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AVAILABILITY CALCULATIONS FOR NUCLEAR MATERIAL PROCESSING FACILITIES

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by

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ABSTRACT

Methods for developing reliability and maintainability information and integrating it into availability calculations useful in the design and development of nuclear fuel processing facilities are being investigated. Effective availability (actual productive time) is of greater interest than the more traditional operating availability, which only indicates the time a system is available for operation if needed. Actual productive time calculations allow more precise estimates of redundant equipment and surge storage needs, so that facilities can be sized with greater confidence that they will meet production commitments. Judgmental estimates of reliability and maintainability from personnel involved in equipment design can be used as interim data to guide developmental efforts. These data can be used in computer modeling of integrated process operations. Simulated process operations can be used to study the effects of various redundant equipment and surge storage configurations on plant effective availability (i.e., the time the plant is actually producing at a prescribed rate). The judgmental estimates and the operations model can be upgraded as actual reliability and maintainability data are generated in demonstration plants. This will lead to a better understanding of the design requirements for commercial-scale plants.

1. INTRODUCTION

To determine the cost and the price of goods, manufacturing plant throughput must be precisely known. Plant throughput is highly dependent on the capability of the manufacturing equipment within the plant. This capability includes the cost of operating the equipment, the amount of hours it is available for operation, the amount of hours it actually operates, and the output per equipment unit. The capability of nuclear material processing plants such as fuel fabrication facilities, spent fuel reprocessing facilities, and waste processing facilities is important in minimizing their contribution to the increasingly expensive cost of power generation. This paper suggests that techniques for calculating the operational availability and efficiency of plants for manufacturing consumer goods can be modified and applied to nuclear material processing facilities as an aid in developing plant designs that will meet production goals.

2. AVAILABILITY CALCULATIONS

General Atomic Company (GA)[1] has investigated methods of calculating the availability of remote nuclear material processing systems (Refs. 1,2), and a new method which differs from standard methods of calculation has been proposed. In a standard processing or manufacturing plant, the effects of system unavailability can be offset by including redundant or diverse systems in the plant design which continue to operate when the primary

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system fails. Feed and product material can be stored between process steps so that when a system is unavailable, the operation of neighboring systems will not stop. Three major differences from a standard plant must be considered in the design of a nuclear material processing plant:

1. Hot cell space is expensive to build and expensive to operate; therefore, space for redundant equipment and surge storage should be limited.

2. The equipment itself is expensive because of stringent quality assurance requirements and special design for remote operation; therefore, the number of pieces of equipment should be limited.

3. In addition to maintenance down time, process interruptions or delays can occur owing to stringent quality control measurement and nuclear material accountability requirements.

The net effect of these differences is that cell space and equipment redundancy must be minimized while providing an acceptable and economic production capacity.

Several modifications to traditional availability definitions are proposed for calculating a plant availability factor that can be meaningfully related to actual production capacity. This has been done to determine a measure of system capability, where system capability is defined as actual production measured against cost and time. Figure 1 shows the suggested components of system capability. Both design adequacy and efficiency must be considered along with the traditional availability definition. For purposes of this discussion, design adequacy is assumed to be the province

