEL	54
MODERATOR	55
CORE GEOMETRY.....	56
ASSIGNMENT	57
B. MAJOR COMPONENTS OF CANDU REACTORS.....	58
KEY CANDU COMPONENTS.....	59
THE REACTOR CORE STRUCTURE.....	60
SHIELDING	63
ON POWER FUELLING	63
THE MODERATOR SYSTEMS	64
THE MAIN MODERATOR SYSTEM	64
MODERATOR AUXILIARIES	65
MODERATOR HEAT SOURCES.....	67

THE HEAT TRANSPORT SYSTEMS	67
THE MAIN HEAT TRANSPORT SYSTEM	67
HEAT TRANSPORT AUXILIARIES	69
OTHER FEATURES OF THE HTS LAYOUT.....	70
MODERATOR AND HTS HEAVY WATER.....	71
ASSIGNMENT	72
C. HEAT PRODUCTION AND REACTOR REGULATION	74
HEAT FLOW IN THE MAIN HEAT TRANSPORT SYSTEM.....	74
REACTIVITY MECHANISMS.....	76
FINE REACTIVITY REGULATION.....	76
COARSE REACTIVITY CONTROL.....	78
MANUAL AND AUTOMATIC REACTIVITY ADJUSTMENTS	79
ASSIGNMENT	80
D. REACTOR, PERSONNEL AND PUBLIC PROTECTION	82
HAZARDS	82
NITROGEN-16 AND OXYGEN-19	82
TRITIUM	83
OTHER HAZARDS	84
SAFETY SYSTEMS.....	84
SHUTDOWN SYSTEMS	84
EMERGENCY COOLANT INJECTION (ECI)	87
CONTAINMENT.....	89
TWO-OUT-OF-THREE TRIP SYSTEM	91
ASSIGNMENT	93
THE CONVENTIONAL SIDE OF THE STATION	95
INTRODUCTION.....	95
A. STEAM AND FEEDWATER CYCLE.....	96
THE BOILER (STEAM GENERATOR)	97
THE STEAM/FEEDWATER CYCLE	100
THE STEAM SYSTEM	100
BOILER FEEDWATER SYSTEM.....	108
LOW PRESSURE FEEDHEATING SYSTEM.....	110
THE DEAERATOR AND STORAGE TANK.....	110
HIGH PRESSURE FEEDHEATING SYSTEM.....	111
LUBRICATION SYSTEM.....	112
THE TURNING GEAR.....	112
CHEMICAL CONTROL.....	112

ASSIGNMENT	113
B. THE GENERATOR.....	116
AC GENERATOR ENERGY CONVERSION.....	116
GENERATOR COOLING	117
ASSIGNMENT	118
C. CONVENTIONAL AND RADIOLOGICAL HAZARDS.....	119
CHEMICAL ENERGY.....	119
THERMAL ENERGY	119
ELECTRICAL ENERGY	119
MECHANICAL ENERGY.....	120
NOISE ENERGY	120
PRESSURIZED FLUID ENERGY	120
RADIATION ENERGY	120
ASSIGNMENT	121
ENERGY BALANCE AND UNIT CONTROL	123
INTRODUCTION	123
A. EFFICIENCY AND ENERGY CONVERSION	124
ENERGY CONVERSIONS IN A CANDU STATION.....	124
EFFICIENCY OF NUCLEAR GENERATION.....	125
ASSIGNMENT	127
B. ENERGY BALANCE.....	128
MEASURED PARAMETERS	128
BOILER PRESSURE CONTROL (BPC).....	129
UNIT MODE OF OPERATION	131
REACTOR LAGGING MODE.....	131
REACTOR LEADING MODE.....	131
IMPORTANT PROGRAMS	131
REACTOR REGULATING SYSTEM (RRS)/ REACTOR POWER CONTROL.....	133
BOILER PRESSURE CONTROL (BPC)	133
UNIT POWER REGULATION (UPR)/ TURBINE LOAD CONTROL.....	133
BOILER LEVEL CONTROL (BLC)	133
HEAT TRANSPORT SYSTEM PRESSURE AND INVENTORY CONTROL (HTSP)....	134
ASSIGNMENT	134
C. UNIT OPERATIONAL CONTROL.....	136
OPERATOR/COMPUTER INTERFACE.....	137
ASSIGNMENT	138

