TRIUMF	UNIVERSITY OF ALBERTA EDMONTON, ALBERTA	
	Date 1993/03/19	*File No.* TRI-DNA-93-1
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Subject Beamline 1A collimators A and B revisited—déjà vu (all over again)		

Introduction

An upgrade of beamline 1A in the region of target 1AT2 is begining. During discussions of what can be readily accomplished, the question of the usefulness of collimator B has (again) arisen. The reason for this is shown in figure 1, a section of drawing E-3217, showing the downstream end of the collimator. Cooling lines for the collimator assembly are contained in a short section of pipe and necessitate two vacuum joints, one at the collimator exit and one at the connection to the beam tube leading to the 1AQ14/15/16 triplet downstream. The latter joint is broken each time the triplet is removed for repair and there always is a danger that the joint at the collimator may be broken in the operation. Were that to happen, not only would reconnection be extremely difficult but the personnel effecting the repair would be subjected to a significant radiation dose. Thus, if the collimator was no longer necessary, one vacuum joint could be eliminated along with a (potential) water leak.

This question has been investigated in the past, most notably by Templeton et al[1]. They studied beam spills from 1AT1 to the TNF using the program REVMOC and concluded that, indeed, collimator B was necessary to protect the triplet from radiation damage. They also specified the designs for the collimator downstream of the 1AT1 target as well as those downstream of 1AT2.

REVMOC has the provision whereby a beam may be tracked from, say, point A to point B at which location the coordinates of the beam particles are written to a file. These coordinates may then be used to trace the beam from the point B to another location further down the beamline. Thus, for example, beam could be traced from the stripper foil to 1AT1, beam coordinates dumped out at the exit of the target and those coordinates used to trace from 1AT1 to 1AT2. At the exit of 1AT2, coordinates could again be dumped out and these latter coordinates used to trace from there to the TNF. This technique has the advantage that one is effectively working with one beam all along the beamline; any changes, such as those caused by multiple scattering, are reflected at points further down the beamline. This was not done in the study of Templeton et al. Rather, they used uniformly populated beams at the entrance of each of the targets. Because of this it was decided to attack the question again from an alternate point of view.

It was also noted by C. Kost[2] that the REVMOC program had evolved during the intervening years and that such a study would indicate whether such evolution was for the better or the worse.

In this report the calculations of Templeton et al. are repeated using REVMOC listings given in their report. This is done primarily to check the consistency of the program over time. A similar check is done with a REVMOC file that was used in some of the calculations that went into the original report[2]. Then a new set of spill calculations is made using the coordinate input/output provision of REVMOC.

Consistency calculations

As was noted above, the first consistency checks were made by repeating the calculations of ref[1] using the files listed in appendices 5.1 and 5.2 of the report. Beam spills tabulated in the report were then compared to the present results.

The first file run was that listed in appendix 5.1 of ref[1] and is a calculation of the spill from a 3 cm Be target at 1AT1. This run is for a collimator that has a 4.75 cm radius at its downstream end (and *not* 5.6 cm as given in the heading of the listing). A comparison of data from tables 6 and 7 of the original report and the present calculations is given below in table 1. Spills are expressed as a percentage of the beam incident on the 1AT1 target. Unless otherwise indicated, the data of column 2 is taken from table 6, line 2 of the 1A500 mode.

Table 1
Comparison of spill calculations between 1AT1 and 1AT2

Location	From ref[1][a]	This work[a]	This work[b]	This work[c]	This work[d]
In 1AT1[e]	7.92	7.47	7.36	7.49	7.49
1AT1 → 1AQ9[e]	0.32	0.39	0.39	0.34	0.41
In 1AQ9[e]	1.90	1.74	1.66	1.76	1.68
In collimator	1.80	3.10	2.79	3.04	2.95
In 1AQ10 and 1AQ11	0.29	0.41	0.32	0.46	0.37
1AQ11 → 1AQ12	0.11	0.22	0.12	0.11	0.16
In 1AQ12 and 1AQ13	0.06	0.01	0.01	0.01	0.02
Surviving at 1AT2	87.00	85.20	86.14	85.74	85.72

[a] One 3 cm piece of Be at 1AT1, treated as a collimator.
[b] Ten 3 mm pieces of Be at 1AT1, treated as a collimator.
[c] One 3 cm piece of Be at 1AT1, treated as an absorber.
[d] Ten 3 mm pieces of Be at 1AT1, treated as an absorber.
[e] Average of 6 runs on 3 cm Be listed in table 7 of ref[1].