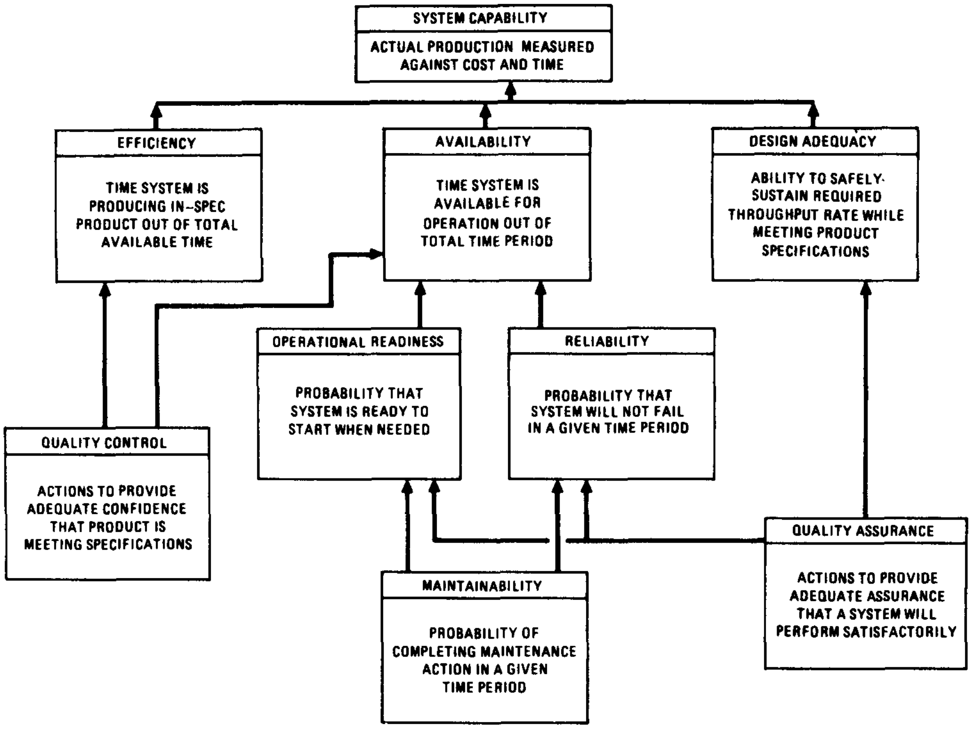


Fig. 1. Components of system capability

of quality assurance activities. However, efficiency can be considered concurrently with availability in the following manner. Operational availability can be defined as

$$\text{operational availability} = (\text{operating time} + \text{ready time})/(\text{operating time} + \text{ready time} + \text{down time}) \quad ,$$

where operating time is the time equipment is operating within acceptable limits, ready time is the time equipment is operable but cannot operate owing to unavailability of feed or product surge storage, and down time is maintenance, quality control, and accountability down time.

Except for the inclusion of quality control and accountability measurement down time, the above definition is similar to the traditional definition:

$$\text{availability} = \text{up time}/(\text{up time} + \text{down time}) \quad .$$

The percentage of time that a product is actually produced during the available time can then be calculated as

$$\text{efficiency} = \text{operating time}/(\text{operating time} + \text{ready time}) \quad ,$$

and effective availability as a measure of system capability can be defined as

$$\text{effective availability} = (\text{operational availability}) \times (\text{efficiency}) \quad .$$

That is,

$$\text{effective availability} = \text{operating time}/(\text{operating time} + \text{ready time} + \text{down time}) \quad .$$

This effective availability measure will give a more accurate measure of actual production capability based on system interdependency than more traditional availability definitions. For example, if a processing system that operates on a 10-h cycle is ready to operate but cannot owing to 5 h of down time in the feed system, its effective availability is only 50%. If a standard definition of availability were used, the availability would have been calculated as 100%, since the system was theoretically operable and the need for redundant systems or system resizing would not have been recognized. The effective availability represents the time the system actually operates and produces and is a better measure for determining system throughput. This refined definition becomes extremely important in considering the trade-offs between the cost of redundant operating systems and the cost of hot cell space and remote operating equipment.

3. RELIABILITY/MAINTAINABILITY DATA

An availability calculation can only be as accurate as the data used for the basis of the calculation. Down time is, of course, a major contributor to the reduction of both operational and effective availability, and the accuracy of down time estimates is important for the credibility of availability calculations.

