TRIUMF **Document-129655**

Operational Model for ARIEL
Design Note TRI-DN-16-05

Document Type: Design Note

Release: 3 **Release Date:** 2017-10-20

Author(s): Robert Laxdal

	Name:	Signature:	Date:
Author:	Robert Laxdal	FOR APPROVAL	
Reviewed By:	Adam Garnsworthy		
	Eric Guetre		
	Alex Gottberg		
	Marco Marchetto		
	Yuri Bylinsky		
	Anders Mjos		
	Violeta Toma		
	Grant Minor		
Approved By:	Reiner Kruecken		
	Oliver Kester		

History of Changes

Release Number	Date	Description of Changes	Author(s)
1	2016-02-11	Description of Changes from the initial draft based on feedback – moved maintenance day to Tuesday for both drivers to get an earlier start on RIB production after target change – added 1 Target development shift (TDS) for each target – Added 36 hour maintenance day every 9 weeks	R. Laxdal Reviewed and signed by all except G. Minor – not officially released
2	2016-03-18	- Made corrections as suggested during Review phase of Rev. 1 - Section 7 - Added target waste strategy - Section 8 - Added ramp-up model - Section 9 - Added non-standard operation cycles as discussed with A. Gottberg - Section 11 – modified summary	R. Laxdal
3	2016-05-02	Updated with changes from review - added section 10 on reliability as discussed with A. Mjos	R. Laxdal
3	2017-10-20	Updated Section 6 on required resources to operate ARIEL and Section 10 where an Action plan was considered for dealing with infant mortality of targets. Updated the summary to reflect additions to Section 10.	R. Laxdal

Keywords: P0342, ARIEL facility, operation model, RIB hours

Distribution List: ariel2team@lists.triumf.ca

1 Overview

1.1 Introduction

ARIEL (Advanced Rare IsotopE Laboratory) will add two new independent production targets and two new driver beams (one electron and one proton) to augment the existing production via protons at the ISAC target station. Beams will be produced in ARIEL and then sent via low energy beamlines to connect to the ISAC beamlines. Presently the ARIEL building is complete. A new high-intensity electron linac (up to 10mA) with 30-MeV capability (upgradeable to 50-MeV) has been installed as a second driver to produce radioactive ion beams via photo-fission. By 2020 a new proton beamline will be added (BL4N) from the existing cyclotron and the new target areas will be outfitted with target modules and support facilities.

A major goal of ARIEL is to provide infrastructure to allow the delivery of three simultaneous radioactive ion beams (RIB) to ISAC experimental areas. Beam scheduling and operation will be much more complex than in the present case. This document presents an operation model to help inform not only the design of the infrastructure but also the resources required to operate the facility.

The model proposes a delivery scheme for three simultaneous beams considering operational constraints including shutdown periods, maintenance periods, target exchange and conditioning and tuning time and experimental constraints such as experiment length and priority. In general the operation model shows that a beam delivery in excess of 9000 hours is feasible while trying to minimize the resources that would have to be added. A total of 9000 hours would triple present capability (~3000 hours). The model is based on a three-week cycle where each of the three target stations is outfitted with a new target every three weeks. The target start-ups are staggered in time with respect to the other stations such that a new target is started each week in one of the three stations.

The model suggests a `RIB Factory' approach where the target cycle is maintained as a top priority trumping maximum flexibility. This differs from the present mode where target cycles are somewhat variable depending on the target and the experimental program. In the RIB Factory approach all targets are on the same 3-week cycle and the experimental program is scheduled to fit the facility schedule. Some variants on the three-week cycle are discussed in Section 9 but in all cases the regular weekly `heartbeat' is maintained. Target/source failures in one station would be mitigated so as not to disrupt operation in the other target stations. Some intervention would be considered especially for cases of infant mortality. These cases are discussed in Section 10. Section 6 estimates the resources required to operate the fully operating ARIEL. The model compares the additional infrastructure to the existing infrastructure for the various technologies to estimate the additional resources required in each service group. The additional resources assume an enhanced efficiency of operation based on a proactive rather than reactive model.

1.2 Definitions and Acronyms

% reliability	Hours of actual delivery as a fraction of hours of scheduled delivery
AETE	ARIEL Electron Target East station
AM shift	Experimental shift from 08:30 to 20:30
APTW	ARIEL Proton Target West station
ARIEL	Advanced Rare IsotopE Laboratory
Beam conditioning	Using the beam to heat the target to promote outgassing before production can begin
Conditioning station	Installing TM and target container in the conditioning station to precondition the target to temperature and voltage before installing on-line
Delivered RIB hours	Hours of RIB delivery to a scheduled destination at rates above the agreed minimum threshold established in a run plan meeting
Experimental shifts	Twelve-hour shifts allocated to experiments for scheduled beam delivery
HE experiments	High energy experiments – after ISAC-II SC-linac
ITE	ISAC Target East station
ITW	ISAC Target West station
LE experiments	Low energy experiments – at source potential
LEBT	Low Energy Beam Transport
LEBT-I LEBT-II	Beam paths into the ISAC-I low-energy area. (Note: There are three possible destinations from both ISAC and ARIEL, ILE1, ILE2, and the Francium PNC facility, but only two can be used at any one time.)
ME experiments	Medium energy experiments – after ISAC-I RFQ and DTL
OLIS	ISAC Off-Line Ion Source
On-line conditioning (no beam)	Heating the target artificially and ramping the source potential to outgas the target material and condition surfaces for HV operation
Operator fraction	The fraction of an operator needed for a particular activity in one shift
Operator shifts	Eight-hour operations personnel shifts: 07:00–15:00, 15:00–23:00, and 23:00–07:00. (Note: These are not the same as the twelve-hour experimental shifts described above.)
PM shift	Experimental shift from 20:30 to 08:30 the next day
RIB	Radioactive Ion Beams
TDS	Target Development Shift – dedicated shift to explore yield of ions from a target/source combination geared for development
Yield	Shifts that are dedicated to measuring the production yield of the isotopes required for the immediate experimental campaign

1.3 References

The following documents can be used to better understand the scope and requirements

- ARIEL-II Project Plan - Document-118283
- P0342 ARIEL-II CFI funding application, Document-114911
- ARIEL Top Level Requirements, Document-118534

2 Assumptions

The proposed Operation Model is based on the following assumptions:

2.1 Operations assumptions

2.1.1 The complex will initially be operated from two control rooms: the Main Control Room (MCR) and the ISAC Control Room (ICR).

2.1.2 The MCR will oversee after-hours site security, cyclotron building and e-tunnel services /work, meson hall and BL2C experimental/production areas, and operation of the cyclotron, proton beamlines (BL1A, BL2C, BL2A and BL4N), the electron linac, and the electron beamline.

2.1.3 The ICR will oversee services/work in the ISAC and ARIEL building and operation of ITE/ITW, AETE, APTW, LE beamlines in ARIEL and ISAC, and the ISAC post-accelerator complex.

2.1.4 The eventual goal will be to operate all facilities from a common control room.

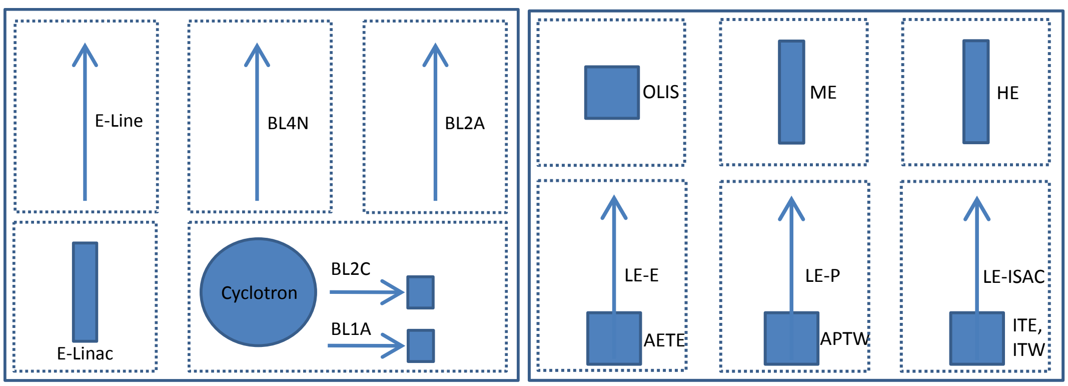

Fig. 1: (a) Accelerator oversight for the MCR (b) Accelerator oversight for ISAC CR

2.2 Driver schedule assumptions

2.2.1 There are two drivers, the e-Linac and the 500 MeV cyclotron. The e-Linac will produce RIB at AETE and the cyclotron will produce RIB at ITE/ITW and APTW.

2.2.2 The cyclotron will have one twelve-hour maintenance period (1 shift) per week on Tuesday AM. In principle the maintenance day could be shorter (*i.e.* maintenance if required).

2.2.2.1 Cyclotron beam development will be planned on every third Monday (AM and PM shift), coinciding with the APTW target exchange.

2.2.2.2 A three-shift cyclotron maintenance period will be required for a cryogenics defrost every nine weeks starting with the Monday AM shift. There will be no beam development in this three-week period. There will be four cyclotron beam development shifts every nine weeks. An eleven-week cyclotron shift schedule is shown in Fig. 2.

	Target	Su		Mo		Tu		We		Th		Fr		Sa	
Week	Exchange	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	ITE					Maint.									
2	APTW			Beam Development		Maint.									
3	AETE					Maint.									
4	ITW					Maint.									
5	APTW			Beam Development		Maint.									
6	AETE					Maint.									
7	ITE					Maint.									
8	APTW			Maint.	Maint.	Maint.									
9	AETE					Maint.									
10	ITW					Maint.									
11	APTW			Beam Development		Maint.									

Fig. 2: Cyclotron weekly schedule – A twelve-hour maintenance shift occurs every Tuesday AM. Beam development shifts occur every three weeks starting Monday AM and coinciding with APTW target exchanges. Every nine weeks there is a three-shift cyclotron maintenance period starting Monday AM and coinciding with an APTW target exchange.