SUPPORT SYSTEMS.....	139
INTRODUCTION.....	139
A. ELECTRICAL SYSTEMS.....	140
MAJOR COMPONENTS.....	140
CLASSES OF POWER.....	142
CLASS IV POWER.....	143
CLASS III POWER.....	143
CLASS II POWER.....	143
CLASS I POWER.....	143
EMERGENCY POWER SYSTEM (EPS).....	144
ASSIGNMENT.....	145
B. WATER AND AIR SYSTEMS.....	147
LIGHT WATER SYSTEMS.....	147
WATER TREATMENT.....	148
CONDENSER COOLING WATER.....	149
COMMON SERVICE WATER.....	149
LOW PRESSURE SERVICE WATER SYSTEM.....	149
HIGH PRESSURE RECIRCULATING SERVICE WATER SYSTEM.....	149
EMERGENCY WATER SYSTEM.....	150
OTHER WATER SYSTEMS.....	150
AIR SYSTEMS.....	150
INSTRUMENT AIR.....	150
SERVICE AIR.....	151
BREATHING AIR.....	151
ASSIGNMENT.....	151
C. IDENTIFICATION SYSTEM.....	153
EQUIPMENT IDENTIFICATION.....	153
FIELD IDENTIFICATION.....	155
PIPING.....	155
FLOWSHEETS.....	155
ASSIGNMENTS.....	156
D. SITE SUPPORT SYSTEMS.....	157
BULK ELECTRICAL SYSTEM.....	157
CENTRALIZED MAINTENANCE SERVICES.....	158
BRUCE BULK STEAM SYSTEM.....	159
ASSIGNMENT.....	159

E. WASTE MANAGEMENT	160
LIQUID WASTE MANAGEMENT	160
INACTIVE DRAINAGE	161
ACTIVE DRAINAGE	161
SOLID WASTE MANAGEMENT	162
IRRADIATED FUEL STORAGE	162
WASTE VOLUME REDUCTION AND STORAGE	162
ASSIGNMENT	163
F. HEAVY WATER PRODUCTION AND MANAGEMENT	164
HEAVY WATER PRODUCTION	164
ENRICHING	164
FINISHING	166
HEAVY WATER MANAGEMENT	166
LOSS RECOVERY	167
UPGRADING	168
TRITIUM REMOVAL	168
ASSIGNMENT	170
APPENDIX	173
COMPARISON OF COMMERCIAL NUCLEAR REACTOR TYPES	173

INTRODUCTION

BRIEF HISTORY OF CANDU

The CANadian Deuterium Uranium (CANDU) reactor, a product of Atomic Energy of Canada Limited (AECL), is a Canadian invention that evolved from war-time experimentation at the Chalk River Nuclear Laboratories northwest of Ottawa. Commercial construction and operation of CANDU reactors was pioneered by Ontario Hydro in the early 1960s. The CANDU design, using heavy water for cooling and moderation, differs significantly from reactors used in the United States and many other countries. It is more expensive to build, but its use of natural uranium and on-power fuelling make it less expensive to operate. Its heavy water moderator and reactor core geometry also make it inherently fail-safe.

CANDU reactors have been purchased by a number of utilities apart from Ontario Hydro. CANDU reactors are currently operating in Quebec, New Brunswick, India, Pakistan, Argentina and Korea, and several reactors are under construction in Romania. The Indian programme has been the most extensive, starting with an early partnership with AECL and later Ontario Hydro that led to the commissioning of a CANDU reactor in 1972, and culminating in recent years with an independent CANDU programme of significant proportions.

