CANDU Concept Maps

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Summary:

Herein, we illustrate the overall concepts and topics in the various disciplines involved in the design and operation of CANDU reactors. This provides some guidance for the detailed study of CANDU reactors made possible by the many documents available through the CANTEACH web site http://canteach.candu.org.

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1 Introduction

In the following, we look at CANDU from the top down, i.e. starting with the big picture and work our way into the systems and subsystems of CANDU to gain an understanding of how they are designed and why they are designed that way. This is obviously a work in progress that will evolve from a working outline. In considering why CANDU is designed the way it is, we need to place the plant in its societal context to establish the boundary conditions and limits imposed on the overall design (see How and Why is CANDU designed the way it is by W. Garland, Doc# 20000101) and work inward, first on the overall plant level to establish a rough overall design, then consider the systems needed and finally work down to the component level. Of course the component and system levels have constraints and properties of their own, such as the basic phenomena and processes as illustrated in Figure 1, which dictate what can be done and this information must be fed up to the plant and overall context level. It is necessarily an iterative process. The outlines in this document merely hint at some of the considerations.

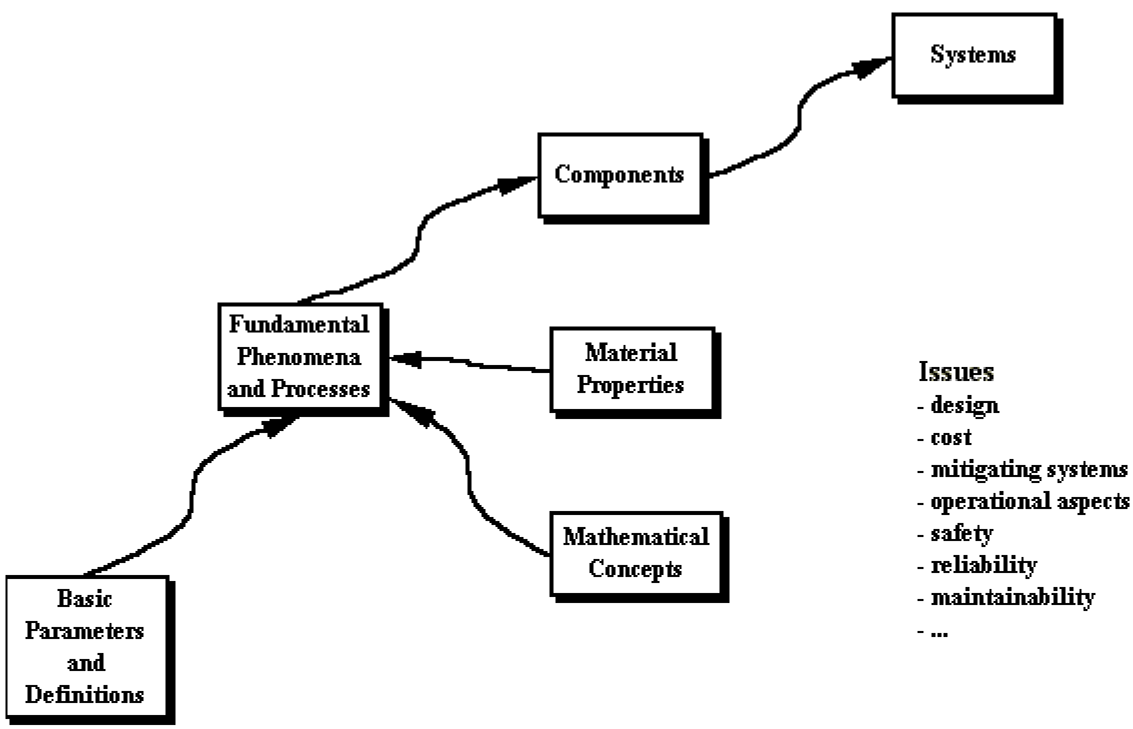

Figure 1 Generic Concept Map.

2 Overview Outline

First we look at an overview outline to help in the conceptualization of the major considerations that go into plant design. Discipline specific outlines are given in subsequent sections.