2.2.3 The electron linac will have a ‘no beam delivery’ shift for maintenance or beam development Tuesday AM. In principle these ‘no beam delivery’ periods could be shorter than a shift or on an ‘as required’ basis.

2.2.4 The e-Linac will have additional ‘no beam delivery’ shifts every three weeks during the AETE target exchange. At least three shifts will be available for beam development or maintenance starting Monday AM. The e-Linac weekly schedule is shown in Fig. 3.

	Target	Su		Mo		Tu		We		Th		Fr		Sa	
Week	Exchange	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	ITE					Main/Dev									
2	APTW					Main/Dev									
3	AETE			Main/Dev	Main/Dev	Main/Dev									
4	ITW					Main/Dev									
5	APTW					Main/Dev									
6	AETE			Main/Dev	Main/Dev	Main/Dev									
7	ITE					Main/Dev									
8	APTW					Main/Dev									
9	AETE			Main/Dev	Main/Dev	Main/Dev									
10	ITW					Main/Dev									
11	APTW					Main/Dev									

Fig. 3: e-Linac weekly schedule. A twelve-hour maintenance or development shift occurs every Tuesday AM. Every three weeks during the AETE target exchange there is a three-shift maintenance/beam development period starting Monday AM.

2.3 Target schedule assumptions

Week	Exchange
1	ITE
2	APTW
3	AETE
4	ITW
5	APTW
6	AETE
7	ITE
8	APTW
9	AETE
10	ITW
11	APTW

Fig. 4: Week by week target exchange schedule

2.3.1 ISAC (ITW/ITE) will be operated on a six-week rotation with three weeks each per target (Fig. 4).

2.3.1.1 The proton beam will be delivered to ITE for three weeks followed by proton delivery to ITW for three weeks.

2.3.2 AETE and APTW will be on three-week rotations with AETE and APTW start-up and change-over staggered by one week.

2.3.2.1 ITW/ITE target start-up will be staggered with respect to AETE and APTW

2.3.2.2 2.3.2 and 2.3.2.1 mean that there will be one target start-up each week.

2.3.3 A target exchange in AETE/APTW will not affect operation in APTW/AETE – the two ARIEL targets will be fully independent including services.

2.3.4 Since there will be three targets changed every three weeks, 35 targets will be needed each year assuming 35-week operation (~8 months).

2.3.4.1 If the electron linac runs 43 weeks per year (~10 months) then 38 targets will be needed.

2.4 Beam delivery assumptions

2.4.1 Beam delivery to the LE areas will be ≥80% efficient. This is a top-level requirement.

2.4.2 Beam delivery to ME/HE areas will be ≥75% efficient. This is a top-level requirement.

2.4.3 There will be two paths to LE experimental areas (LEBT-I and LEBT-II) and one path to experimental ME/HE areas.

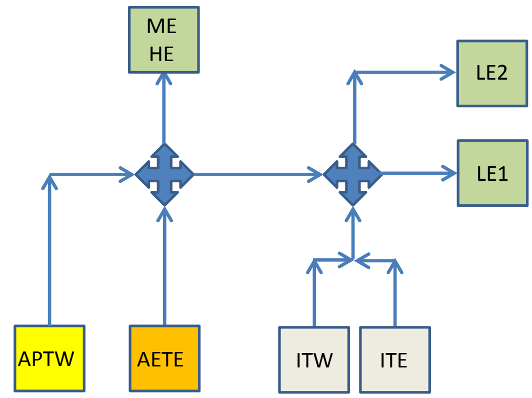

Fig. 5: Schematic of allowed paths to the three generic experimental areas.

2.4.3.1 There will be only one LE path from ARIEL to ISAC for simultaneous delivery. ME/HE beams will be delivered from ARIEL only.

2.5 Experiment assumptions

2.5.1 RIB experiments will be of varying length from five shifts to twenty shifts with an average of approximately nine shifts/experiment (from 2015 experiment data).

2.5.1.1 LE delivery on average will have shorter runs (approx. seven shifts/exp't).

2.5.1.2 ME/HE delivery on average will have longer runs (approx. twelve shifts/exp't).

2.5.2 LE beam delivery will be preceded by one shift of tuning for each new beam or destination.

2.5.3 ME/HE delivery will be preceded by one shift of on-line LE tuning and one shift of RIB tuning specific to high energy delivery including CSB tuning and switchover. Pilot-beam tuning from OLIS will also be required – one shift for ME beams and two shifts for HE beam.

3 Target cycles

Given 2.3.1 and 2.3.2, the following operating cycles for each of the target stations are proposed. The cycles include not only target exchange and installation time but also driver development and maintenance time, driver beam development, yield measurements and target development shifts (TDS). A main reason for having maintenance day on Tuesday for both drivers is to have the possibility of starting production no later than the Friday AM shift so that technical and beam delivery experts are on hand. One yield shift is assigned to each new target and is scheduled immediately after start-up and initial tuning to the yield station. One TDS shift is assigned to each target. The TDS shifts are scheduled approximately one week after start-up coming out of maintenance day.

3.1 ITE/ITW on-line target life cycle

A seven-week schedule for ITE and ITW is shown in Fig. 6. It is similar to that for existing operation except that cycle times vary at present depending on the target and the experimental program.

3.1.1 The ISAC target station will be operated in a six week rotation with three weeks operation cycle for ITW and ITE.

3.1.1.1 Cycle will start with ITW operating for the last shift (Monday PM) and ITE ready to take beam

3.1.1.2 Swap shielding Tuesday AM from ITW to ITE (**1 shift** but typically takes only 3 hours). This could allow for a short Maintenance day (4-5 hours)

3.1.1.3 Week 1: ITE on-line – assume **two shifts** for target conditioning with beam, **1 start-up shift** for LE tuning and **one yield shift** before beam delivery. ITE RIB production **7 shifts** (cyclotron beam development or maintenance **2 shifts)**. ITW begins cooldown that lasts for one week.

3.1.1.4 Week 2: The next maintenance day (Tuesday AM) – disconnect and move ITW target module to hot cell (**1 shift** but typically takes 6 hours – so maintenance day could be 8 hours). ITE is used for TDS (**1 shift**). ITE resumes on-line production for **12 shifts.** ITW target is exchanged in hot cell then new target and module is moved to the conditioning station.

3.1.1.5 Week 3: The next maintenance day (Tuesday AM) – move ITW module back on-line – typically takes **1 shift** (12 hours). ITE will resume on-line operation for **13 shifts.** ITW will be conditioned on-line.

3.1.1.6 Week 4: The next maintenance day (Tuesday AM) shielding will be swapped from ITE to ITW and the cycle continues as above with ITW/ITE reversing roles.

3.1.2 After 6 weeks the full cycle will continue

ITE	Su		Mo		Tu		We		Th		Fr		Sa	
Week	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	Condition on-line without beam				Maint.	Condition-beam		Start	Yield	Production				
2	Production		Beam dev/Maint		Maint.	TDS	Production							
3	Production				Maint.	Production								
4	Production				Shields	Cooldown								
5	Cooldown				Tar-> HC	Tar. X			Conditioning station					
6	Conditioning station				Cond->Ta	Condition on-line without beam								
7	Condition without beam				Maint.	Condition-beam		Start	Yield	Production				

ITW	Su		Mo		Tu		We		Th		Fr		Sa	
Week	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	Production				Shields	Cooldown								
2	Cooldown				T> HC>X	Tar. X			Conditioning station					
3	Conditioning station				Cond->Ta	Condition on-line without beam								
4	Condition on-line without beam				Maint.	Condition-beam		Start	Yield	Production				
5	Production		Beam dev/Maint		Maint.	TDS	Production							
6	Production				Maint.	Production								
7	Production				Shields	Cooldown								

Fig. 6: Seven-week schedule for ITE/ITW

3.2 APTW on-line target life cycle

3.2.1 APTW will be operated in a three week cycle. A 7 week schedule for APTW and AETE is shown in Fig. 7.

3.2.1.1 The last operating shift will be Sunday AM – beam off Sunday 20:30 for Sunday PM (**1 shift)** cooldown

3.2.1.2 Week 1: Monday AM 08:30 - begin target exchange – two days (**4 shifts**)

3.2.1.3 Wed AM 08:30 - begin conditioning the target with beam (**2 shifts**)

3.2.1.4 Thursday AM 08:30 - target ready for beam tuning (**1 shift**) and yield (**1 shift**)

3.2.1.5 Friday AM 20:30 – RIB production will begin for **8 shifts**

3.2.1.6 Week 2: Tuesday AM 08:30 – maintenance day (**1 shift**) – Tuesday PM – TDS (**1 shift**) - then resume on-line operation for **12 shifts**

3.2.1.7 Week 3: Tuesday AM 08:30 – maintenance day (**1 shift**) – then resume on-line operation for **10 shifts**

3.2.1.8 Week 4: Sunday PM 20:30 – beam off for target cooldown and target exchange

3.3 AETE on-line target life cycle

3.3.1 As per 2.3.2 AETE will be operated in a three week cycle

3.3.1.1 The last operating shift will be Sunday AM – beam off Sunday 20:30 for Sunday PM (**1 shift)** cooldown

3.3.1.2 Week 1: Monday AM 08:30 - begin target exchange – two days (**4 shifts**)

3.3.1.3 Wed AM 08:30 - begin conditioning the target with beam (**2 shifts**)

3.3.1.4 Thursday AM 08:30 - target ready for beam tuning (**1 shift**) and yield (**1 shift**)

3.3.1.5 Friday AM 20:30 – RIB production will begin for **8 shifts**

3.3.1.6 Week 2: Tuesday AM 08:30 – maintenance day (**1 shift**) – Tuesday PM – TDS (**1 shift**) - then resume on-line operation for **12 shifts**

3.3.1.7 Week 3: Tuesday AM 08:30 – maintenance day (**1 shift**) – then resume on-line operation for **10 shifts**

3.3.1.8 Week 4: Sunday PM 20:30 – beam off for target cooldown and target exchange

APTW	Su		Mo		Tu		We		Th		Fr		Sa	
Week	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	**Production**				**Maint.**	**Production**								
2	**Productio**	**Cooldown**	**Tar. X**		**Tar. X**		**Cond-beam**		Start	Yield	**Production**			
3	**Production**				**Maint.**	TDS	**Production**							
4	**Production**				**Maint.**	**Production**								
5	**Productio**	**Cooldown**	**Tar. X**		**Tar. X**		**Cond-beam**		Start	Yield	**Production**			
6	**Production**				**Maint.**	TDS	**Production**							
7	**Production**				**Maint.**	**Production**								

AETE	Su		Mo		Tu		We		Th		Fr		Sa	
Week	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	**Production**				**Maint.**	TDS								
2	**Production**				**Maint.**	**Production**								
3	**Productio**	**Cooldown**	**Tar. X**		**Tar. X**		**Cond-beam**		Start	Yield	**Production**			
4	**Production**				**Maint.**	TDS								
5	**Production**				**Maint.**	**Production**								
6	**Productio**	**Cooldown**	**Tar. X**		**Tar. X**		**Cond-beam**		Start	Yield	**Production**			
7	**Production**				**Maint.**	TDS								

Fig. 7: 7 week schedule for APTW and AETE. The week numbers are relative to those used in Fig. 6.

