Tritium Gas Target Safety Algorithm for Jefferson Lab

Roy J. Holt
Argonne National Laboratory
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Introduction

The goal is to develop a safe tritium target for use in Hall A at Jefferson Lab for the 12-GeV experiments[1,2] E12-10-103 and E12-11-112. Our overall philosophy for developing the conceptual design and safety devices has been to minimize the amount and density of tritium necessary for the experiment and to keep the systems and procedures as simple and reliable as possible. In this report we present an algorithm that can be used to minimize risk during operation of the target in the JLab electron beam. The overall approach used here is based on the concept of fuzzy logic.

Fuzzy logic risk table

Table 1. Risk vs. operating parameters

	Risk Level			
Parameter	Extremely Low	Low	Medium	High
Curies	<10	100	1000	5000
Beam current (μA)	<1	5	25	60
Pressure (psi)	<10	100	500	1500
Beam trips	<1000	1E4	1E5	2E5
Time (d)	<10	50	200	365-730

The risk levels essentially match those from the JLab ESH manual[3] and were chosen in the following manner. For the number of curies, a value of 10 Ci was chosen to be very low risk. If 10 Ci of tritium were released in Hall A, for example, the amount of tritium absorbed onto surfaces would not reach an actionable level[4] and the site boundary limit of 10 mrem could not be exceeded under any scenario[5]. Thus, this value was assigned a very low risk level. The 5,000 Ci level has the potential to exceed the site boundary limit (10 mrem) under conservative scenarios. Also, with a full, unmitigated release of 5,000 Ci into the Hall, the Hall could become contaminated to an actionable level (>10000 dpm/100 cm^2) even with a 12,000 cfm Hall A fan turned on within one hour of the full release. With a full release of 1000 Ci, the site boundary limit will not be violated and even the lowest speed Hall A fan can prevent contamination to an actionable level. The beam current of 1 μA was chosen as extremely low risk because an uncooled, high-pressure (200 atmosphere) tritium gas target with even a stainless steel cell was operated[6] at HEPL at Stanford successfully at 0.5-1 μA. The high-risk value of 60 μA was chosen because solid Fe targets have failed at this beam current and the administrative limit at JLab for Al targets is 40 μA. The very low risk for pressure is set at the limit where there would be no concern from a pressure vessel safety viewpoint, 10 psi. The high risk value of 1500 psi is set at the threshold where the target cell reaches the yield strength of Al 2024-T3511 at room temperature. The risk level for beam trips is equated to cycle fatigue. For example, we assume that for each beam trip, the target windows cool and when the beam is turned back on, the target windows heat. This gives rise to a cycling of the stress on the window. Cycle fatigue[7] occurs after 100,000 cycles that take the stress near half the yield stress level of the material. Our plan is to stay well under the yield stress level by at least a factor of four. Thus, conservatively, we set the moderate risk level at 100,000 cycles and high risk at 200,000 cycles. The risk level for time is set by cryotarget operating experience at JLab. Experience indicates that there have been six major cryotarget failures in 30 Hall-years of operation at JLab. Thus, we set the high-risk level at approximately 1-2 years of continuous operation and the very low risk at 10 days.

Algorithms to relate these risk levels to operating parameters

Here it is assumed that the risk level rises exponentially with the operating parameters and falls exponentially to zero as the operating parameter approaches zero. Thus the overall algorithm takes the following form:

$$\text{Risk}_P = (1 - \exp(-P/C_P))\exp(P/C_P),$$

where P is the value of the parameter and C_P is the high risk value from table 1. The risk becomes a sum of the individual risk factors for each parameter, P, *i.e.*

$$\text{Risk} = \Sigma_p \, \text{Risk}_P$$

Here P refers to the beam current, number of curies, and target pressure. The number of days is fixed at the total PAC days (61 = 42 + 19 days) that were allocated for the two experiments. Although the tritium target is expected to be in the beam approximately half this time, the number of PAC days often is doubled to account for overall operating efficiency. Thus, the PAC days were used. Also the proposals assumed a 1000 Ci target and 25 μA operation for the tritium target for the low cross sections parts of the proposal. Then the number of days, *ndays*, scales according to the formula:

$$\text{ndays} = (61)(1000)(25)/((\text{nci})(\text{ib}))\ ,$$

where *nci* is the actual number of curies of the target and *ib* is the beam current in microamps.