Accurate reliability and maintainability data are important in assessing the corrective maintenance component of down time. Reliability can be defined as the probability that an item will perform its intended function for a specific interval under stated conditions, or

$$\text{reliability} = 1 - \text{probability of failure} \quad .$$

TABLE I
FAILURE ANALYSIS AND CORRECTIVE MAINTENANCE, CONDENSER ASSEMBLY

Principal Failure Mode	Principal Failure Mechanism	Est. Failure Rate (Failures/Oper. Year)		Corrective Maintenance
		Prob. 90%	Prob. 10%	
Condenser leaks	Weld cracks	0.2	<1.0 >0.1	Reweld condenser
	Corrosion	0.3	<0.5 >0.2	Replace condenser
	Overpressurization	Negligible		Replace condenser
Loss of cooling water	Valve fails	0.5	<2.0 >0.1	Replace valve
	Pipe breaks	0.2	<1.0 >0.1	Repair pipe

TABLE II
FAILURE MODE ANALYSIS & CORRECTIVE MAINTENANCE, CONDENSER ASSEMBLY

Failure Mode	Failure Mechanism	Lognormal Distribution Parameters for Failure Rate (Per Operating Year)				Statistical Moments			Corrective Maintenance
		5th Percentile λ0.05	Median λ0.50	95th Percentile λ0.95	Uncertainty Factor f	Mean E (λ)	Variance Var (λ)	Std. Dev. SD (λ)	
Condenser leaks	Weld cracks	0.07	0.32	1.39	4.38	0.47	0.28	0.53	Reweld condenser
	Corrosion	0.18	0.32	0.57	1.80	0.34	0.02	0.12	Replace condenser
	Overpressurization	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Replace condenser
Loss of cooling water	Valve fails	0.07	0.45	3.06	6.83	0.89	2.28	1.51	Replace valve
	Pipe breaks	0.07	0.32	1.39	4.38	0.47	0.28	0.53	Repair pipe

Maintainability can be defined as the probability (when maintenance action is initiated under stated conditions) that a system will be restored to a specified operational condition within a particular period of down time. In a practical sense, the probability of failure and the time to repair failures are the components to work with to determine down time attributable to corrective maintenance. Since processing facilities have generally not operated with commercial-scale throughput and rigorous reliability and maintainability data have not been gathered, it is necessary to make judgmental estimates for early design phase availability calculations. These estimates are best made by design engineers familiar with the equipment. The results can be standardized to some degree by using techniques such as failure modes and effects analysis (Ref. 3).

A structured format for presenting data will also help ensure the uniformity of the estimates and remove some of the uncertainty from them. Table I shows a suggested format for collecting failure mode and effects analysis results from design engineers. The design engineer can make an educated guess as to the range of probable failures. For example, the valve failure in Table I is postulated to occur at a rate greater than once per ten years but less than twice per year, with the most likely rate being once every other year. The estimates in Table I can then be converted to statistical parameters that define failure rate curves as shown in Table II. (Reference 2 defines the conversion methods.) The failure rate curves can be used in place of actual failure rate data to obtain useful information during early design stages.

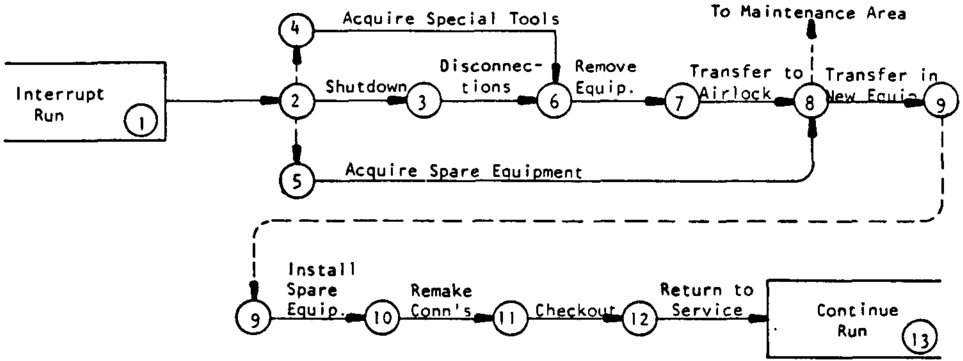
Maintainability data estimates can be developed in an analogous manner. Design engineers can develop corrective maintenance procedures and estimated times for performing maintenance. Figure 2 gives an example of a standardized format for presenting statistical parameters developed from engineering estimates. The standardized maintenance procedures shown in Fig. 2 represent a "remove and replace" maintenance philosophy as opposed to "repair in place."