4 RIB production

A top-down approach has been used to estimate the number of hours of RIB available for each of the three target areas during a three-week cycle. For each area the total number of shifts available in a three-week period, 42, is reduced by various tasks including cooldown, target exchange, on-line conditioning, maintenance, yield measurements, TDS, start-up and beam development. Since some of the ITE/ITW tasks are done off-line while the other ITW/ITE target is on-line more RIB shifts are available from ITE/ITW (32) than from APTW or AETE (30).

In addition to these pre-determined shifts there are additional procedural days required depending on the experiments scheduled during the three-week cycle. Each new experiment requires one shift for tuning. The number of experiments in a three-week cycle can be estimated based on an average experiment length for LE and ME/HE experiments. In the top-down analysis, LE experiments are assumed to be seven shifts long and ME/HE twelve shifts long (2.5.1.1 and 2.5.1.2). ITE/ITW will typically only serve LE experiments (2.4) while AETE and APTW will serve a mixture of LE and ME/HE. After these procedural shifts are added, 27, 26, and 26 shifts are available for RIB delivery from each of ITE/ITW, APTW and AETE in a three-week period.

The total RIB hours scheduled per year are calculated based on 35 weeks of operation for the cyclotron (ITE/ITW, APTW) and 43 weeks for the e-Linac (AETE). The delivered RIB hours are based on the expected availability for LE and ME/HE experiments (2.4.1 and 2.4.2).

A summary of the analysis is given in Tables 1 and 2. From this analysis, based on the assumptions underlying the model, 9270 hours of RIB delivery would be possible in a year of stable operation.

ITW/ITE weeks	3
shifts total	42
cooldown	0
target exchange	0
on-line cond.	-2
maintenance	-3
beam dev/maint	-2
Start	-1
Yield	-1
TDS	-1
Shifts available	32
LE Experiments	4.6
Procedure	-5
RIB shifts/3 weeks	27
RIB hours/3 weeks	324
RIB hours/35wks	3780
RIB hrs deliver (80%	3024

AETE weeks	3
shifts total	42
cooldown	-1
target exchange	-4
on-line cond.	-2
maintenance	-2
Start	-1
Yield	-1
TDS	-1
shifts available	30
LE experiments (6)	2.0
Accel Exp (10)	1.8
procedures	-4
Net shifts	26
RIB hours/3wks	312
RIB hours/35wks	3640
RIB hrs/43 weeks	4472
RIB/hours @77%	3443

APTW weeks	3
shifts total	42
cooldown	-1
target exchange	-4
on-line cond.	-2
maintenance	-2
Start	-1
Yield	-1
TDS	-1
shifts available	30
LE experiments (6)	2.0
Accel Exp (10)	1.8
procedures	-4
Net shifts	26
RIB hours/3wks	312
RIB hours/35wks	3640
RIB/hours @77%	2803

Table 1: Top down assessment of ISAC/ARIEL RIB delivery for the three target areas.

Target Area	Wks/year	RIB sched	RIB deliv
ITW/ITE	35	3780	3024
APTW	35	3640	2803
AETE	43	4472	3443
Totals			**9270**

Table 2: Summary of RIB delivery for ISAC/ARIEL based on a top-down assessment.

5 Nine-week strawman schedule

In order to gain insight into potential conflicts not highlighted by the top-down analysis a nine-week strawman beam schedule has been constructed assuming three operational target areas, two simultaneous LE beams, and one ME/HE beam. The schedule utilizes experiments of different lengths that are chosen to make efficient use of the shifts available from each target. The schedule is shown in Fig. 8. The smallest time unit used in the strawman schedule is one twelve-hour shift. There are fourteen columns corresponding to the fourteen shifts per week. There are ten weeks plotted and each week contains five rows representing the four target areas plus OLIS. Colour is used to denote the activity in a particular shift and the colour key is given in Fig. 10. In some cases tuning shifts are moved around where possible to help level Operator loading while trying to maximize RIB output.

The average number of delivered shifts through the fourteen-shift weekly cycle is shown in Fig. 9. This plot shows how the maintenance and procedural activities that occur mid-week impact the RIB output. The maintenance schedule is required to avoid the load on technical people during the weekend.

Week		Su		Mo		Tu		We		Th		Fr		Sa	
		AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
	Cyclotron	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	e-Linac	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		0.2	0.2	0.2	0.2	0.6	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
1	ITW							0.1	0	0.1	0.1	0.1	0.1	0.1	0.1
	ITE							0.8	0.1	0.1	0.1	0.1	0.1	0.8	0.1
	APTW							0.4	0.4	0.8	1	0.85	0.25	0.25	0.25
	AETE							0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
		2.2	2.2	2.2	2.2	2.6	2.4	4.6	2.8	3.3	3.5	3.35	2.75	3.45	2.75
2	ITW	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	ITE	0.1	0.1	0.1	0.1	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.8	0.1
	APTW	0.25	0.25	0.25	0.25	0.3	0.3	0.8	0.9	0.4	0.4	0.4	0.4	0.4	0.4
	AETE	0.1	0	0.1	0	0.1	0	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1
	OLIS					1		1							
		2.75	2.65	2.75	2.65	4.4	3.7	4.7	3.8	3.7	3.9	3.7	3	3.7	3
3	ITW	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1	0.1
	ITE	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0
	APTW	0.4	0.4	0.4	0.4	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	AETE	0.1	0.1	0.1	0.1	0.3	0.3	0.8	0.9	0.4	0.4	0.4	0.4	0.4	0.4
	OLIS					1		1							
		3	3	3	3	4.6	3.9	4.5	4	3.7	3.5	2.8	2.8	2.8	2.8
4	ITW	0.1	0.1	0.3	0.3	0.3	0.3	0.8	0.1	0.1	0.1	0.1	0.8	0.1	0.1
	ITE	0	0	0	0	0.1	0	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1
	APTW	0.1	0	0.1	0	0.1	0	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1
	AETE	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	OLIS					0.4									
		2.8	2.7	3	2.9	3.8	3.1	3.9	3.1	3.6	3.8	3.6	3.6	2.9	2.9
5	ITW	0.1	0.1	0.1	0.1	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.8	0.1	0.1
	ITE	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	APTW	0.1	0.1	0.1	0.1	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	AETE	0.4	0	0.1	0	0.1	0	0.4	0.4	0.8	1	0.85	0.25	0.25	0.25
	OLIS			1											
		2.9	2.5	3.6	2.5	3.4	3.7	3	3	3.4	3.6	3.45	3.55	2.85	2.85
6	ITW	0.1	0.1	0.1	0.1	0.3	0	0	0	0	0	0	0	0	0
	ITE	0.2	0.2	0.2	0.2	0.1	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1	0.1
	APTW	0.1	0.1	0.1	0.1	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	AETE	0.25	0.25	0.25	0.25	0.3	0.3	0.8	0.9	0.4	0.4	0.4	0.4	0.4	0.4
	OLIS					1		1							
		2.85	2.85	2.85	2.85	4.6	3.9	4.5	4	3.7	3.5	2.8	2.8	2.8	2.8
7	ITW	0	0	0	0	0.1	0	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1
	ITE	0.1	0.1	0.3	0.3	0.3	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.8	0.1
	APTW	0.1	0	0.1	0	0.1	0	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1
	AETE	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	OLIS					0.4									
		2.8	2.7	3	2.9	3.8	3.1	3.9	3.1	3.6	3.8	3.6	2.9	3.6	2.9
8	ITW	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	ITE	0.1	0.1	0.1	0.1	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	APTW	0.1	0.1	0.1	0.1	0.3	0.3	0.9	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	AETE	0.4	0	0.1	0	0.1	0	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1
	OLIS			1	1										
		2.9	2.5	3.6	3.5	3.4	3.7	3.8	3.3	3.7	3.9	3.7	3	3	3
9	ITW	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.8	1	0.8	0.1	0.1	0.1	0.1
	ITE	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0
	APTW	0.4	0.4	0.4	0.4	0.3	0.8	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	AETE	0.1	0.1	0.1	0.1	0.3	0.3	0.85	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	OLIS					1									
		3	3	3	3	4.6	3.9	3.55	3.35	3.55	3.35	2.65	2.65	2.65	2.65
10	ITW	0.1	0.1	0.3	0.3	0.3	0.3								
	ITE	0	0	0	0	0.1	0								
	APTW	0.1	0	0.1	0	0.1	0								
	AETE	0.25	0.25	0.25	0.25	0.3	0.8								
	OLIS	2.65	2.55	2.85	2.75	3.4	3.5								
	Average	2.875	2.7375	3.1	2.9125	4.075	3.625	3.98125	3.45625	3.61875	3.66875	3.2875	3.0375	3.0375	2.8625

Fig. 8: Nine-week strawman schedule. Colour key is shown in Fig. 10. Green tones correspond to beam delivery and the numbers in each shift entry (and summary rows and columns) correspond to fractions of operators needed for each shift.