The reason for splitting the target into 10 pieces in the present runs is that one 3 cm piece is too thick for accurate energy-loss calculations to be made. (Indeed, the program itself suggests a division into (at least) 4 pieces.) The smaller the divisions are, the more accurate is the energy-loss determination.

The first three rows of the second column are, as noted, obtained by averaging data given in table 7 of the 1977 report. This is possible because losses upstream of the collimator are independent of its aperture. Consequently, data from table 7 may be used in these cases. The reason that the target is treated both as an absorber and as a collimator is more a cross-check of the program's treatment of the two cases rather than of necessity, although the latter approach was used in ref[1]. In the collimator case, the Be target was treated as a collimator with a 10 μm hole.

From the data given in table 1 it is seen that there is, in general, good agreement between the 1977 and 1993 results. It was pointed out as long ago as 1977[3] that "... because of the accuracy of multiple scattering theory, beam spills of less than 1% should be interpreted as an indication of a probable region of spill and not as an exact figure. ...". Agreement between the treatment of collimators and absorbers by the program is particulary encouraging. However, there is serious disagreement between the old and new results as to the predicted beam spill in the collimator. This is not understood considering the otherwise good agreement. Because of this and the fact that the file to which comparison was being made does not correspond to what is claimed, the entire comparison is brought into question. So another approach was tried.

The first line of the 1A500 mode in table 7 of ref[1)] contains data for a collimator with an aperture of radius 5.6 cm at its exit point. Calculations for a collimator of this aperture were made; its opening angle was taken as 18 mr as noted in the report. The results of this comparison are given in table 2.

Table 2
Comparison of spill calculations between 1AT1 and 1AT2 for a 5.6 cm radius collimator

Location	From ref[1)][a]	This work[a]	This work[b]
In 1AT1	7.50	7.27	7.58
1AT1 → 1AQ9	0.36	0.36	0.39
In 1AQ9	1.80	1.71	1.70
1AQ9 → M11	0.37	0.38	0.39
At M11	0.26	0.25	0.20
In M11 septum region	0.35	0.54	0.43
Septum → collimator	0.29	0.33	0.25
In collimator	1.00	1.23	1.46
In 1AQ10 and 1AQ11	0.47	0.56	0.61
1AQ10/11 → 1AQ12/13	0.05	0.06	0.07
Surviving at 1AT2	87.00	87.31	86.91

[a] One 3 cm piece of Be at 1AT1.
[b] Ten 3 mm pieces of Be at 1AT1.

The data presented in table 2 shows good agreement between the 1977 results and that obtained with the present program. Having reached agreement on the spills between 1AT1 and 1AT2, we repeat the process with a comparison of the calculated spills between 1AT1 and the TNF. For this purpose we use the data given in appendix 5.2 of ref[1)]. Results of this comparison are given in table 3. Data for the 1977 calculation are taken from the first row (1A500 mode) of table 4 of ref[1)]. In all cases, losses are given as percentages of the beam *incident* on 1AT2. Note that collimator A has no liner in these calculations.

Table 3
Comparison of spill calculations between 1AT2 and TNF

Location	From ref[1)][a]	This work[a]	This work[b]	This work[c]
In 1AT2	22.20	21.91	23.03	22.86
In collimator A	6.00	6.17	5.58	5.52
In collimator B	5.60	6.48	6.28	6.21
Total in 1AQ14/15/16	0.15	0.25	0.21	0.25
Total in scrapers	1.14	0.66	0.62	0.54
Total between scrapers	0.07	0.02	0.01	0.01
Scrapers → TNF	0.61	0.33	0.05	0.10
Surviving at TNF	63.60	64.10	64.16	64.43

[a] One 10 cm piece of Be at 1AT2.
[b] Ten 1 mm pieces of Be at 1AT2.
[c] Twenty 0.5 mm pieces of Be at 1AT2.