Context Level

'Why' based on social needs and issues

- Comparison to alternate energy forms
- Consideration of available resources

Plant Level

'Why' based on the fundamentals that span a number of systems

- clean sheet approach
    - fission
        - fission products
            - kinetic energy -> heat
                - decay heat
                    - long term cooling
                - cooling
                - useful work via heat engine
                    - heat removal
                    - heat rejection
                - process heat
            - radiation inventory
            - risk
                - workers
                - public
        - radiation
            - shielding
            - material damage
        - burnup
            - refueling
        - fuel and moderator design
        - measurement
            - process control
- plant design assessment
    - critique of existing designs
        - simple calculations to evaluate certain effects
        - criteria
            - coolant temperature

        - erosion / corrosion
        - vibration / fretting
        - fluence
        - measurement / control
        - pressure
        - cost
            - algorithms
        - legacy
            - seminal papers
    - engineering limits
        - velocity
        - quality
            - erosion / corrosion
            - swell / shrink
            - CHF
    - design decisions
        - horizontal channels
        - refuelling
        - thermosyphoning
            - placement of heat sinks and sources
        - fuel
        - coolant
        - moderator

Systems Level

'Why' based on system level considerations

- reactor physics
- heat transport system
    - how does it work?
        - flow balance
        - heat duty diagram
        - HTS efficiency vs thermodynamic efficiency
            - need high T, therefore high P
        - heat balance
        - layout
        - pump NPSH
        - flow control
            - on / off pump
            - variable quality
    - optimization
        - D2O holdup
        - feeder layout

- tube growth accommodation
- pipe sizing
- options
  - pros and cons of boiling
  - alternate coolants
  - separate moderator
- ideal HTS
  - low pressure
  - high T
  - high heat capacity
  - high conductivity
  - good moderator
  - low friction
  - cheap
  - coolant doesn't decompose
  - coolant doesn't become radioactive
  - coolant is non-corrosive
- secondary side
- balance of plant
- chemistry

