Mathematics - Course 121

INTRODUCTION

As the following table of lifetime capacity factors shows, CANDU nuclear generating units have out-performed all other types of nuclear stations in the world.

Table 1

World Comparison of Lifetime Capacity Factors of Nuclear Units 500 MW(e) and Larger (to 1980)

CANDU - PWR	77%
PWR	57%
BWR	55%
GCR	45%

This outstanding performance is attributable in part to a comprehensive and coordinated program of research and development, design, manufacturing, construction, and operations. A significant feature of this program, which has been operating since 1942, is feedback of operating experience to researchers, designers and manufacturers.

By 1981, Ontario Hydro had accumulated 82 reactor-years' operating experience with CANDU units. Right from the start, Nuclear Operations at Ontario Hydro has followed a Management by Objectives approach. The basic objectives fall under the following five headings:

- Worker Safety
- Public Safety
- Environmental Emissions
- Reliability
- Cost

Numerical indices have been established to *quantify* performance in each of these five areas, so that performance can be *measured*, compared with targets, and *analysed* for trends. The reliability of plant systems is critically important to achieving objectives in all of these five years.

The following are a few highlights of performance abstracted from the May, 1980 report "Candu Operating Experience", by McConnell, et al. (1)

1. Worker Safety

During 55 million manhours (1962-79):

- zero fatalities
- very low injury rate (2.8 per million manhours)
- zero injuries due to radiation
- zero serious radiation exposures (>25 rem per annum).

2. Public Safety and Environmental Emissions

During 72 reactor-years' operation:

- zero fatalities
- zero injuries of any kind for any reason to any member of the public
- zero radioactivity releases resulting in a measurable dose to any member of the public
- radioactivity risk criteria met at every station in every year.

3. Reliability

Table 2 shows the ranking of Ontario Hydro's eight CANDU units in the world's 104 large (>500 MW(e)) units. See also Table 1 which compares CANDU with PWR, BWR and GCR reactors).

Table 2

Canadian Ranking in World's 104 Commercial Reactors
500 MW(e) and Larger - Lifetime

Unit	Gross Capacity Factor (%)	World Rank
Pickering 2	85	1
Pickering 1	83	3
Bruce 4	79	4
Bruce 3	78	5
Pickering 4	78	6
Pickering 3	78	7
Bruce 1	70	18
Bruce 2	61	43

4. Cost

Nuclear generation is cheaper than thermal generation via fossil fuels because the cost of fossil fuels is about ten times the cost of uranium fuel per unit energy output. For example, the total unit energy costs (including debt retirement, fuelling, operating, maintenance and administration costs) at Pickering NGS-A and Lambton TGS are 10.90 and 19.37 mills per kWh, respectively. (These stations are comparable in size and vintage.)

High reliability of plant systems is crucial to achieving Ontario Hydro's five basic objectives as explained below:

1. Worker Safety

The more reliable the plant equipment, the fewer manhours required to maintain equipment, and hence, the less worker exposure to death or injury.

2. Public Safety

There is no risk to public safety unless both process and safety systems fail simultaneously. Hence, the more reliable these systems, the safer the public.

3. Environmental Emissions

The more reliable the plant process and safety systems, the lower the risk of radioactivity releases to the environment, for example, via process water effluent.

4. Reliability

The more reliable plant systems, the less time on forced outage, and hence the higher the plant capacity factor.

5. Cost

The more reliable the plant process systems:

a) the fewer maintenance personnel required, ie, the lower maintenance costs, and

b) the fewer forced outages which reduce the plant capacity factor and hence, the better the return on plant investment.

It is clear that obtaining and maintaining highly reliable plant systems is an objective common to all five basic objectives of Nuclear Operations. Achieving highly reliable plant systems involves virtually every phase of the project-design, purchasing, commissioning, operations and maintenance.

The general aim of this course is to provide the trainee with sufficient background in elementary reliability theory that he will be able to

a) when designing equipment or systems:

- recognize that cost and reliability are the two major considerations, the one usually weighing against the other.
- estimate system reliability from component reliabilities.
- estimate component redundancy required to meet target reliability.

b) when purchasing equipment:

- interpret manufacturer's reliability specifications
- ask for appropriate data if not supplied voluntarily.
- recognize farcical or meaningless claims, eg,
  "bridges the reliability gap"
  "up to 100 million mechanical operations"
  "dependable performance"
  "proven reliability", etc.

c) when commissioning equipment/systems, devise means of demonstrating equipment/system reliability.

d) when 'operating' plant equipment/systems:

- recognize the importance of collecting accurate data on failures, outages and repairs.
- calculate component/system reliability from failure rate data.
- rationalize the need for, and design, maintenance schedules (especially for preventive maintenance and/or replacement of components).
- rationalize the need for, and design, test schedules for passive safety systems.

e) rationalize the role of station reliability in minimizing cost of electricity and maximizing plant safety.

f) rationalize the existence of Reliability Departments in Ontario Hydro, and interpret reports published by such groups.

The term "reliability" has been used in the foregoing without definition because its technical meaning is similar to its meaning in the common vernacular. However, a definition of reliability as a quantity which can be calculated or measured is required for technical applications.

Working Definition of Reliability of a Device

- *the probability that the device will perform its purpose adequately for the period of time intended under the operating conditions encountered.*

Note that the reliability is a probability, and has a numerical value ranging from 0 for the impossible event to 1 for the inevitable event. Note too that this probability usually has a time dependency which can be mathematically modelled. Although more advanced treatments model both degree of performance and variations in operating conditions, this introductory course assumes only two degrees of performance - either the device is fully capable of, or utterly incapable of, performing its intended purpose. The operating conditions are assumed constant.

Reliability theory is the application of the methods of probability and statistics to predict system reliability on the basis of operating experience (failure rates).

Limitations of Reliability Techniques

1. The validity of reliability calculations is based on the assumption of statistical regularity in equipment failures due to normal causes. Failures due, for example, to sabotage, or to collisions between earth and other celestial bodies do not enter the picture.

2. Reliability Theory cannot be used to predict precise events or times thereof, only probabilities and statistical averages. For example, one could not calculate the precise time and duration of the next forced outage on Pickering NGS unit 3, but one could calculate the expected frequency and average duration of forced outages on unit 3, or the probability that a forced outage will occur within, say, 90 days.

Reference:

(1) L.G. McConnell et. al., Candu Operating Experience, Report NGD-9 (May, 1980)

ASSIGNMENT

1. Explain the implications of station reliability for Ontario Hydro's objectives in the following areas:

   (a) Public Safety

   (b) Worker safety

   (c) Environmental emissions

   (d) Reliability of electricity supply

   (e) Cost

2. State the working definition of the reliability of a device.

3. State two basic limitations on the applicability of reliability theory.

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