Considering the accuracy of the multiple scattering calculations, it is concluded that, in general, the older and newer calculations are in reasonable agreement. One might argue that the present results tend to predict slightly higher spills in the target, collimator B and triplet and slightly lower elsewhere than do the early calculations. Some of the differences may be caused by different binning techniques being used in in the different calculations. However, differences of a few tenths of percent are not significant in these calculations. For example, a different random number seed was used for the runs in the two rightmost columns than was used for the runs listed in columns 2 and 3. This alone can cause an increase or decrease of 0.1–0.2% in spill at one part of the line and move it to another place (or places) either upstream or downstream. Although differences of the order of 0.5% may be of significance (and are in terms of energy deposition), it is not felt that these results are inconsistent.

The final cross-check that was made was to rerun another file similar to that used in the calculations presented in ref[1]). For this, run #1134a of the MTS interactive computing book #2 was located in the archives by C. Kost[2]). This run, made on 1978/06/15, was from 1AT2 to the TNF with a 10 cm Be target, small collimator A and an *untapered* collimator B of half-aperture 3.85 cm (although the run is entitled "No B"). Such a comparison is most useful because the outputs of the old and new versions of the REVMOC program may be directly compared.

For this test the 1978 run was duplicated and also rerun with ten 1 mm and twenty 0.5 mm slices of Be. Other runs with collimator B *actually* removed and with coordinate input were also made. The results are given in table 4 below.

Table 4

Comparison of spill calculations between 1AT2 and TNF—1978 versus 1993

Location	From 1978[a]	This work[a]	This work[b]	This work[c]	This work[d]	This work[e]
In 1AT2	22.01	22.04	23.02	22.86	22.76	23.28
In collimator A	9.87	10.81	9.57	9.21	9.31	9.65
In collimator B	0.73	1.15	1.02	0.99	1.35	0.22
Total in triplet	0.54	0.80	0.65	0.76	0.93	0.88
In scraper S1	0.18	0.16	0.14	0.12	0.21	0.12
In scraper S3	0.35	0.12	0.10	0.11	0.13	0.06
In scraper S4	0.68	0.14	0.14	0.07	0.18	0.10
Surviving at TNF	64.77	63.65	64.98	65.73	64.83	65.40

[a] One 10 cm piece of Be at 1AT2.
[b] Ten 1 mm pieces of Be at 1AT2.
[c] Twenty 0.5 mm pieces of Be at 1AT2.
[d] As [c] but with a beam traced from the stripper foil.
[e] As [b] but with collimator B *really* out.

It is important to stress that the collimator configuration of this last test is *not* the collimator that is installed in the beamline. That used in this calculation was a 1.03 m length of copper with a 7.75 cm diameter hole drilled through it. Agreement between present and past calculations is reasonably good up to the exit of the first scraper, although there may be a tendancy for the present calculations to predict slightly larger spills in collimator B and in the triplet. There seems to be a discrepancy in the predictions for spills in the downstream scapers, with the older calculation predicting more spill in these regions—particularly in scraper 4. Again, however, these apparent discrepancies may be entirely statistical.

This calculation is interesting in that it shows why a collimator with a simple hole is not used in the beamline. Were such a collimator removed, It is predicted that less spill—by a factor of 4 or so—would occur in the collimator B region and, the same time, spill in the triplet would not increase significantly.

New calculations

As mentioned in the introduction, the main purpose of this study was to see if calculations in which beam was tracked from the stripper foil and through the targets would produce spill predictions that differed significantly from those that have been presented above. To this end, some 20,000 particles were traced from the stripper foil through a 10 mm Be target at 1AT1 at which point the coordinates of the beam particles were output. These coordinates were used as input for a second run that tracked the beam to the front face of the 1AT2 target where, again, beam-particle coordinates were output. This, rather than tracing particles through the 1AT2 target and then dumping out the coordinates, was done in order that a comparison with data presented above could be made.

[That three runs were made was dictated by the program itself and efficient use of CPU time. The existing program cannot handle enough beamline elements to trace from the stripper foil to the TNF in one run. By dumping particle coordinates out at the entrance of 1AT2, the computer time required to trace various cases to the TNF is significantly reduced relative to that required to trace all of the way from the stripper foil—even if the program could handle all of the beamline elements. Further, breaking the beamline into sections made comparison with the input of ref[1] much easier.]