Component Level

'Why' based on component characteristics and limitations

- valves
- pumps
- instrumentation

3 Reactor Physics

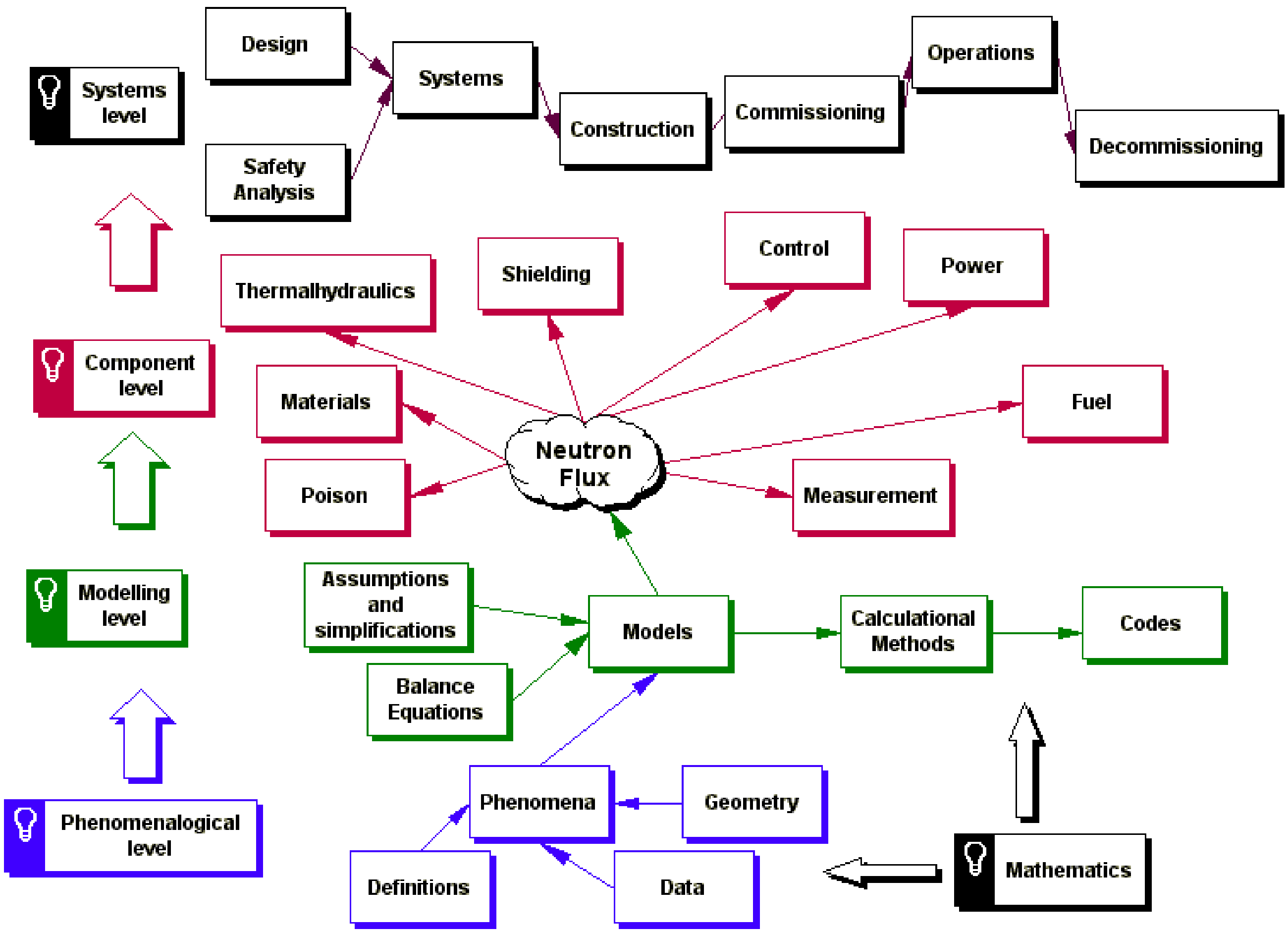

Figure 2 Reactor Physics Concept Map.

1. Basics / Phenomena level
   a. Nuclear structure [C1.1] ← reference notation, see list at end of this section.
      i. N, A, Z
      ii. Isotopes
      iii. Mass
      iv. Mass defect and binding energy
      v. Nuclear energy levels
      vi. Radioactivity
         (1) half-life
         (2) becquerel
         (3) activity / activation buildup

- b. Basic definitions [EP4D3] [C1.7] [C1.3]
  - i. r, Ω, E, t
  - ii. Neutron density, n [C1.1]
  - iii. Flux, φ [AECL-TTM1] [C1.1]
  - iv. Current, J [AECL-TTM1] [C1.1]
  - v. Microscopic cross section, σ [C1.1]
    - (1) E dependence [RMC511]
  - vi. Macroscopic cross section, Σ[C1.1]
    - (1) E dependence [RMC511]
- c. Conservation of energy [AECL-TTM1]
  - i. Equivalence of mass and energy [C1.1]
  - ii. Chemical vs nuclear
- d. Nuclear interactions [EP4D3] [AECL-TTM1] [C1.1] [C1.3]
  - i. Absorption
    - (1) Fission
      - (a) fission products [AECL-TTM1] [C1.1]
      - (b) energy release [C1.1]
      - (c) power and fuel consumption [C1.1]
    - (2) capture
    - (3) $\alpha=\sigma_c/\sigma_f$ [RMC511]
  - ii. Scattering
    - (1) elastic [C1.1]
    - (2) inelastic [C1.1]
  - iii. Types [AECL-TTM1]
    - (1) (n,2n), (n,2n), nu [RMC511] [C1.1]
    - (2) (n, gamma) [C1.1]
    - (3) (n, alpha) [C1.1]
    - (4) (gamma, n) photoneutrons [C1.1]
  - iv. Interaction rate
    - (1) magnitudes and statistical fluctuations [C1.7]
    - (2) effective cross section [RMC511]
    - (3) reaction rate = $\Sigma\varphi$ [RMC511] [C1.1]
  - v. Delayed neutrons and Precursors [C1.7]
  - vi. Neutron spectra
    - (1) prompt [C1.7] [C1.1]
    - (2) delayed [C1.7]
    - (3) Maxwellian [C1.1]
    - (4) 1/E [C1.1]
    - (5) Westcott convention [RMC511]
  - vii. Neutron energy cycle [RMC511]
  - viii. Moderation process and moderator properties [C1.1]
- e. Neutron balance [EP4D3] [C1.7] [C1.1]
  - i. Variation with lattice pitch [C1.1]
- f. Chain reactions [EP4D3]