All the examples discussed so far represent estimates made using engineering judgment. There must be a provision for obtaining hard data before a great deal of confidence can be placed in availability calculations. Preliminary data can certainly be useful, however. For example, a summary of combined failure rate and maintenance estimates was developed for a high-temperature gas-cooled reactor (HTGR) spent fuel reprocessing plant head end (Table III). Even this preliminary estimate pointed to a trouble spot in one system; i.e., screener blinding in the fuel element size reduction system was likely to cause 3400 h of down time per year. Thus, work on a solution was begun immediately.

It should be apparent from the condenser example in Tables I and II and Fig. 2 that a great deal of estimated data must be collected and subsequently upgraded when an entire plant is involved. The examples in this paper only address one aspect of down time for one piece of equipment. Because of the large quantity of data for a complete plant, it is practical to maintain estimates in a computerized data storage and retrieval system that can be updated as increments of information are added or revised.

Equipment: Condenser	Maintenance Requirement: Repair Vessel (Weld)

Issue	Date	By	Description	Rev	Appr.
A	2/6/78	STULA	Estimate Lognormal Distributions		YIP
B	5/19/78	SHAKMAND	Calculate Statistical Parameters		



Step	Lognormal Parameters for Step Execution Time (Time, Minutes)				Statistical Moments	
	5th Percentile $\tau_{0.05}$	Median $\tau_{0.50}$	95th Percentile $\tau_{0.95}$	Uncertainty Factor f	Mean $E(\tau)$	Variance $Var(\tau)$
1-2	60	120.0	240	2.0	131.0	3,340.0
2-3	60	104.0	180	1.73	110.0	1,420.0
3-6	0	0	0	0	0	0
4-6	30	60.0	120	2.0	65.6	835.0
6-7	20	34.6	60	1.73	36.6	158.0
7-8	0	0	0	0	0	0
5-8	0	0	0	0	0	0
8-9	0	0	0	0	0	0
9-10	30	73.5	180	2.45	85.2	2,510.0
10-11	0	0	0	0	0	0
11-12	30	60.0	120	2.0	65.6	835.0
12-13	120	170.0	240	1.41	174.0	1,370.0
				SUM	602.0	9,630.0

Component repair time distribution:

	Min	H
Mean	602.0	10.0
Variance	9,630.0	2.68
SD	98.2	1.64
5th Percentile	441.0	7.35
95th Percentile	763.0	12.7

Fig. 2. Maintainability network diagram

TABLE III
UNSCHEDULED DOWN-TIME DISTRIBUTION

	Fractional Down-Time Distribution Parameters (h/yr)	
System	Mean E (λ_T)	Standard Deviation SD (λ_T)
Fuel element size reduction	3890	3520
Adjusted fuel element size reduction(a)	480	
Fuel element burning	276	220
Particle classification	10	16
Particle crushing and burning	143	93
Dissolution and liquid-solids separation	370	88
Solids handling	55	62
Adjusted head-end total	1334	

(a) Assumes that solution is found for screener blinding.

4. PROCESS SIMULATION

Process operation computer simulations which incorporate random failures and random repair times selected from curves generated by statistical parameters, as given by the examples in Section 3, can be useful in making estimations. A simulation model can be used to integrate down time estimates and process operating parameters to evaluate the effects of one plant system on another; that is, the effects of feed and product stoppages due to failures can be traced through the entire plant operation, and effective availability can be estimated. A simulation model of HTGR spent fuel reprocessing operations is under development at GA (Ref. 1). This model will be used to examine HTGR nuclear fuel reprocessing plant operating parameters such as maintainability, reliability, availability, equipment redundancy, and surge storage requirements and their effect on process operations and plant throughput.