Details of collimator A were taken from drawing D-3445, Rev 2. A 'small' insert was used; its entrance aperture is given as 0.787 in (2 cm) diameter and its taper as 1° 8′ 45″ (20 mr). Those for collimator B were obtained from drawing E-3702, Rev 2. This drawing gives an entrance diameter of 3.033 in (7.704 cm) tapering inward at 4° 47′ 07″ (83.519 mr) for a distance of 9.125 in (23.1775 cm). There an outward taper of 1° 05′ 40″ (19.102 mr) begins and continues for a distance of 23.5 in (59.7 cm). The remaining 8.65 in (22 cm) has an outward taper of 1° 35′ 34″ (27.799 mr). The dimensions of the collimator B are those used in ref[1]. However, because collimator A had a large aperture in those calculations, its entrance aperture was modified to 2 cm diameter and a 20 mr taper was added so as to permit a meaningful comparison to be made. The results of this set of calculations is given in table 5. All calculations were done with twenty 0.5 mm slices of Be at 1AT2. Spills are expressed as percentages of the beam *incident* on the 1AT2 target.

Table 5
Comparison of spill calculations between 1AT2 and TNF with and without coordinate input

Location	Ref[1] modified[a]	This work[b]	Ref[1] modified[c]	This work[d]
In 1AT2	23.36	22.60	22.67	23.38
In collimator A	9.53	8.34	9.22	8.75
In collimator B	1.95	3.46	0.26	0.99
Total in 1AQ14/15/16	0.21	0.31	0.06	1.31
Total in scrapers	0.74	0.75	0.11	0.69
Total between scrapers	0.03	0.04	0.00	0.10
Scrapers → TNF	0.33	0.28	0.06	0.34
Surviving at TNF	63.87	64.11	65.27	64.15

[a] Collimator B in, TRI-DN-77-18 data with small collimator A, no coordinate input.
[b] Collimator B in, beam coordinates traced from stripper foil.
[c] Collimator B out, TRI-DN-77-18 data with small collimator A, no coordinate input.
[d] Collimator B out, beam coordinates traced from stripper foil.

The data presented in table 5 is quite interesting. Consideration of data in columns 2 and 4 indicates that when the coordinates of beam particles are chosen randomly from an input set of phase spaces, the use of a 'small' collimator A negates the need for the installation of collimator B. Indeed, the installation of collimator B is predicted to increase the amount of beam spilled in the triplet! Conversely, with a 'traced' beam—a beam that has been tracked from the stripper foil in this case—REVMOC predicts that it is essential that collimator B be in place in order that the triplet be protected from excess beam spill. In this case, collimator B reduces spill in the triplet by a factor of three relative to that without the collimator in place.

The cause of this would appear to be the 'memory' that the traced beam has of its interactions with the stripper foil, the 1AT1 target and other components in the beamline. Although the beam spot at the exit of the 1AT2 target is more highly concentrated in x-y space, the beam contains much larger spreads of divergence and momentum than does a beam with its particle coordinates randomly selected from an input set of phase spaces. Consequently, by the time that the traced beam has reached collimator B the particles at the edges of its phase spaces have spread out sufficiently that they are caught by the collimator.

Discussion

The purpose of this investigation was twofold; first was a comparison with the results of an earlier version of the program and second was to re-establish the necessity of the retention of collimator B.

Comparison of present-day results with earlier ones was done first. This was difficult in some instances in the comparisons with the data of ref1) because of the difficulty in knowing if the proper comparisons were being made. It was much easier to compare with the 1978 run because the actual output was available. It is felt that the older and present runs are in reasonable agreement. It does appear, however, that today's program predicts somewhat lower spills downstream of collimator B than did the older version of the program.

The main purpose of this study was to see if collimator B was really necessary. It was the author's hope that, by tracing particles from the stipper foil through both targets that it would prove unecessary because particles with large divergences would be cut off by collimator A and the remaining beam focussed the triplet. However, the results given in table 5 indicate that this is not the case. It is clear that in order to protect the triplet, *collimator B is essential.*

It should be pointed out, however, that although that collimator protects the triplet from beam spill, it becomes active from beam loss within itself. This leads to high radiation doses to personnel that are required to effect repairs in that region. Fortunately, this has not been required to date.