            i. Multiplication, k, rho
            ii. Four / six factor formula [RMC511] [C1.1]
            iii. Geometry effects [C1.1]
                (1) intro to leakage
                (2) Fick's law
                (3) critical shape
                (4) flux distributions
                (5) homogeneous / heterogeneous
                (6) flux flattening
                (7) reflector
            iv. Critical mass [AECL-TTM1] [C1.1]
            v. Need for control [AECL-TTM1]
        g. Decay heat [C1.1]
2. Modelling level
        a. General neutron balance [C1.3]
            i. Generic mass / particle balance equation [C1.7]
            ii. Boltzmann transport equation [C1.7]
            iii. General precursor balance equation [C1.7]
        b. Energy Partitioning [C1.7]
            i. Age theory [RMC511]
            ii. Multigroup definition [C1.3]
            iii. Condensation [C1.3]
        c. Transport approximations
            i. P_L theory
            ii. Diffusion approximation (P_1) [EP4D3]
                (1) Derivation of Fick's Law
                (2) Validity
                (3) Matrix form of the Diffusion equations [C1.7] [C1.3]
        d. Spatial mesh [C1.7]
            i. Core
            ii. Cell
        e. Boundary and Initial conditions [C1.7]
            i. Edges
            ii. Interfaces
        f. Numerical methods [C1.7]
            i. Finite differences [EP4D3]
            ii. BC and IC treatment [EP4D3]
            iii. Explicit vs implicit [EP4D3]
            iv. Convergence
            v. Consistency
            vi. Stability
            vii. Truncation error
        g. Statics
            i. One speed neutrons - fixed sources [EP4D3] [C1.7]

(1) Spectral radius
(2) LU decomposition
(3) Gaussian elimination
(4) Jacobi
(5) Gause-Seidel
(6) Successive Over-Relaxation (SOR)

ii. 1-D reactor [EP4D3] [C1.7]
(1) Criticality search / eigenvalues [C1.3]

iii. Multigroup [EP4D3] [C1.7]

iv. Numerical criticality [EP4D3] [C1.7]
(1) Power method

v. Cell calculations [EP4D3] [C1.7]

vi. Adjoint flux [C1.3]

vii. Perturbation theory [C1.3]

h. Space-Time Kinetics [C1.7]

i. Separation of variables [C1.3]
(1) Point kinetics [EP4D3] [C1.3]
(a) descriptive and simple equations [C1.1] [C1.2]
(b) analytical soln
(i) prompt jump [C1.1] [C1.2]
(ii) prompt criticality [C1.1] [C1.2]
(iii) inverse method [C1.3]
(iv) reactor trips [C1.1] [C1.2]
(v) neutron source effects [C1.1] [C1.2]
(c) numerical integration
(2) Adiabatic
(3) Quasi-static
(4) IQS

ii. Synthesis
(1) Modal expansion
(2) Space-time synthesis
(3) Nodal method of Avery

iii. Direct methods
(1) Finite differences
(2) Exponential transforms

i. Computer Codes

i. Nuclear data
(1) NJOY
(2) ENDF

ii. Cell codes
(1) POWDERPUFS-V [C1.5] [AECL-TTM1]
(2) WIMS and WIMS-AECL [AECL-TTM1]
(3) DRAGON

iii. Supercell codes [AECL-TTM1]

(1) MULTICELL
(2) DRAGON
iv. Core codes
(1) CERBRUS (IQS) [C1.5]
(2) SMOKIN (Modal) [C1.5]
(3) 3DDT
(4) DONJON
(5) RFSP [AECL-TTM1]
v. Fuel Management
(1) RFSP [C1.5]
vi. Monte Carlo
(1) MCNP
vii. Plant optimization
(1) AESOP

3. Component level
a. Depletion [EP4D3]
i. Fuel reaction chains [RMC511] [AECL-TTM1]
(1) U235, P239, P240, P241, P242, U238, fission products [C1.1]
(2) Burnup (MW h / kg) [AECL-TTM1] [C1.1]
ii. Burnup equations
iii. Fluence [RMC511]
iv. Fission yields [RMC511]
v. General solution [RMC511]
vi. Calculations [RMC511]
(1) Reactivity change [C1.1]
(2) Burnup
b. Poison [EP4D3] [C1.1]
i. Cross sections [RMC511]
ii. Equations
(1) Burnable [RMC511]
(2) Non-burnable [RMC511]
iii. Reactivity worth
iv. Xenon oscillations
v. Flux tilt
c. Dynamics / Coupled Neutronics-Thermalhydraulics [C1.5]
i. Feedback [EP4D3]
ii. Heat transfer [EP4D3]
iii. Thermalhydraulics [EP4D3]
iv. Temperature effects [C1.1] [C1.2]
(1) Doppler
v. Spectrum effects [C1.1] [C1.2]
vi. Coolant effects [C1.1] [C1.2]
(1) Void
(2) Density