The risk for the number of cycles or beam trips is accounted for by the formula:

$$\text{Risk}_{cyc} = (1 - \exp(-\text{ncyc}/\text{cychi}))\exp(\text{ncyc}/\text{cychi})\exp(\text{press}/\text{presshi})\exp(\text{ib}/\text{ibhi}),$$

where *ncyc*, *cychi*, *press*, *presshi*, *ib* and *ibhi* are the number of cycles, the high risk number of cycles, the target pressure, the high risk target pressure, the beam current, and the high risk beam current, respectively. Here we assumed that the beam trip risk increases exponentially with the beam current and the target pressure as well as with the total number of trips. This risk is also summed with *Risk* above to obtain the total risk. Conservatively, we assumed that beam trips occur at the rate of 500 per day. No additional weighting is given to any of the risk factors.

Results

Fig. 1 shows the total risk as a function of beam current when the number of curies is held at 1000 Ci. Of course, as the beam current decreases, the time and number of cycles increases accordingly. Also as the time for the experiment increases, the target material decreases from natural decay and this further adds to the time that the target must be in operation.

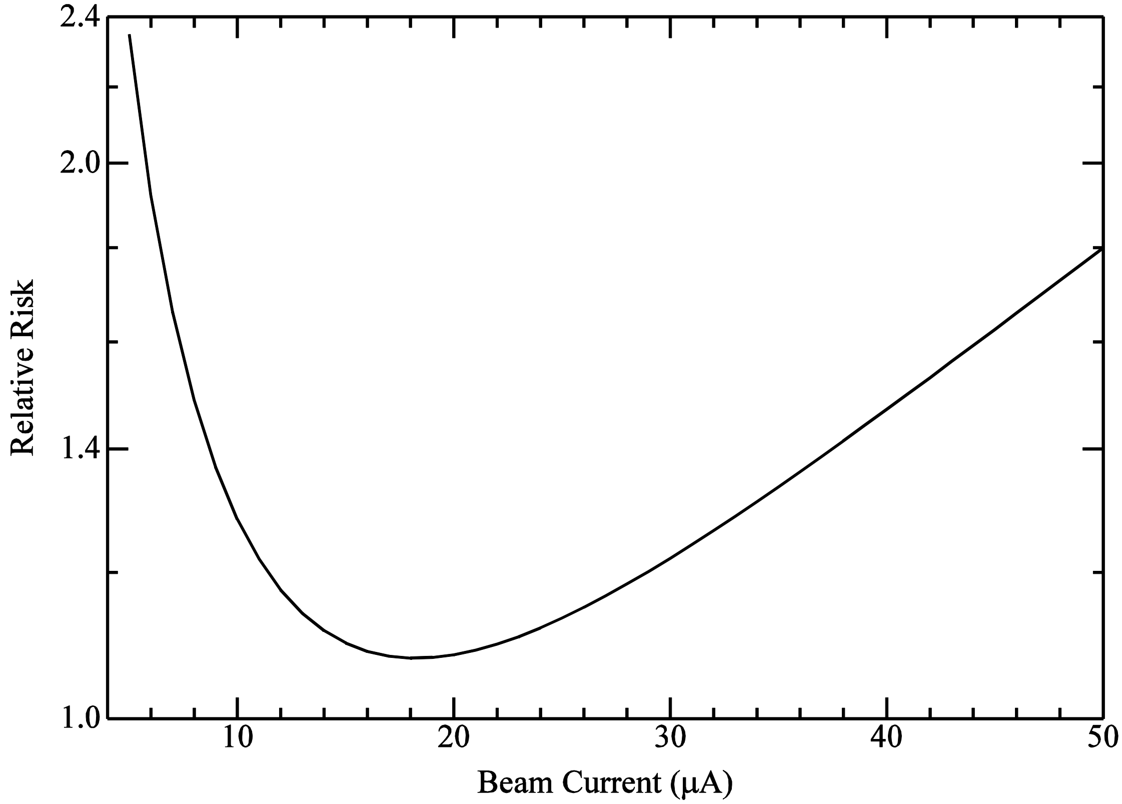

Fig. 1: Relative risk vs. beam current when target is 1000 Ci. The optimum current is 18 μA. This assumes that the high risk value for time is 730 days.

Fig. 2 shows the risk as a function of the number of curies. As the number of curies increases, the pressure also increases accordingly since the target volume is fixed.