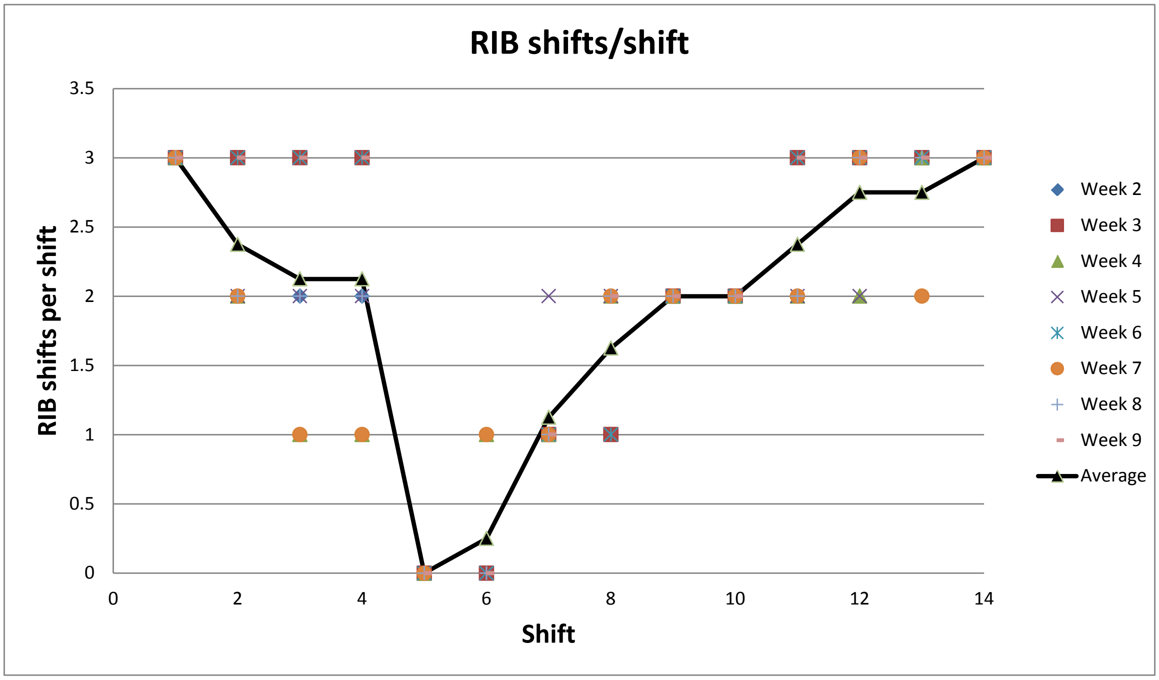

Fig. 9: Number of RIB shifts delivered as a function of shift slot in the week (Sunday AM is shift 1 and Saturday PM is shift 14) for each week in the strawman schedule and the nine-week average. Full operation with APTW, AETE and one of ITW/ITE represent three RIB shifts per schedule shift.

5.1 Operations resource load

The impact on operations personnel resources was estimated by assigning an 'operator fraction' value to each of the shift activities. The 'operator fraction' corresponds to what fraction of an operator's time per shift would be devoted to the particular activity. The colour key and 'operator fraction' values are shown in Fig. 10.

move shield	0.1
Cooldown	0
Driver tuning	0.2
Target to Hot Cell	0.1
Maintenance	0.3
target exchange	0.1
hot cell to target	0.1
condition	0.2
condition w beam	0.4
operate LE	0.1
operate ME	0.25
operate HE	0.4
cyclotron	0.1
e-Linac	0.1
OLIS pre-tune	1
LE tuning	0.8
ME tuning	0.85
HE tuning	0.9
Yield	1
Beam dev	0.3
cond-stat	0.1
TDS	0.3

Fig. 10: Colour key and `Operator Fraction' per shift per activity

The strawman schedule has been populated with the operator fraction values to give an operator resource loading value for each shift. The assumption is that two operators are required as a base (one in the MCR and one in the ICR) and that fractional values are added to these base values. The shift activities have been adjusted in order to limit the operator loading value to less than five in any one shift.

This exercise suggests that three operators in the MCR and three operators in the ICR could run the facility. It is anticipated that if the control rooms could be joined into one TRIUMF Control Center that only five operators per shift would be required.

A shift-by-shift operator loading for the strawman schedule is shown in Fig. 11. The plot shows that operator load peaks mid-week.

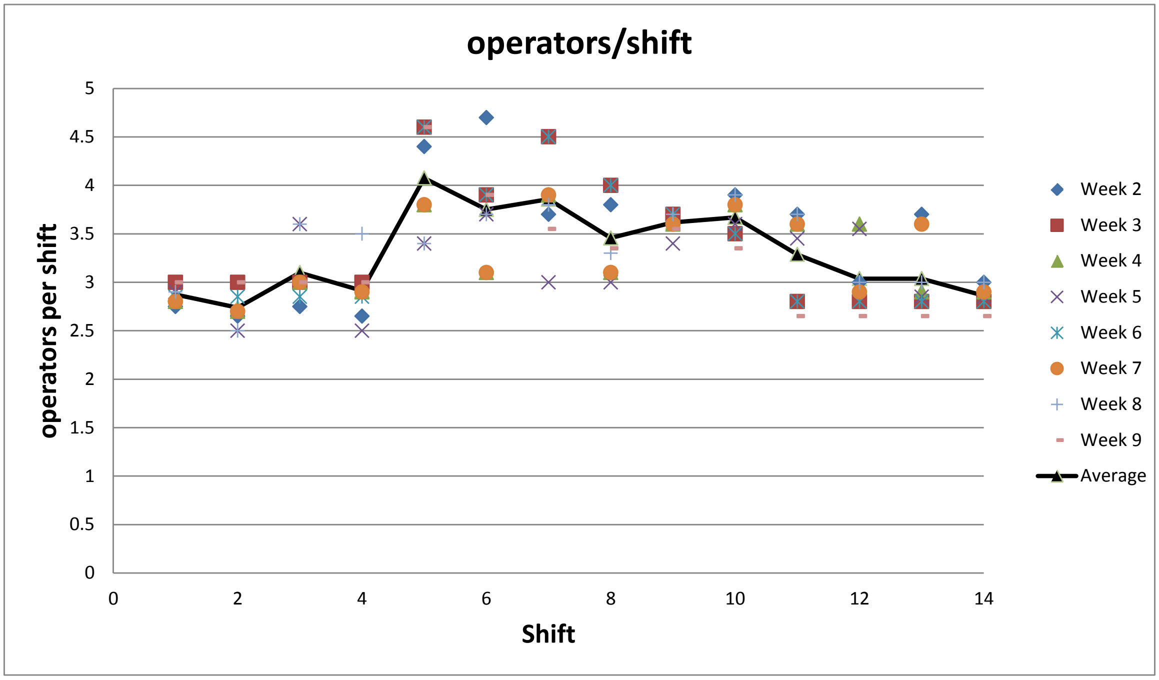

Fig. 11: Operators required over the nine-week cycle as a function of shift slot during the week (Sunday AM is shift 1 and Saturday PM is shift 14).

5.2 Experts resource load

Several experts (accelerator/RIB physicists) will be needed to augment beam delivery and assist Operations in the ARIEL era. The tasks include LE and accelerator tuning and supervision, CSB tuning and supervision, RIB production development, yield measurements, and production supervision. They do not include participation on the cyclotron beam development which will be handled by another set of experts and where the load is in line with the present effort. The load on experts was estimated by assigning an ‘expert fraction’ value to each of the shift activities. The ‘expert fraction’ corresponds to what fraction of an expert’s time per shift would be devoted to the particular activity. The colour key and ‘expert fraction’ values are shown in Fig. 12 and the summary plot is shown in Fig. 13. The crude analysis indicates that three or four specialized experts (typically post-docs) in addition to existing professional support staff will be required to support beam delivery. The functions would include the tuning and supervision of the CSB, accelerators, low energy beamlines and separators, on-line sources including LIS, and RIB target development.

move shield	0.1
Cooldown	0
Driver tuning	0.2
Target to Hot Cell	0.1
Maintenance	0.2
target exchange	0.1
hot cell to target	0.1
condition	0.2
condition w beam	0.3
operate LE	0.2
operate ME	0.25
operate HE	0.3
cyclotron	0.1
e-Linac	0.1
OLIS pre-tune	0.6
LE tuning	0.6
ME tuning	1.4
HE tuning	2
Yield	0.8
Beam dev (cyclotror	0.1
cond-stat	0.2
TDS	1.6

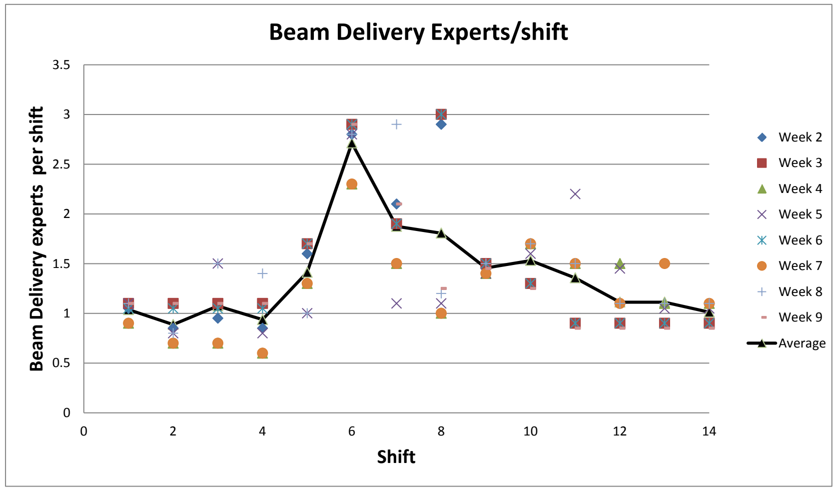

Fig. 12 and 13: Expert fraction load per activity and summary expert load on a week-by-week basis as a function of shift slot.