Interim development and operation of this model allows definition of full-scale plant operational requirements as a guide for development programs. Simulated operations enable prototypical equipment sizing and identification of redundant equipment and surge storage requirements, which in turn allows preparation of preliminary plant arrangements to guide remote handling and maintenance equipment development. As the design of a plant evolves, estimated parameters can be replaced with more reliable data, and availability calculations can be refined. Figure 3 presents a hypothetical example of how data upgrading and process simulation can be used through the design, construction, and operation phases of a demonstration reprocessing plant. This information should prove extremely useful in the

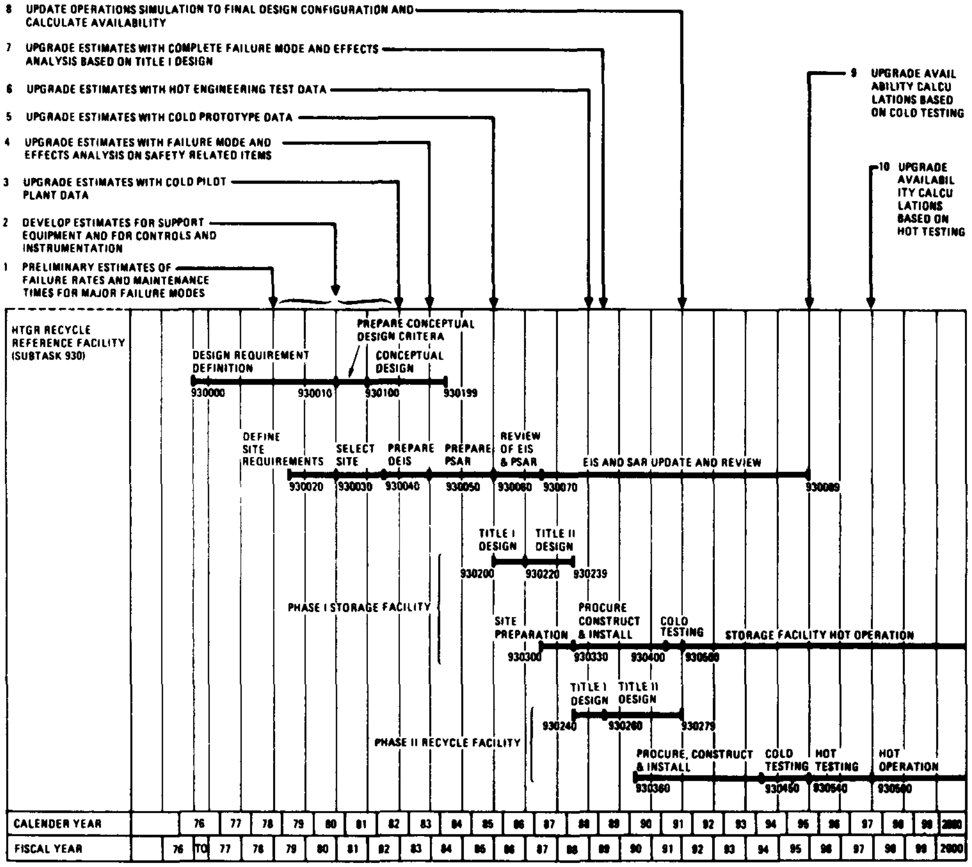


Fig. 3. Reliability, maintainability, and availability growth related to demonstration reprocessing plant design and construction

design and construction of a full-scale commercial facility, since the simulation model will ultimately be upgraded with actual operating data from the demonstration facility.

5. SUMMARY

Reliability, maintainability and availability estimates can be useful in the early stages of nuclear material processing facility design and can serve as a guide to the development effort. Judgmental estimates from personnel involved in design can be used as interim data in computer modeling of integrated process operations. Process operation simulation can be used to study the effects of redundant equipment and surge storage configurations on plant effective availability, i.e., the time the plant is actually producing material at a prescribed rate. The effective availability is a more precise measure of a plant's actual production capability than more traditional operational availability definitions. Judgmental estimates and the operations model can be upgraded as actual reliability and maintainability data are generated in demonstration plants. This will lead to a better understanding of the design requirements for commercial-scale plants.

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