- vii. Moderator effects
- viii. Geometry effects
    - (1) Creep
    - (2) Sag
- ix. Codes and code methodology

d. Power and power measurement [C1.1] [C1.2]
- i. Thermal vs neutron power
- ii. Decay heat
- iii. Photoneutrons
- iv. Detectors and instrumentation
    - (1) General intro
    - (2) Reactions used
    - (3) Thermal
        - (a) boron
        - (b) fission
        - (c) self-powered
    - (4) Applications
    - (5) Flux mapping
    - (6) Common problems

4. Systems level
    - a. Operational control
        - i. Approach to criticality [C1.1] [C1.2]
    - b. Systems
        - i. CANDU
            - (1) Basic characteristics of CANDU lattice [AECL-TTM1]
                - (a) typical burnup
            - (2) Core design [C1.4]
                - (a) fuel [AECL-TTM1]
                - (b) pressure tube concept [AECL-TTM1]
                - (c) moderator [AECL-TTM1]
                - (d) calandria
                - (e) reactivity devices [AECL-TTM1]
                - (f) liquid zone control [AECL-TTM1] [C1.1] [C1.2]
                - (g) mechanical control absorbers [AECL-TTM1] [C1.1] [C1.2]
                - (h) adjuster rods [AECL-TTM1] [C1.1] [C1.2]
                - (i) booster rods [C1.1] [C1.2]
                - (j) moderator level [C1.1]
                - (k) detector systems [AECL-TTM1]
                - (l) flux mapping [AECL-TTM1]
                - (m) void reactivity [AECL-TTM1]
            - (3) Methodology for r/p analysis [C1.4]
            - (4) Initial fuel loading [C1.4]
            - (5) Commissioning [C1.4]
            - (6) Safety systems

(a) SDS1
(b) SDS2
(i) moderator dump [C1.1]
(ii) moderator poison [AECL-TTM1] [C1.1]
(c) ROP
ii. PWR
iii. BWR
iv. MAPLE
v. SLOWPOKE [C1.5]
vi. MNR [EP4D3]
c. Fuel Management (CANDU) [C1.5] [AECL-TTM1]
i. Objectives [RMC511] [C1.1]
ii. Tools
iii. Core assumptions
(1) Equilibrium [RMC511] [C1.1]
(2) Fresh [RMC511] [C1.1]
(3) k_∞ [AECL-TTM1]
(4) Radial flattening [AECL-TTM1]
(5) Channel power cycle [AECL-TTM1]
iv. Simulations
v. Strategies and effects [RMC511]
(1) Core tracking
(2) Channel peaking factor [AECL-TTM1]
(3) Bidirectional fuelling and axial distribution [C1.1]
vi. Fuelling machine
vii. On-power refuelling [RMC511] [AECL-TTM1]
viii. Xenon effects [AECL-TTM1]
ix. Cobalt production
x. Fuel cycle costs [RMC511]
xi. Fuel inventory [RMC511]
xii. TUEC [RMC511]
d. CANDU Safety Analysis [C1.5]
i. Feedback mechanisms
ii. DBAs
iii. Reactor physics
iv. Thermalhydraulics
v. Coupled r/p - t/h
e. SLOWPOKE safety analysis [C1.5]
i. LOCA analysis
ii. Reactor model - point kinetics
iii. Feedback models
iv. Thermalhydraulic model
v. Simulation

References:

C1.1 Chulalongkorn - Module 1.1, Nuclear Theory, same as OPG Science Fundamentals 22106 by Ian Cameron, July 1997 (R-1) given by Chaplin. This is an update to the older OH course 227. OH 227 contains a section on radioactive buildup which is not in OPG 22107. OPG 22106 contains a section on Detectors and Instrumentation which is not in OH 227.

C1.2 Chulalongkorn - Module 1.2, Nuclear Physics and Reactor Theory Supplementary Text by John Groh.

C1.3 Chulalongkorn - Module 1.3, Reactor Kinetics by Daniel Rozon.

C1.4 Chulalongkorn - Module 1.4, Reactor Physics and Fuelling Strategies, TDAI 244 (1980) by Pasanan, given by Brenciaglia.

C1.5 Chulalongkorn - Module 1.5, Reactor Core Analysis and Fuel Management, Rozon and Rouben.

C1.7 Chulalongkorn - Module 1.7, Neutronic Analysis of Reactors by Jean Koclas.