5.3 Length of experiments

The lengths of the experiments were varied in order to fit the available shifts and to reflect a typical mix of ISAC experiments. The experiment lengths used for the nine-week strawman case are shown in Fig. 14a,b. A mixture of shorter shifts with a few longer shifts was used.

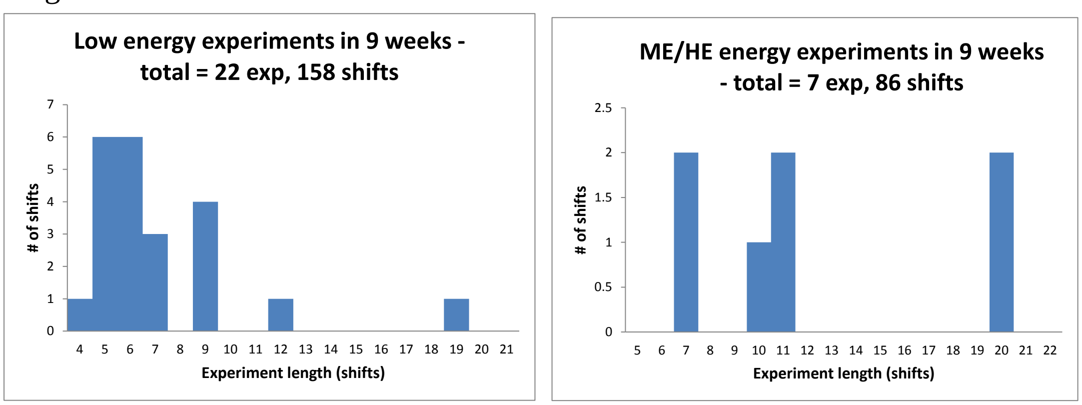

Fig. 14ab: Experiment length statistics for the strawman nine-week schedule.

5.4 Summary of nine-week strawman

A summary of the strawman beam delivery is shown in Table 3. There are 246 shifts of beam delivery with 82, 81, and 81 shifts from ISAC, APTW, and AETE, respectively.

Experiments are on average seven, eight, and fifteen shifts long for the LE, ME, and HE areas.

There are 29 experiments with fourteen taking beam from ISAC, eight from APTW, and seven from AETE. Of these 22 are LE, three are ME, and four are HE.

9 weeks	**Total**	**ITE/ITW**	**APTW**	**AETE**
shifts	244	82	81	81
LE shifts	158	82	53	23
ME shifts	25	0	7	18
HE shifts	61	0	21	40
Exp total	29	14	8	7
LE exp	22	14	5	3
ME exp	3	0	1	2
HE exp	4	0	2	2
Sh/exp	8.4	5.9	10.1	11.6
LE sh/exp	7.2	5.9	10.6	7.7
ME sh/exp	8.3		7.0	9.0
HE sh/exp	15.3		10.5	20.0

Table 3: A summary of the nine-week strawman schedule.

5.5 Extrapolating to full-year operation

Results from the strawman schedule can be extrapolated to yearly operation by taking into account the weeks of operation for each driver (35 weeks for the cyclotron and 43 weeks for the e-Linac). The results are shown in Table 4.

The number of RIB hours delivered assumes 80% availability for LE beams and 75% availability for ME/HE beams. The total number of RIB hours per year from this analysis is 9569. There are 128 experiments completed with 88 LE, thirteen ME, and seventeen HE.

Weeks		**35**	**35**	**43**
		ITE/ITW	**APTW**	**AETE**
Tot shifts	**1021**	**319**	**315**	**387**
LE shifts	635	319	206	110
ME shifts	113	0	27	86
HE shifts	273	0	82	191
Exp total	**119**	**54**	**31**	**33**
LE exp	88	54	19	14
ME exp	13	0	4	10
HE exp	17	0	8	10
Total hrs	**12251**	**3827**	**3780**	**4644**
LE hrs	7619	3827	2473	1319
ME hrs	1359	0	327	1032
HE hrs	3273	0	980	2293
RIB hrs	**9569**	**3061**	**2959**	**3549**
LE hrs	6095	3061	1979	1055
ME hrs	1019	0	245	774
HE hrs	2455	0	735	1720

Table 4: A summary of the strawman schedule prorated for full-year operation.

5.6 Shift scheduling guidelines

Experiments can be longer or shorter than those in the strawman. In general longer experiments are more efficient since they reduce the number of tuning shifts required, keeping in mind that for maximum RIB hours the experiment lengths need to align with the three-week target cycle specified in the proposed operational model.

Given the above assumptions about the target rotation cycle each target area has a unique set of three time segments devoted to RIB delivery between maintenance or development periods.

- ITE/ITW – segment1, segment2, segment3 = 7, 12, 13 shifts
- APTW – segment1, segment2, segment3 = 8, 12, 10 shifts
- IETE – segment1, segment2, segment3 = 8, 12, 10 shifts

It is most efficient to organize experiment lengths to fit these blocks with the following guidelines:

- a target cycle begins at segment1 and ends after segment3
- each experiment requires one procedural shift to be taken out of the shifts available
- one segment can be divided into two shorter experiments
- an experiment can be made longer by stringing two or three segments together

- if a target material is required for a beam time shorter than the three-week cycle it is recommended to leave the target area dormant after beam delivery ends until the next target exchange period for that target station – the time could be filled with beam development or maintenance activities (variants to allow a cycle shorter than three weeks are discussed in Section 9).

6 Technical resource loading

6.1 Top-down estimation:

Technical resource loading is also a critical part of operating an RIB factory efficiently. It is essential that a detailed plan for operational resources in terms of costs and personnel in the period leading up to full ARIEL implementation be developed. A crude top-down analysis can be done by comparing the scale of the current infrastructure to that in the full ARIEL scenario. Table 5 details the existing infrastructure and the additional facilities in the full ARIEL era.

Existing Infrastructure	**Additions**
ISIS	e-Linac
500MeV Cyclotron	e-Line
BL1A, BL2C, BL2A	BL4N
ITE/ITW	AETE/APTW
LEBT	A-LEBT
CSB-ECR	CSB-EBIT
OLIS	
RFQ, DTL, ISAC-II	
MEBT, HEBT, DSB, SEBT	

Table 5: Existing and additional facilities in the full ARIEL era.

Each of the new facilities can be considered as an additional load on service groups. A crude top-down assessment can be arrived at by considering each technology and scoring the increased fractional load when comparing the existing load to the additional load. A summary of that analysis is given in the following tables. In Table 6 the present complement of staff is summarized in terms of group and employee category.

Department	Group	Tech	P&S	BAE	PDF	#
OPS/Beam Delivery	**OPS Driver**	17	1			18
	OPS RIBs	10	1			11
	OPS TR13	2	1			3
	Beam Delivery	1	1	1	2	5
	Stable sources	2	1			3
Systems	**Controls**	4	4			8
	Vacuum	3	2			5
	Cryogenics	3	2			5
	Diagnostics	5	3			8
	High Voltage	3	2			5
	DC PS	3	2			5
RF/SRF	**HLRF**	2	5			7
	SRF	4	1	1		6
	LLRF	2	2	1	1	6
Targets/source	**Production/ OPS**	4	2			6
	RH	6	2			8
	R&D		5	3	0	8
	ARIEL Dev't			3	1	4
	Laser source			2	1	3
Beam physics	**beam physics**		4	4	0	8
Totals	**Totals**	**71**	**42**	**16**	**5**	**134**

Table 6: Present complement of staff broken down by group and employee category.

Table 7 includes a relative assessment of effort in old and new installations for each group. Not all groups impacted by the new infrastructure are included in the table but estimates could follow a similar methodology. Better estimates can be arrived at using detailed parts count, existing time sheets and reliability estimates.

			Existing Driver				Future Driver			Existing RIB						Future RIB			
Department	**Group**	**#**	Cyclotron	BL1A	BL2A	BL2C	e-Linac	e-Line	BL4N	IPW	ITE	OLIS	LE-ISAC	ME	HE	APTW	AETE	LEBT1	LEBT2
OPS/Beam Delivery	**OPS Driver**	18	2	0.2	0.2	0.2	0.2	0.2	0.2										
	OPS RIBs	11								0.2	0.2	0.2	0.3	0.3	0.2	0.3	0.3	0.4	0.3
	OPS TR13	3																	
	Beam Delivery	5	0.2	0.2	0.2		0.2	0.2	0.2				0.5	0.3	0.2			0.4	0.4
	Stable sources	3	1				0.4					1						0.6	
Systems	**Controls**	8	1	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.1	0.3	0.3	0.3	0.3	0.3	0.4	0.3
	Vacuum	5	1	0.8	0.6	0.2	0.3	0.6	0.6	0.6	0.6	0.1	0.6	0.6	0.4	0.6	0.6	0.8	0.6
	Cryogenics	5	1				1								2				
	Diagnostics	8	1	1	0.5	0.2	0.3	0.8	0.5				1	0.5	0.5			1.2	1
	High Voltage	5	1.5				0.3			0.5	0.5	0.5	1			0.5	0.5	1.2	1
	DC PS	5	1	1	1	0.5		1	1			0.1	0.2	0.5	0.5			0.2	0.2
RF/SRF	**HLRF**	7	1				0.5							1	1			0.1	
	SRF	6					0.25								1				
	LLRF	6	4				6						1	8	40			2	
Targets/source	**Production/ OPS**	6								5	5					13	15		
	RH	8	0.5	0.2	0.1	0.1	0.1			0.5	0.5					0.5	0.5		
	R&D	8								0.5	0.5					0.2	0.5		
	ARIEL Dev't	4																	
	Laser source	3								0.5	0.5					1	1		
Beam physics	**beam physics**	8	1	0.2	0.2	0.1	0.3	0.1	0.2				0.1	0.2	0.2			0.1	0.1
Totals	**Totals**	**134**																	

Table 7: Relative effort by each group broken down by old and new infrastructure.