CANDU is one of many reactor designs in use throughout the world. The predominant design in use in the United States and many other countries is the pressurized light water reactor. Other designs include boiling water reactors and graphite moderated reactors (gas cooled designs in Britain, water cooled in the former Soviet Union). More information on reactor designs is provided in an Appendix to this course.

ADMINISTRATION

COURSE OBJECTIVE

This is intended to be the first course in the initial technical training programme for new hires. The **overall objective** of the course is:

to familiarise new employees with the basic terminology and concepts associated with the Nuclear Business with the intent of fostering better understanding and more effective communication within and between work groups.

This is achieved by introducing the function, operation and interactions of the CANDU station and processes associated with CANDU. At the same time this course will also introduce you to:

the technology of CANDU and the importance of economical, reliable operation;

the general process hazards and conditions;

the importance of various CANDU safety concepts and environmental concerns.

The course will enable you to represent CANDU technology knowledgeably to the public.

AUDIENCE

This course is intended for new employees in the following major job families within the Nuclear Business:

Operators,
Mechanical Maintainers,
Control Technicians,
Chemical Technicians,
Civil Maintainers,
Management and Professional Technical Staff.

It is also suitable for anyone requiring a basic introduction to CANDU. To have the maximum effect, the course should be delivered to trainees soon after they have been hired. Staff who have been working at a Nuclear Station for more than one year will gain little from this course.

PROGRAMME STANDARD

The **overall objective** for the course is provided above. In addition, each module of the course is introduced by a **module objective**. These

objectives serve to highlight the general intent of each level of the course. The module objectives are in turn supported by **enabling objectives** which focus on the material to be learned in each section. The checkout is based entirely on the enabling objectives. Often the course text will delve deeper into a topic than is required to meet these objectives. This is intended to provide background and context, **but remember you will only be tested on the enabling objectives.**

In this and subsequent courses, you are required to achieve a mark of at least **80% on the course checkout.**

COURSE STRUCTURE

The course begins with an introduction to the operating philosophy of the Nuclear Business, followed by an examination of the reactor and turbine sides of the CANDU station. The two sides are tied together by a short module on overall unit control. A final module addresses both those systems with a major support role within the station, and other important systems and processes outside the stations (such as heavy water production). Course delivery is spread over a period of seven days including time for structured review and a checkout on the last afternoon.

Each of the modules in the course has been laid out in a common format with a common way of highlighting information to make it easier for you to absorb. Each module begins with a brief introduction that includes the module objective (see above). The module objective lists a number of key points that will be covered. These are lettered A, B, C, etc. and these letters conform to the major sections of the module. Each major section begins with a list of enabling objectives (see above). The text that follows will cover off the objectives in order, but there is no explicit tie back to the enabling objective. A number of subtitles are used within each section to break the material down further in a logical fashion. The **MAJOR SUBTITLE** is in bold capitals and underlined. The **NEXT LEVEL OF SUBTITLE** is in bold capitals. Being aware of this convention will help you to understand the structure of the material. Other conventions to be aware of are the use of:

- **bullets (• a key point)** to highlight lists of key points of information;
- **bold type** to highlight the first occurrence of a **significant new term**, or a particularly important piece of information;
- **footnotes** to provide related information that does not fit in the flow of the text and is not required to satisfy an enabling objective.

Assignment questions are generally provided at the end of a major section of a module. These are not marked. They are provided to help you check your understanding of the information required to satisfy the enabling

objectives. Please take the time to answer the assignment questions as you work through the material. It will pay off in preparing you for the final checkout.

LOOKING FORWARD

Upon completion of this course, further technical courses will be provided in the areas of science fundamentals and equipment principles specifically related to the job functions of the trainee.¹ In addition to the technical courses, all trainees will receive training in the following subjects:

- general safety;
- fire protection;
- emergency first aid;
- initial radiation protection;
- information management.

¹ For M&P staff, these courses may be delayed by a work experience assignment at a nuclear facility of up to 10 months.