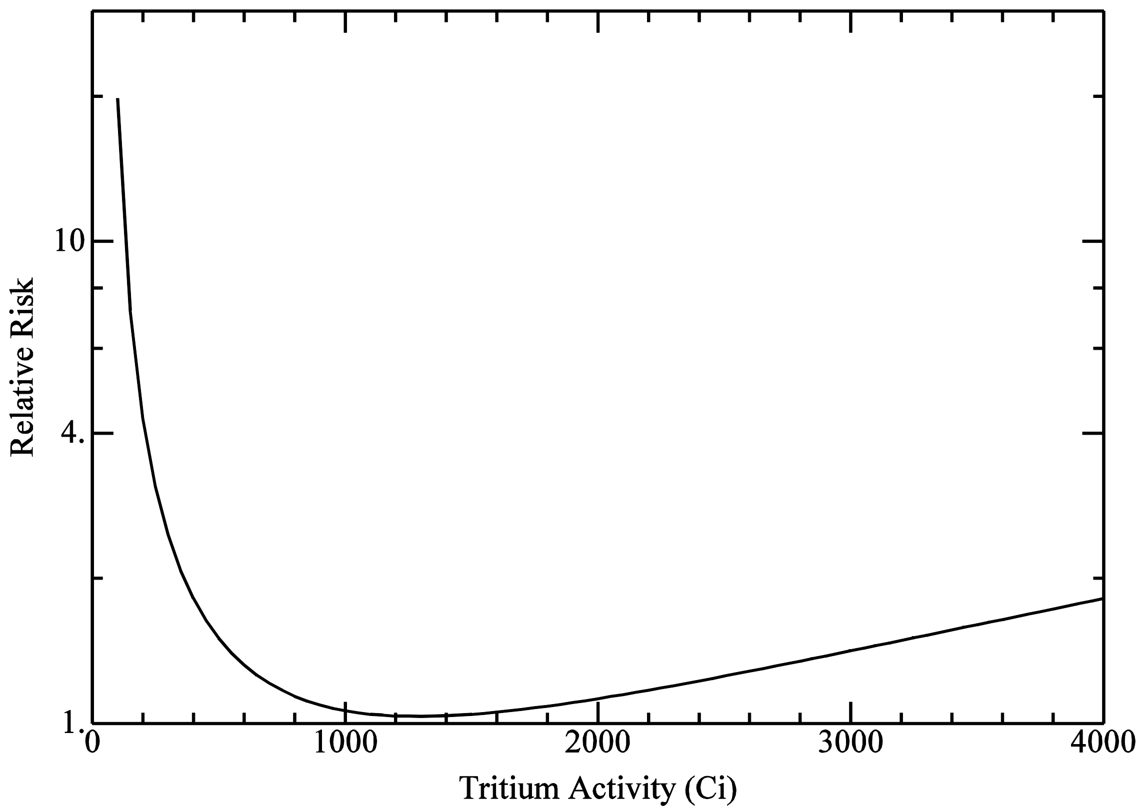

Fig. 2: Relative risk vs. curies when the beam current is 18 μA. The optimum target activity is 1300 Ci. This assumes that the high risk time is 730 days.

If we now assume that high risk occurs at 365 days of continuous operation rather than 730 days, we obtain the following results. The optimum beam current becomes 21 μA and the optimum target activity, 1350 Ci. These results are shown in Figs. 3 and 4.

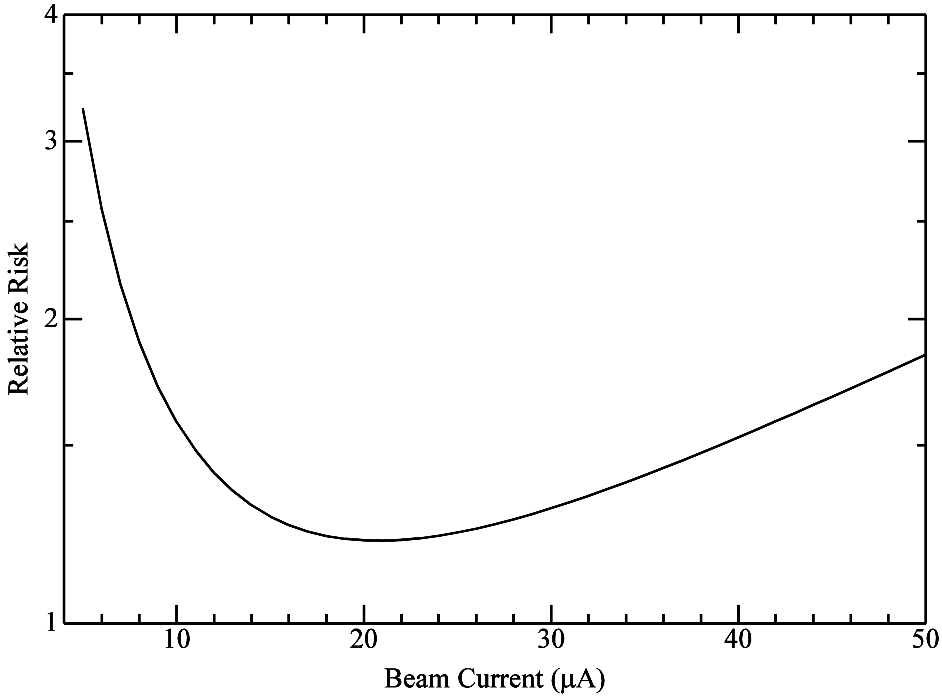

Fig.3: Relative risk vs. beam current when target is 1000 Ci. The optimum current is 21 μA. This assumes that the high risk value for time is 365 days.