EP4D3 McMaster - Engineering Physics 4D3, Nuclear Reactor Analysis, a 4th year reactor physics course based on Duderstadt and Hamilton given by Bill Garland.

RMC511? Royal Military College - Nuclear Engineering 511, Nuclear Fuel Engineering, a graduate course by Hugues Bonin.

AECL-TTM1 AECL Technical Training Material - Reactor Physics by Ben Rouben, February 2000.

4 Thermalhydraulic Concepts

1. Basics / Phenomena level
    a. Nomenclature
    b. General conservation equation
    c. Mass balance
    d. Momentum balance
    e. Energy balance
    f. Equation of state
    g. Macroscopic vs microscopic (lumped vs distributed)
    h. Heat transfer
        i. Conduction
        ii. Convection
            (1) forced
            (2) free
        iii. Radiation
    i. Fluid mechanics
        i. Friction and pressure drop
        ii. Potential flow
        iii. Viscous flow
            (1) Velocity profiles
            (2) turbulence
        iv. Compressible flow (gas)
        v. Flow measurement
        vi. Boundary conditions
        vii. Correlations
    j. Two-phase flow
        i. Models
        ii. Flow regimes
        iii. Boiling
            (1) Pool
            (2) Convective
        iv. Condensation
2. Modelling level
    a. Node-link form for systems
    b. Distributed form for components
3. Components level
    a. Fuel - coolant heat transfer
        i. Overview
        ii. General heat conduction equation
        iii. Plates
        iv. Radial heat transfer (pins)

(1) fuel
(2) gap
(3) sheath
(4) coolant
(5) overall delta T

v. General thermal energy equation
vi. Axial temperature distribution
vii. Axial quality distribution
viii. Critical heat flux

b. Fuel
  i. Metallurgical considerations
  ii. Possible fuels (U, Th, Pu, ...)
  iii. Metal vs ceramic
  iv. Plates vs pins
  v. Brook's summary
c. Feeders
  i. NUCIRC
  ii. Sizing
  iii. Layout
  iv. Creep allowances
d. Endfittings
e. Headers
  i. Sizing
  ii. Flow distribution
f. Pumps
  i. Sizing
  ii. NPSH
  iii. Head-flow curve
  iv. 4 quadrant characteristics
g. Heat exchangers
h. Steam generators
  i. Sizing
  ii. Integral or separate preheater
  iii. Recirculation
  iv. Material selection
  v. Costing
  vi. Area margin
i. Valves
  i. Types and characteristics
  ii. Equations
  iii. Sizing
  iv. Standards
j. Pressure vessels
  i. Standards

ii. relief valve sizing
k. Measurement devices
i. Flow
(1) orifice
(2) ultrasonic
ii. Temperature
(1) RTD
(2) thermocouple
iii. Pressure
iv. Level
4. Heat Transport System
a. How does it work?
i. Simple circuit and heat balance
ii. Flow operating point - pump head vs flow and losses vs flow
iii. Simple equations
iv. Simple heat duty diagram
v. Solutions to simple case
(1) flow approximately constant
(2) primary T floats on top of the secondary T
(3) secondary side governed by SS P
(4) variation with power
vi. HTS efficiency vs thermodynamic efficiency
vii. PIC
viii. Control and transient behaviour
b. An ideal HTS
i. Low P, high T
ii. Coolant cheap, stable to P, T and radiation, non corrosive
iii. Hign heat capacity
iv. Hign conductivity
v. Moderator properties
vi. Low friction
vii. Gord Brooks' paper
c. Design considerations
i. Variations on a theme (# of pumps, layout, figure of 0, 8, split core in Bruce, ...)
ii. Layout for thermosyphoning
iii. Pump downstream of the SG for NPSH considerations
iv. Boiling on primary side
(1) incentives
(2) problems
(a) swell and shrink
(b) instabilities
(i) figure of 8
(ii) ledinegg

(iii) ...

v. Water hammer

vi. Resonant pressure waves (as per Darlington fuel breakup problem)

vii. Limitations

(1) pump size

(2) SG size

(3) core size

(4) velocity

(a) erosion

(b) corrosion

(c) fretting

(5) steam quality and void fraction

(6) CHF and CPR

(7) D2O holdup

(8) creep (axial and radial)

viii. Measurements

ix. Optimization

(1) AESOP equations and procedure

(2) pipe sizing

x. Feeder layout

xi. SG sizing

xii. Control

xiii. Simulation

(1) tools

(2) runs

(a) steady state

(b) power run up - overpressure protection

(c) trips

(d) Class IV power failure

(e) ...