6.2 Estimate of increased effort

The information from the previous section can be used together with the existing resource allocation to estimate the required resources to operate the expanded ARIEL facility. The present manpower allocation comprises the baseline core individuals and added manpower to support the ARIEL project. The information in Table 7 is synthesized in Table 8 to estimate an `Extra Effort' factor. The factor corresponds to the additional amount of work required in a particular group due to the new infrastructure. The `Extra Work' column refers to the number of additional workers that would be required assuming no improvement in efficiency. It is derived by multiplying the present number of group members with the `Extra Effort' category. This estimate shows that without improved efficiency that the technical staff would need to increase by 85 over the present complement of 134.

Department	Group	drive-old	RIB-old	drive-new	RIB-new	Factor	Extra Work
OPS/Beam Delivery	OPS Driver	2.6	0	0.6	0	0.23	4.4
	OPS RIBs	0	1.4	0	1.3	0.93	11.1
	OPS TR13	0				0.00	0.0
	Beam Delivery	0.6	1	0.6	0.8	0.88	4.4
	Stable sources	1	1	0.4	0.6	0.50	1.5
Systems	Controls	1.7	1.6	0.7	1.3	0.61	4.8
	Vacuum	2.6	2.9	1.5	2.6	0.75	4.5
	Cryogenics	1	2	1	0	0.33	1.7
	Diagnostics	2.7	2	1.6	2.2	0.81	6.5
	High Voltage	1.5	2.5	0.3	3.2	0.88	4.4
	DC PS	3.5	1.3	2	0.4	0.50	2.5
RF/SRF	HLRF	1	2	0.5	0.1	0.20	1.4
	SRF	0	1	0.25	0	0.25	1.5
	LLRF	4	49	6	2	0.15	0.9
Targets/source	Production/ OPS	0	10	0	28	2.80	16.8
	RH	0.9	1	0.1	1	0.58	4.6
	R&D	0	1	0	0.7	0.70	5.6
	Laser source	0	1	0	2	2.00	6
Beam physics	beam physics	2.1	0.5	0.6	0.2	0.31	2.5
Totals	Totals						85

Table 8: The new work for each category is compared to the existing work to come up with the fractional increase of work and the `Extra Work' quantity. `Extra Work' corresponds to the number of additional staff required to perform a task given no improvements in efficiencies.

Table 8 is useful in analyzing the most important areas where efficiency should be focused. Key amongst these is in target production and laser sources where the number of targets and LIS experiments will significantly increase over current numbers. Within Operations the effort from Beam Delivery will almost double and the number of RIB operators will need to grow to three per shift in a two control room scenario. Certainly the factory model is essential to help reduce peak demand. Within the technical groups the equipment serviced by HV, Vacuum and diagnostics will almost double.

7 Target waste management

The operational model can help set the boundary conditions for the target waste management plan. During full operation ARIEL will be producing two targets every three weeks or 26 targets per year with and additional twelve targets per year being produced at ISAC. Since there are two target exchanges every three weeks in ARIEL it means there is one week where the target hall is more available for target manipulation. This could include post-irradiation examinations and/or target material separation. In order to keep up with target inventory two targets will need to be disposed of every three weeks during production; if more manageable, some (or all) of the target disposal could be done during shutdowns.

7.1 Target waste management assumptions and estimates

- ISAC waste disposal will continue as it is now with the proviso that the average number of targets per year will grow from the present nine or ten to twelve and the target rotation will be fixed at three weeks. Current processes will be evaluated in terms of efficiency with the move to the RIB factory paradigm.
- ARIEL target waste disposal will be done within the ARIEL complex and will utilise the ARIEL target decay storage vault and the ARIEL hot cell for packaging.
- The ARIEL target will be installed in a hermetic vessel that is pre-conditioned before going on-line to allow a quick target exchange.
- After irradiation ends there will be a twelve-hour cooldown. The vessel will then remotely disconnected from the on-line module, taken off-line and moved to the ARIEL decay storage vault.
- The target vessels will be held in the ARIEL decay storage for a time that depends on the level of activation and the effective half-life of the activity.
- The standard TRIUMF shipping containers are Class A (F-308) containers that are accepted by Canadian Nuclear Laboratories (CNL). The ARIEL hermetic target vessels will be too large for these containers.
- When the decay period is over the target vessel will be removed from decay storage and taken to the hot cell. The highly active target bodies will be separated from the less active vessel body. The target bodies will be placed in a Class A container and the target vessels placed in a 45-gallon drum.
- More than one body may be stored in the Type A flasks depending on the level of activation. Target shipping and disposal costs are based on the number of flasks

so disposing of multiple targets in each flask will be cheaper than disposing of a single target per flask.

- ARIEL proton irradiation at APTW will match ISAC present irradiation initially so that Targets for proton irradiation will initially be based on standard materials – SiC, Ta, ZrC, Nb, UC with known post-irradiation activity and reactivity. These materials are deemed safe for handling and disposal.

The activation of ARIEL APTW targets can be estimated from our experience at ISAC. For typical proton irradiation at ISAC, and for standard target materials, the dose rate as a function of time at 1 m from a Class A (F-308) flask with five target containers stored within has been estimated by Joe Mildenberger of TRIUMF's Radiation Protection Group. Dose rates as a function of target materials plus Ta containment tube are shown in Fig. 15. The shipping limit for an F-308 flask is also shown.

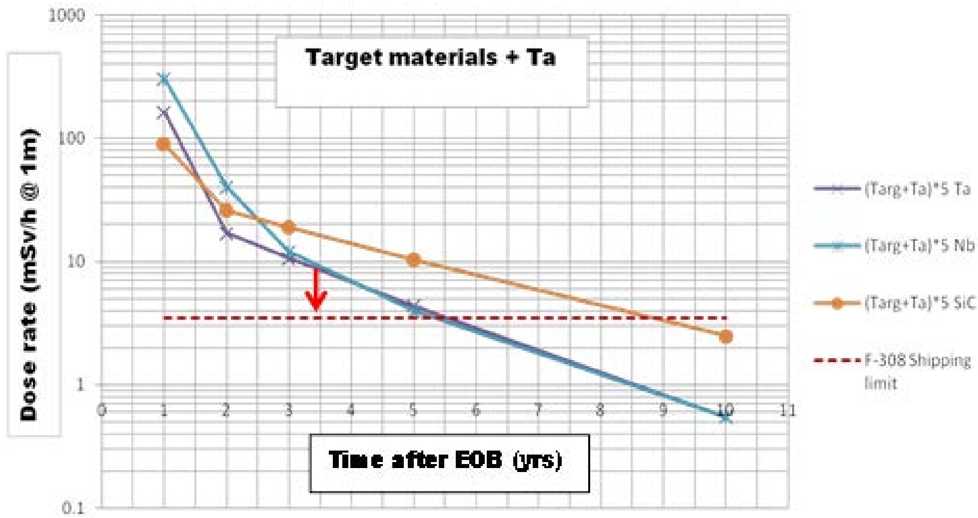

Fig. 15: Dose rate as a function of time at 1 m from a Class-A F308 shipping container assuming five irradiated ISAC Ta target tubes and their associated target material are contained within. Curves for three different target materials are presented. (courtesy Joe Mildenberger)

Dose rates as a function of time for target canisters irradiated at APTW/ITW/ITE and stored in an unshielded 45-gallon drum are shown in Fig. 16. The shipping limit is also shown. The dose rates from AETE irradiated targets are expected to be less than for APTW irradiated targets.

New materials of increasing reactivity (LaC, ThC, UC) including graphite fibers and nano-carbides are foreseen. New materials will be developed in the target chemistry labs. The use of these new materials will be predicated on the development of safe handling practices and safe post-processing. This development work will be done in the laboratory and will be certified for use on-line only after procedures and processes for handling and disposal are fully documented and peer reviewed.

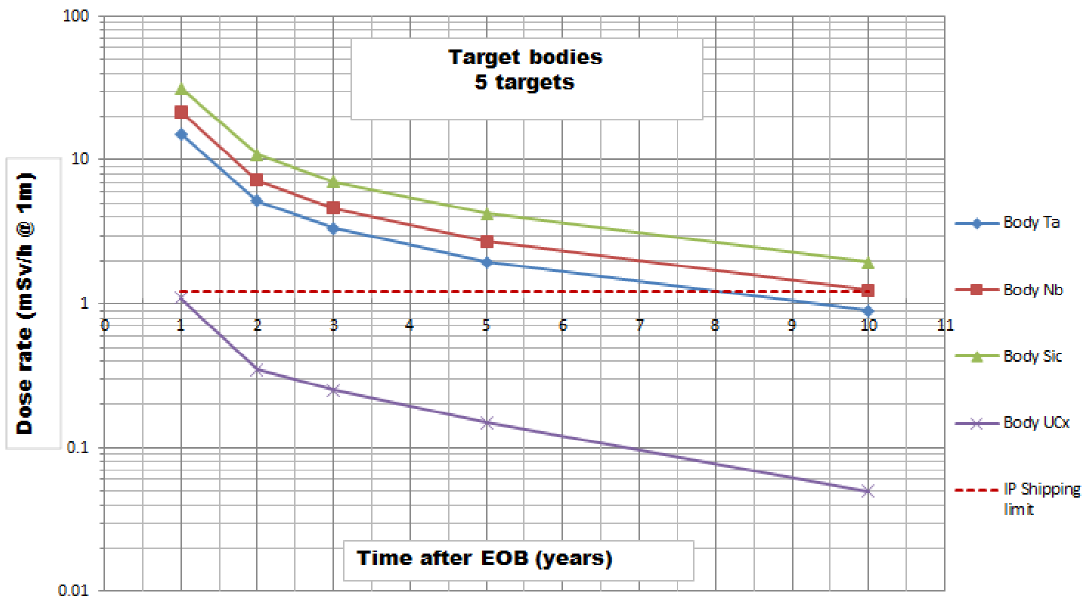

Fig. 16: Dose-rate at 1m from a 45 Gallon drum containing 5 target bodies after irradiation typical to ISAC and for different target materials (courtesy Joe Mildenberger)

8 Ramp up to full production

The waste management strategy, operational model, and ARIEL-II schedule can be used to estimate a model of operation in the intervening years between now and full production.