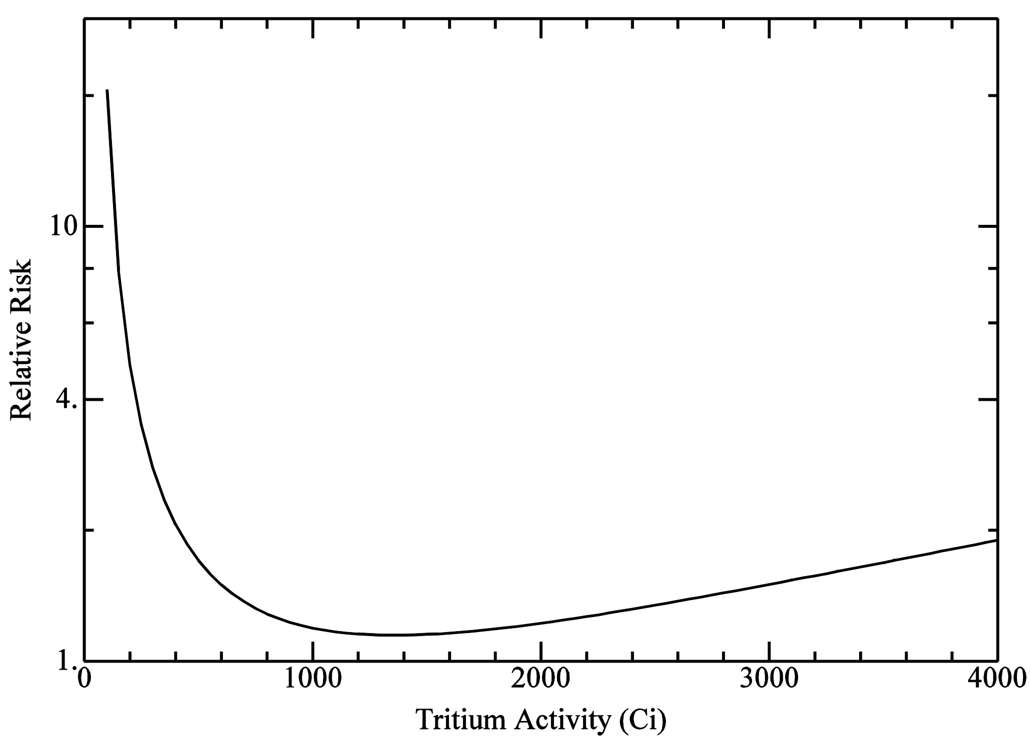

Fig. 4: Relative risk vs. curies when the beam current is 21 μA. The optimum target activity is 1350 Ci. This assumes that the high risk time is 365 days.

Table 2. Optimum operating parameters and relative risk levels for assumption that 365 days of operation is high risk

	Parameter					
Time High Risk (days)	Curies	Beam Current (μA)	Operating Pressure at 90K (psi)	Beam Trips	Time (days)	Total Relative Risk
365	1350	21	60.8	27228	54.5	-
Relative Risk	0.31	0.42	0.04	0.22	0.16	1.15

Table 3. Optimum operating parameters and relative risk levels for assumption that 720 days of operation is "high" risk

	Parameter					
Time High Risk (days)	Curies	Beam Current (μA)	Operating Pressure at 90K (psi)	Beam Trips	Time (days)	Total Relative Risk
730	1300	18	58.5	33044	66.2	-
Relative Risk	0.30	0.35	0.04	0.25	0.10	1.04

Conclusions

A simple algorithm has been used to study the dependence of risk on the operating parameters of the experiment. In particular, it was found that the optimum target activity and beam current are represented by broad minima that span a relatively large range: 900-2000 Ci and 15-24 μA, respectively. This analysis only applies to the tritium target.

Acknowledgements

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[2] P. Solvignon et al, JLab Experiment E12-06-112, 2011.
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[6] E. B. Hughes, M. R. Yearian, R. Hofstadter, Phys. Rev. **151** (1966) 841.
[7] Military Handbook MIL-HDBK-5G, Nov. 1, 1994, pp. 3-112, 3-375.