(3) verification and validation

xiv. Evolution and legacy

xv. Exploration of alternate designs

(1) H2O coolant

(2) organic coolant

(3) common moderator / coolant

(4) fuel design is low pressure - pins still needed?

d. Safety analysis (focus on how design relates to safety)

i. DBA

ii. LOCA

iii. LOR

iv. Loss of flow

v. Flow blockage

vi. Human factors

e. Commissioning
   i. Code lockon
      (1) flow
      (2) heat transfer

f. Operation
   i. Normal
   ii. Upset
   iii. Accident
   iv. Fault diagnosis and response

References:

C1.1 Chulalongkorn - Module 1.1, Nuclear Theory, same as OPG Science Fundamentals 22106 by Ian Cameron, July 1997 (R-1) given by Chaplin. This is an update to the older OH course 227. OH 227 contains a section on radioactive buildup which is not in OPG 22107. OPG 22106 contains a section on Detectors and Instrumentation which is not in OH 227.

5 Corrosion Concepts

1. Overview
    1. What is corrosion
    2. Cost
2. Basics / Phenomena level
    1. Nomenclature
    2. Measurement
    3. Electrochemistry
        1. Ions
        2. pH
        3. Basics balance equations
        4. Potentials
        5. Galvanic cells
        6. Reference electrodes
        7. Dry cells
        8. Limitations of the analogy
    4. Metallurgy
        1. Grain structure
        2. Phase diagrams
    5. Thermodynamics
        1. I am out of my element here for sure - help!
    6. General protection methods
    7. Descaling
    8. 8 forms of corrosion
        1. General
            1. description
            2. equations / calculations
            3. mechanisms
            4. environmental effects
            5. examples
            6. analysis
            7. prevention / mitigation
        2. Galvanic
            1. description
            2. equations / calculations
            3. mechanisms
            4. environmental effects
            5. examples
            6. analysis
            7. prevention / mitigation
        3. Crevice

1. description
2. equations / calculations
3. mechanisms
4. environmental effects
5. examples
6. analysis
7. prevention / mitigation

4. Pitting
    1. description
    2. equations / calculations
    3. mechanisms
    4. environmental effects
    5. examples
    6. analysis
    7. prevention / mitigation
5. Intergranular attack
    1. description
    2. equations / calculations
    3. mechanisms
    4. environmental effects
    5. examples
    6. analysis
    7. prevention / mitigation
6. Selective leaching
    1. description
    2. equations / calculations
    3. mechanisms
    4. environmental effects
    5. examples
    6. analysis
    7. prevention / mitigation
7. Erosion corosion
    1. description
    2. equations / calculations
    3. mechanisms
    4. environmental effects
    5. examples
    6. analysis
    7. prevention / mitigation
8. Stress corrosion cracking
    1. description
    2. equations / calculations
    3. mechanisms
    4. environmental effects

        5. examples
        6. analysis
        7. prevention / mitigation
3. Modelling level
    1. Chemistry
    2. Metallurgy
    3. Corrosion
4. Components level
    1. Hydrogen effects
    2. Steam generator
        1. Conditions
        2. Corrosion mechanisms
        3. Model formulation
        4. Analysis
        5. Prevention / mitigation
    3. Valves
        1. Conditions
        2. Corrosion mechanisms
        3. Model formulation
        4. Analysis
        5. Prevention / mitigation
    4. Pipes
        1. Conditions
        2. Corrosion mechanisms
        3. Model formulation
        4. Analysis
        5. Prevention / mitigation
    5. Vessels
        1. Conditions
        2. Corrosion mechanisms
        3. Model formulation
        4. Analysis
        5. Prevention / mitigation
    6. Heat exchangers
        1. Conditions
        2. Corrosion mechanisms
        3. Model formulation
        4. Analysis
        5. Prevention / mitigation
    7. Condensers
        1. Conditions
        2. Corrosion mechanisms
        3. Model formulation
        4. Analysis

        5. Prevention / mitigation
    5. Systems level
        1. Environmental factors
        2. Interplay of components
        3. Prevention / mitigation

References:

C7.3 Chulalongkorn - Module 7.3, Corrosion for Engineers by Derek Lister.