8.1 Ramp-up assumptions

This ramp-up model is based on the following assumptions:

- ISAC ITE/ITW operation will ramp up from the present nine or ten targets per year to twelve targets per year over the next five years. ISAC will move to a factory three-week cycle over the next six years (2016–2021).
- AETE will start operation in 2021 with a moderate ramp-up of four, seven, ten, twelve, thirteen, and fourteen targets in each of the years 2021–2026, respectively.
- APTW will start operation in 2023 with a moderate ramp-up of four, seven, ten, eleven, and twelve targets in each of the years 2023-2027, respectively.
- AETE target vessels will require, on average, two years in the ARIEL target hall decay storage vault.
- APTW target vessels will require, on average, three and a half years in the ARIEL target hall decay storage vault. From the dose rates shown in Fig. 15 this means

that approximately two target bodies can be shipped in a single Class A F-308 container.

- These decay periods and storage times are consistent with the baseline target hall storage vault capacity of 72 target vessels. It is expected that the irradiation of targets in the first few years will be sufficiently low that shorter decay periods would be possible.

8.2 Ramp-up statistics

The assumptions in Section 8.2 are used to produce a model for target storage and disposal in the intervening years. A summary plot is shown in Fig. 17.

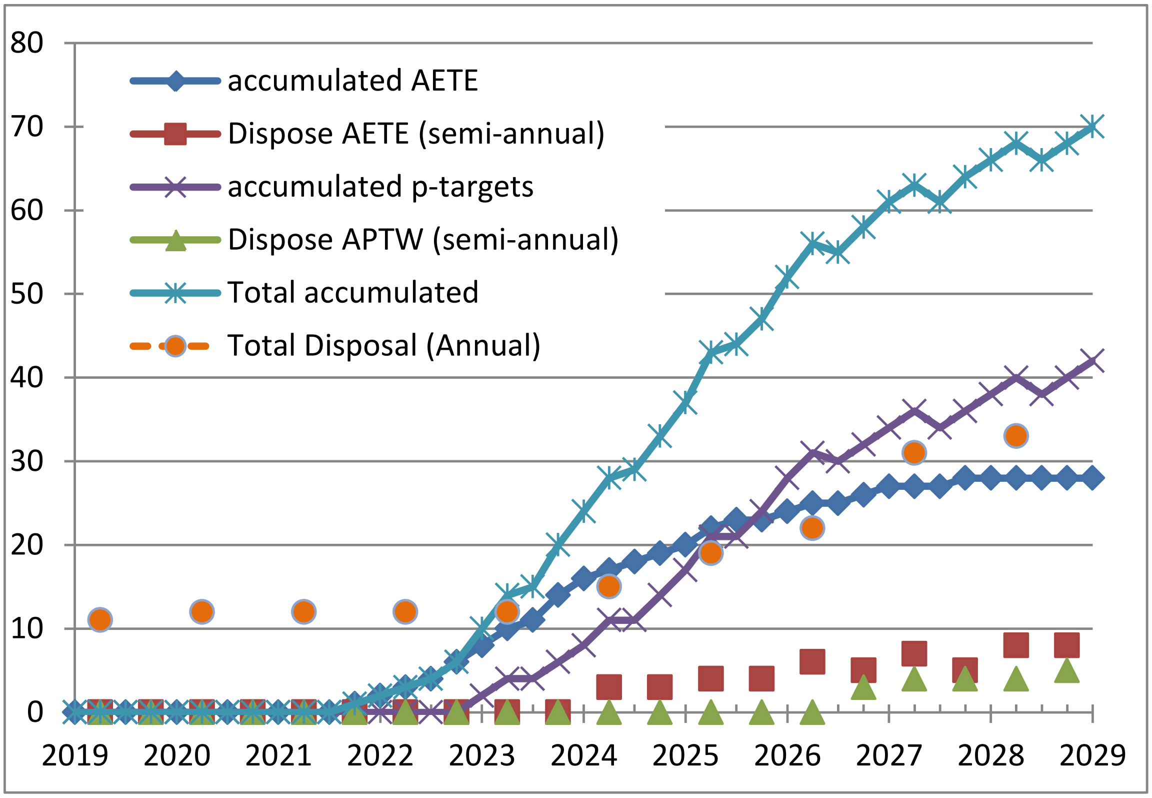

Fig. 17: Ramp-up model for ARIEL target storage and ISAC/ARIEL target disposal. Shown as a function of year are the accumulated AETE and APTW irradiated targets in the target hall storage vault, the semi-annual AETE and APTW target disposal amounts and the total ISAC/ARIEL annual target disposal quantities.

AETE irradiation is expected to begin in 2021 and AETE target disposal in 2023 after two years of storage. APTW irradiation begins in 2023 and disposal in 2027, three and a half years later. In this model it will take until 2029 to build up to the full production 'factory' in terms of both production and disposal with the target hall storage saturating at 68 units. This is in line with the 72-unit target hall storage vault. The storage times of two and three and a half years will depend on the target material and the details of the irradiation. Early targets will receive less activation and may be disposed of earlier than the assumed decay period. The Class A flask could hold up to five targets depending on the level of activation.

RIB hours per year during ramp-up can be estimated from the number of targets used per year, assuming a three-week cycle for each target as described in earlier sections. It is assumed that some of the targets in the first year of operation will only be used for development and not production. The estimated projection of RIB hours as a function of year is shown in Fig. 18.

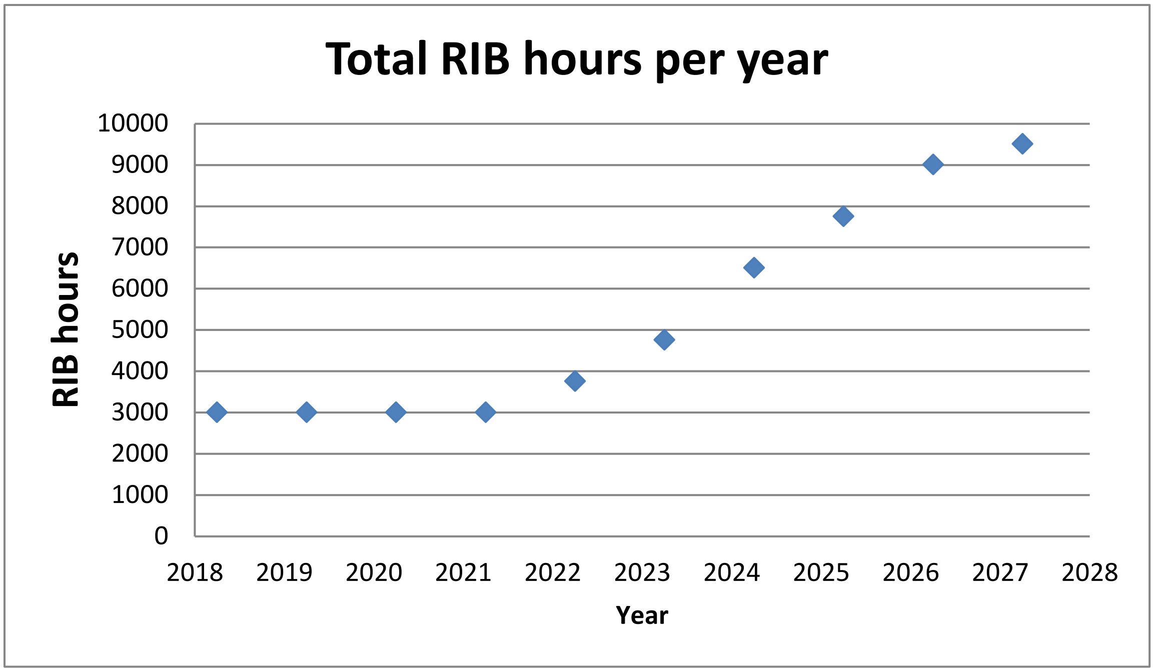

Fig. 18: Projected total RIB hours from ISAC/ARIEL as a function of year.

9 Alternate operation patterns

A consequence of the RIB factory paradigm is that the facility schedule trumps flexibility in beam delivery to a much greater degree than in the present single-user mode. The single-user mode is still dependent on the cyclotron weekly schedule but the target life cycle, though somewhat constrained by target exchange efficiencies and target durability, is still variable. Furthermore, target failures or module problems may elicit an emergency response where the schedule is altered to try to recover experimental time. In the RIB factory paradigm the schedules in the three target areas are tightly coupled so that recoveries from failures would be done so as not to upset the facility cycle and overall schedule. Typically a failure of the target/source would cause delivery from that target to cease until the next target exchange cycle though failures early in the cycle would be handled on a case by case basis. A special sub-set of target failure is infant mortality and given that these failures, though rare, are predicted to occur, and would cause significant downtime if not mitigated, they are considered as a special case in Section 10.

The efficient use of personnel will be paramount in the full-production era. The strength of the factory model is that the technical support for the beam production has a week-to-week regularity that benefits efficiency and reliability. It may be that certain target/source combinations will require less than the two-plus weeks of operation given in the three-week cycle. One way to deal with this case is simply to halt beam delivery to experiments from the target until the target is scheduled for replacement rather than to divert resources for an early exchange. Empty shifts could then be utilized for beam development.

If shorter target cycles become more frequent other target cycle modes can be considered while still maintaining the general features of the facility cycle. The fundamental assumption in all schemes is that only one target is started on any given week. This is to flatten the load on beam delivery personnel due specifically to target ramp-up, beam tuning, and yield measurements. For the alternate cycles a two-week cycle would probably be the minimum given the effort and time required to bring a target on-line. For every two-week cycle there would also be a target area with a four-week cycle to maintain the one target per week pace. Given that assumption, a host of cycle patterns can be considered. Fig. 19 displays a few variants over a seventeen-week operating period. The labels in the figure denote the target area being started up each week. Variant 1 is the standard three-week cycle. Other variants use two-, three-, and four-week target cycles interleaved in various ways. The minimum time for an ITW/ITE target cycle is two weeks.

