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AVAILABILITY OF LARGE-SCALE CRYOGENIC SYSTEM FOR SSC

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SUMMARY OF MODELS I,III,IV AND IV,2

We have examined several models to learn about the availability of the SSC cryogenic system. We have computed the stationary and secular availability for each model. We have also computed estimates for the mean time between failures for each model. Observation of common features among results for these models confirm several expected generalizations.

COMMON CHARACTERISTICS among all these models include:
(1) The system is comprised of 12 identical refrigerator units around a ring.
(2) Each unit operates in its normal, unstressed mode with constant probability-of-failure rate λ .
(3) When a unit goes down (by accident or by plan) repair begins immediately and procedes with constant probability-of-repair rate μ until that unit is returned to operation.
(4) Each unit has 50 percent excess load capacity which is immediately switched in to take over all or part of a half load of a down unit. A unit operates at 150 percent of its normal capacity with constant probability-of-failure rate λ' . We consider two values: $\lambda' = \lambda$ and $\lambda' = 2\lambda$.

DISTINQUISHING CHARACTERISTICS by which the models are differentiated include:
(6) The kill number is the number of down units at which it is stipulated that the whole system must be shut down until at least one of the down units is returned to operation.
(7) The number of repair crews for the system is less than, or equal the kill number.
(8) Feedthrough of the excess capacity of an operating unit to pick up all or part of half of the load of a down unit is treated two ways. In models I, II, III it is assumed that the 50 percent excess capacity of a unit is available to take over only a half load of a down unit that is adjacent to it. In this case the system must be down when any two down units are separated by less than two up units. In this case when j units are down 2j units operate at failure rate λ' and 12 -3j units operate at λ, and collectively the system is operating in this mode with effective failure rate $2j\lambda' + (12-3j)\lambda$. Feedthrough of excess operating capacity is not restricted to adjacent half down unit in models IV and IV,2 . However, to facilitate comparability it is still assumed that when the system operates with j units down its probability-of-failure rate is $2j\lambda' + (12-3j)\lambda$.

The models compared here may be labeled as:

Model I	: 1 Repair crew,	2-unit kill,	Adjacent feedthrough only	
Model II	: 3 " "	3 " "	" "	"
Model IV	: 3 " "	3 " "	Open	"
Model IV,2:	2 " "	2 " "	"	" .

In all cases we consider $\lambda' = 2\lambda$ here, although it is not important generally. Complete specification of the models requires specification of the probability transition rate equations, their solutions, and boundary conditions. However, these are essentially (but not completely) determined by the characteristics listed above.

The most important quantity obtained is probably the long-time limit stationary availability A_∞ . This is shown in the graph in Figure 1 for varying values of the ratio of the single-unit-repair rate μ to the single-unit-failure rate λ for each of the four models considered here. In all cases shown there $\lambda' = 2\lambda$. The corresponding curves for $\lambda' = \lambda$ look almost the same; even at quite small values of μ/λ .

Recent Tevatron experience suggests that the effective μ/λ is probably greater than about 30, and may be as high as 300-400. Certainly in the latter case availability of the cryogenic system is not a problem, no matter which model the SSC ultimately corresponds to most closely. It now seems likely that the SSC cryogenic system will not accomodate free and open feedthrough of the excess operating capacity of refrigerator units much beyond the first adjacent down unit. For this case comparison of our two models without open feedthrough at the lower range of $\mu/\lambda \simeq 30$ suggests the importance of being able to operate with more than a single unit down: 5 percent versus 10 percent unavailability.

While the stationary availability A_∞ is determined by the characteristics of a given model and the unit operating parameters, the behavior of the secular availability A(t) in approaching its long-time stationary limit A_∞ scales roughly universally. For all models the secular eigenmode characterized by the smallest eigenrate λ_1, i.e., the slowest secular relaxation, has $\lambda_1 \cong \mu$ to within a few percent. The amplitude for this relaxation mode A_1 is typically about 1.7 times the stationary unavailability $x_0 = 1 - A_\infty$. The next most important relaxation eigenmode has a rate $\lambda_2 \cong 2\mu$ and amplitude $A_2 \cong -.7x_0$. Other eigenmodes altogether have total amplitude less than about .01 and rates seldom smaller than μ. Thus a more-or-less universal secular relaxation curve can be given in terms of A_∞ and μ for any model. This universal curve is shown in Figure 2.