6 Instrumentation, Control and Electrical Concepts

Drafted by Mike MacBeth

1. Introduction to IC&E for CANDU NPP
   - High level CANDU Plant Block Diagram with parameters noted
   - Discuss operational states and changes in parameters
   - Outline the need for the provision of key indicators and automatic control capability
   - Some simple loop concepts showing the need for Instrumentation, Control and Electrical devices
2. CANDU NPP Regulation and Protection Concepts
   - Introduce Safety Concepts related to I&C, margins, maintenance thresholds
   - Introduce Reliability, Redundancy, Grouping & Separation, Testing.
   - Introduce Regulation Applications - Plant Control
   - Sample Regulation Systems
   - Introduce Protective Applications - Plant Protection
   - Sample Protection Systems
   - Introduce Post Accident Management System (PAMS)
3. Fundamentals of CANDU NPP Instrumentation
   - Introduce key CANDU NPP Instrumentation measurement applications
4. CANDU NPP Instrumentation Equipment and Components
   - Overview of Generic CANDU NPP Instrumentation Equipment and Components
5. CANDU NPP GSI Oriented Instrumentation Equipment and Components Applications
   - Specific examples of CANDU NPP Instrumentation Equipment and Components installations and intended functions
6. CANDU NPP Man-Machine Interface Concepts
   - CANDU NPP Information Presentation Strategies
   - Main Control Room, Secondary Control Area and Local Panel Indicators and Annunciators
   - Human Factors Engineering Concepts, Error Catching and Error Mitigation
   - Post Accident Management
7. Fundamentals of CANDU NPP Electrical
   - Electrical Grouping and Channelization
   - In-Plant Electrical Power Distribution
   - External Grid Connection, Ring Bus and Unit System Service Transformer
   - Automatic Electrical Transfer Concepts

    - Emergency Electrical Transfer Concepts
8. CANDU NPP Electrical Grouping, Classes of Power and Grounding Practices
    - Functional Grouping
    - Classes of Power and Rationale
    - Station Electrical Grounding Practices
9. CANDU NPP Electrical Distribution and Transfers
    - Typical Station Electrical Bus distribution and loads, by Class
    - Transfer logic goals
    - Standby Generator function, logic and loading
10. CANDU NPP Electrical Equipment and Components
    - Generic CANDU Electrical Equipment & Components organized by Voltage and Function
11. CANDU NPP GSI Oriented Electrical Equipment and Components Applications
    - Specific examples of CANDU NPP Electrical Equipment and Components installations and intended functions organized by GSI
12. CANDU NPP Electrical Support for I&C including Distribution and Qualification
    - Class II and Class I Power Review
    - Power Supply Lists, Fusing and Generic I&C Loops
    - Testing of Power Supply Integrity for Odd/Even
    - Sample GSI applications
13. Fundamentals of CANDU NPP Control
    - CANDU Plant Operating Modes (Normal, Alternate)
    - Define Manual, Automatic, Supervisory and Semi-Automatic Modes
    - Control Transfer Strategies and Requirements
14. CANDU NPP Control Equipment and Components
    - Generic Loop Equipment and Components Required for Control Applications
15. Generic Control Strategies and Approaches
    - Introduce concept of Negative Feedback Control
    - Control Modes (PI&D) - function and general application
    - Further Control Concepts (Feedforward, cascade)
16. Overview of CANDU NPP Control Techniques
    - General Control Strategies for sample Key systems
    - Typical Generic CANDU Loop examples
17. CANDU NPP GSI Oriented Control Applications
    - GSI Specific Control loops and Strategies for Key CANDU systems with a review of Control Program rules
    - Overall Plant Control loops and Strategies
18. CANDU NPP I&C Commissioning Concepts
    - General I&C Commissioning Considerations
    - Key system commissioning goals and concerns
19. CANDU NPP Start-up and Approach to Critical I&C Interfaces and Operational Concerns
    - Special I&C Requirements

- Start-up Instrumentation and Range Overlap
- Interfacing System Requirements
- A start-up Scenario

20. CANDU NPP Power-up Maneuvers I&C Interfaces and Operational Concerns
    - Review Interfacing of Key Systems and expected performance
    - Key indicators and Transfers
    - A power-up example
21. CANDU NPP Trips, Upsets and Shutdown I&C Interfaces and Operational Concerns
    - Review of expected unit disturbances like Reactor Trip, Setback, Stepback and Turbine Trip
    - Role of I&C in maintaining stable control of unit during these events
    - Specific CANDU NPP examples of integrated I&C systems and expected process responses.