References

[1] TL Templeton, AS Arrott and PA Reeve, *Spill Calculations and Beam Collimation in Beam Line 1A Between T1 and TNF*, TRIUMF report TRI-DN-77-18, October, 1977.
[2] CJ Kost, *Private communication*, TRIUMF, March, 1993.
[3] GM Stinson, *Collimation Following the LD_2-LH_2 Target on Beam Line IV-A*, TRIUMF report TRI-DNA-77-2, 1977.

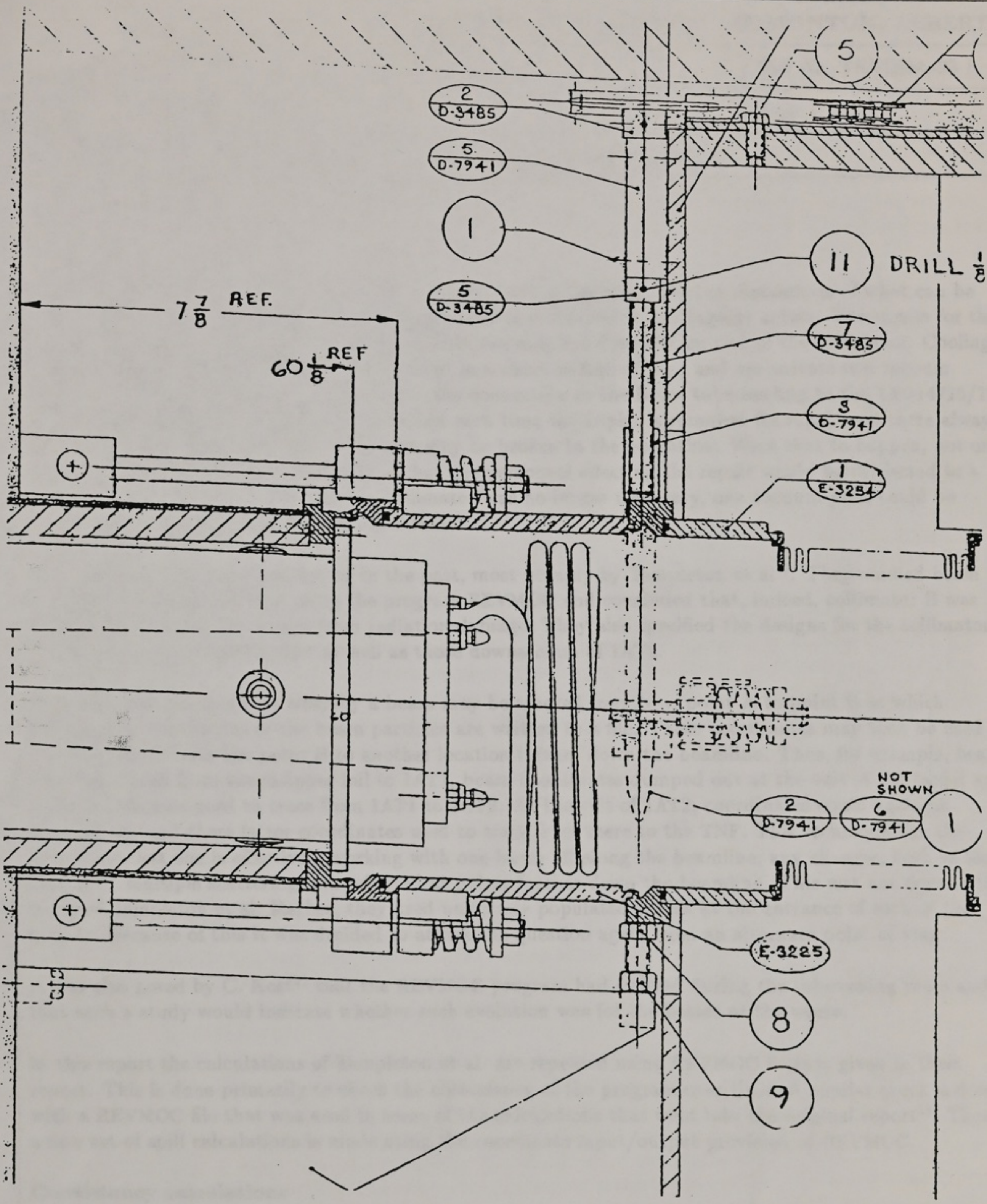

Figure 1. Section of drawing E-3217 showing downstream end of collimator B.