The mean times between failure for these models are computed from the relation

$$\text{MTBF} = \text{MRT}\,[A_\infty/(1 - A_\infty)] \quad ,$$

where the mean repair time is

$$\begin{aligned} \text{MRT} &= 1/\mu && \text{, for model I} \\ &= 1/2\mu(*) && \text{" " III} \quad (*,\ .4968 \cong 1/2) \\ &= 1/3\mu && \text{" " IV} \\ &= 1/2\mu && \text{" " IV,2} \quad . \end{aligned}$$

MRT is the mean time to get the whole system up, starting repair on all its down units when the whole system has gone down. MRT of any given unit is, of course, $1/\mu$. MTBF for the models compared here is roughly proportional to μ because MRT above is proportional to $1/\mu$ and $x_0 = 1 - A_\infty$ is roughly proportional to $(\mu/\lambda)^{-2}$.

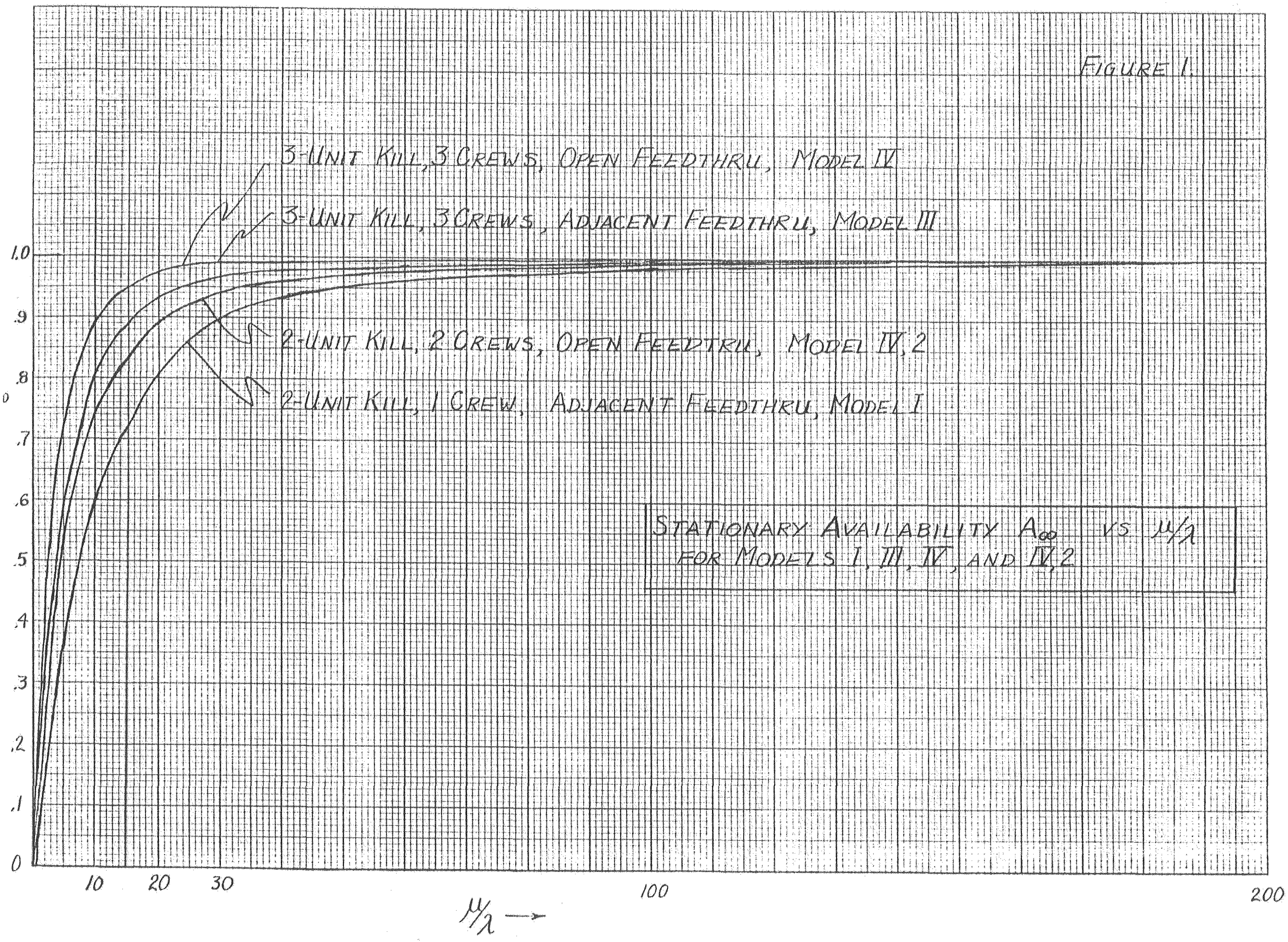
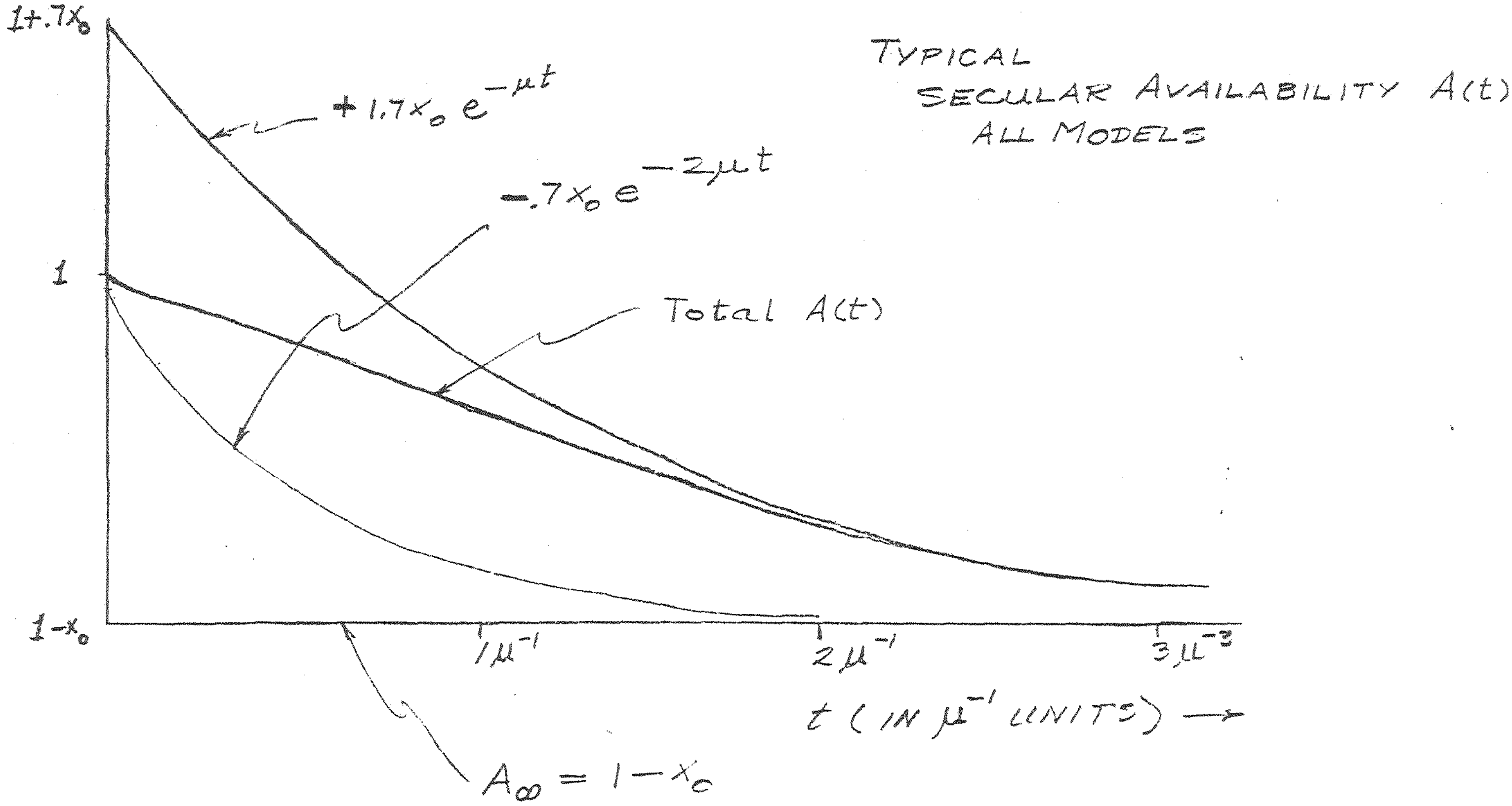


FIGURE 1.
3-UNIT KILL, 3 CREWS, OPEN FEEDTHRU, MODEL IV
3-UNIT KILL, 3 CREWS, ADJACENT FEEDTHRU, MODEL III
2-UNIT KILL, 2 CREWS, OPEN FEEDTRU, MODEL IV, 2
2-UNIT KILL, 1 CREW, ADJACENT FEEDTHRU, MODEL I
STATIONARY AVAILABILITY A_∞ VS μ/λ
FOR MODELS I, III, IV, AND IV, 2
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
10
20
30
100
200
μ/λ →

FIG. 2.


TYPICAL
SECULAR AVAILABILITY A(t)
ALL MODELS
1+.7x₀
1
1-x₀
+1.7x₀ e^{-μt}
-.7x₀ e^{-2μt}
Total A(t)
1μ⁻¹
2μ⁻¹
3μ⁻³
t (IN μ⁻¹ UNITS) →
A∞ = 1 - x₀