For these variants the assumption is that the cyclotron beam development period occurs in the same week as the APTW target exchange. A few of the alternate cycles have been looked at in detail and while they are marginally less efficient than the three-week cycle they still produce more than 9000 hours of RIB per year.

Week	Variant 1	Variant 2	Variant 3	Variant 4
1	AETE	AETE	AETE	AETE
2	ITW	ITW	ITW	ITW
3	APTW	APTW	APTW	APTW
4	AETE	AETE	AETE	AETE
5	ITE	APTW	APTW	APTW
6	APTW	ITE	ITE	ITE
7	AETE	AETE	AETE	AETE
8	ITW	APTW	APTW	APTW
9	APTW	ITW	AETE	ITW
10	AETE	AETE	ITW	AETE
11	ITE	APTW	APTW	ITE
12	APTW	ITE	AETE	APTW
13	AETE	AETE	ITE	AETE
14	ITW	APTW	APTW	ITW
15	APTW	ITW	AETE	APTW
16	AETE	AETE	ITW	AETE
17	ITE	APTW	APTW	ITE

Fig. 19: Various scenarios for weekly target exchange cycles over a 17 week period where two-, three-, and four- week periods are adopted. Variant 1 is the standard three-week cycle.

10 Reliability

The top level requirements for reliability are 90% for drivers (cyclotron and e-Linac), 80% for low energy RIB delivery and 75% for ME/HE RIB delivery. The 80% and 75% figures are a product of the driver efficiency and the RIB production and transportation/ acceleration. Therefore RIB production and transportation require better than 89% reliability and RIB production and acceleration require better than 83% reliability. For this analysis we apportion a reliability of 92% for the target meaning that the facility requires 96% reliability for low energy transport and 91% reliability for transport and acceleration.

The operation model can be used to gain insight on the required performance of any one target station. Assuming 3600 hours per year of scheduled hours of RIB delivery per station, one target station should produce no more than 290 hours of down time or 24 shifts/year. One target in a three week cycle typically produces 26 shifts of scheduled RIB delivery. A principle of the factory model is that target failures are mitigated without disrupting operation in the other two stations. This model suggests that the expected reliability allows no more than one-two target failures per year on any one station depending on the time during the cycle that the failure occurs. Some specific cases are considered below.

10.1 Infant mortality of target

Infant mortality of target vessels will occur. An operational plan that considers mitigation of infant mortality will help to inform aspects of the design and staffing. In the event of infant mortality and assuming routine operation the whole target cycle for one station would be lost. From Table 1 this corresponds to 26 shifts or 312 hours and exceeds the downtime allocation for the target. This means that if the factory model does not allow intervention that the targets must be designed for a reliability well in excess of 1 in 13 failures or <7% failure rate. While this might be attainable given that the targets will be first tested off-line it still is marginal given that other target problems will develop during operation. Since infant mortality is expected to occur at some point during ARIEL operation it is appropriate to consider mitigation strategies with respect to potential down-time and impact on personnel.

10.2 Infant Mortality Mitigation strategies

The standard target exchange in ARIEL is initiated at the end of the Sunday day shift (AM shift) when the driver beam is blocked and a 12 hour cooldown is initiated. As shown in Fig. 7 the strawmen schedule allows 48 hours for target exchange to the point where the first driver beam can be delivered for 24 hours of on-line target conditioning. In the baseline schedule the Monday day shift is used to remove the shielding and then deliver the spent target to the target storage and the Tuesday day shift is used to install a fresh target into the target station and replace the shielding. The target would be prepared for beam delivery overnight by establishing vacuum and various voltages, diagnostics, currents associated with preparing a target for beam.

10.2.1 Case 1 – infant mortality pre-beam

Assume a failure mode where one of the prerequisites for beam on target (vacuum, current, voltage, temperature) cannot be reached and the fresh target has to be aborted. As per the baseline schedule this would be discovered on Tuesday night (PM shift). In this case a recovery sequence could be initiated. Strawman steps to recover performance are noted in the sequences below. The steps assume that a fresh target is available. This assumption means that for successful targets (~90%) the spare target would go back to the target unit inventory

Conservative scenarios - Variants A/B:

1. Wednesday AM – shielding is removed and the defective assembly is moved to a drop area – since this is a non-routine event it is assumed that this is all that occurs although in principle more could be done
2. Thursday AM - a fresh target is picked up and moved to the target station and the shielding is installed
3. Thursday PM – operators prepare the target for beam
4. Friday AM/PM – the target is conditioned with beam
5. Saturday AM – the beam tune is established by OPS
6. **Variant A – yield staff unavailable**
    a. Assume yield staff are not available until Monday
    b. In this case the yield/TDS work would be completed Monday, followed by maintenance day and beam production would start Tuesday PM
    c. In this scenario 7 shifts out of the 30 shifts available for AETE/APTW targets would be lost accounting for 23 shifts and with reduced procedural days (now 3) the total number of shifts available for the cycle would be 20 compared to 26 or a loss of 72 hours of scheduled beam time. This corresponds to 2% of the total hours scheduled for the APTW station per year.
7. **Variant B – yield staff available**
    a. Assume yield staff are available Saturday night and assume that TDS is canceled for this target to reduce the load on yield staff and gain back production time
    b. Beam production would start Sunday AM so that 3 shifts out of the 30 available shifts would be lost accounting for 27 shifts and with the standard 4 procedural days would be 23 compared to 26 or a loss of 36 hours of available beam time. This corresponds to 1% of the total hours scheduled for the APTW station per year.

More Aggressive scenarios – Variant C/D

1. **Variant C – Fast recovery**
    a. Assume that the fresh target can be replaced on the Wed day shift so that beam conditioning can occur on Thursday AM/PM shifts with beam tuning on Friday AM and yield on Friday night

   b. In this case beam production would start Saturday AM – also assume the TDS shift is canceled to reduce load on yield staff and gain back production time
   c. In this scenario 1 shift out of the 30 shifts available for AETE/APTW targets would be lost accounting for 29 shifts and with the standard 4 procedural days would be 25 compared to 26 or a loss of 12 hours of available beam time. This corresponds to 0.3% of the total hours scheduled for the APTW station per year.

2. **Variant D - Early start**
   a. Assume an early knowledge scenario that relies on a 1 shift target exchange (Monday AM with shielding schedule to be placed on Tuesday AM) the failure mode would be discovered Monday PM and the defective fresh target could be exchanged on Tuesday. The shielding could be replaced on Wed morning and beam conditioning could commence soon after. In this case very little time would be lost.

Analysis

A summary of the four variants is presented in Table 8. In all non-routine factory operations the assumption is that the scheduled activities in the other two legs continue so that a problem in one area does not delay or restrict operation in other areas. Since the scenarios considered above occur in a predictable point in the target cycle (infancy) the ramifications for operation in the other lines can be estimated.

For all scenarios (assuming dedicated expert RH personnel are used for all target exchanges) the load on the expert staff is increased by the extra target exchange required. The analysis above shows that for all cases this extra work would occur during the regular week and during day shifts with (in the most pessimistic case) the expert staff required from Mon-Th. Other scenarios show that this could be reduced to Mon-Wed or even within the Mon-Tues baseline period. This means that there would be little impact on the other target stations with the exception of some possible reschedule of work in the ISAC target hall if there was an overlap in expert personnel.

As for other expert groups the yield personnel would need to be scheduled in a non-standard time window. Given the type of personnel (post-docs, physicists, OPS) this should not present a large issue especially if the associated TDS shift for the target is cancelled as discussed above so that the number of yield shifts is not increased. Other expert groups like beam delivery personnel would need to be rescheduled for non-standard start-up but this should not pose a large perturbation to their typical support pattern.

Operations staff may be impacted as start-up would happen on a non-standard day but in all scenarios above there is no case where two targets would be started at the same time since recovery in all scenarios is less than one week.

Variant A where yield staff are unavailable on the weekend reduces the total scheduled yearly hours by 2% per failure. Variant B where yield staff are available as required would reduce the scheduled RIB hours by 3 shifts or by 1% of the yearly scheduled shifts per failure. A further reduction is possible with Variant C if the expert staff is made available to complete the recovery in one day to reduce the lost beam time to 1 shift.

Finally if the fresh target can be installed on Monday, Variant D, (but not the shielding) the defective target could be replaced Tuesday and the shielding placed Tuesday or Wed morning with little impact to the schedule.

10.2.2 Case 2 – infant failure post-beam

In this case the target issue is discovered only after beam is put on the target. Based on the baseline schedule the fault would be discovered on Wednesday. In this case a recovery sequence could be initiated Thursday AM. Steps to carry out a recovery are noted in the sequence below. The steps assume that a fresh target is available. This assumption will be discussed in the conclusion section below.

Conservative scenarios - Variants A/B:

1. Thursday AM – shielding is removed and the defective assembly is moved to the storage vault – since this is a non-routine event it is assumed that this is all that occurs although in principle more could be done
2. Friday AM - a fresh target is picked up and moved to the target station and the shielding is installed
3. Friday PM – operators prepare the target for beam
4. Saturday AM/PM – the target is conditioned with beam
5. Sunday AM – the beam tune is established by OPS
6. **Variant A – yield staff unavailable**
    a. Assume yield staff are not available until Monday
    b. In this case the yield work would be completed Monday, followed by maintenance day and beam production would start Tuesday PM (with no TDS)
    c. In this scenario 7 shifts out of the 30 shifts available for AETE/APTW targets would be lost accounting for 23 shifts and with reduced procedural days (now 3) the total number of shifts available for the cycle would be 20 compared to 26 or a loss of 72 hours of scheduled beam time. This corresponds to 2% of the total hours scheduled for the APTW station per year.
7. **Variant B – yield staff available**
    a. Assume yield staff are available Sunday night
    b. In this case beam production would start Monday AM – also assume the TDS shift is canceled to reduce load on yield staff gain back production time
    c. In this scenario 5 shifts out of the 30 shifts available for AETE/APTW targets would be lost accounting for 25 shifts and with 3 procedural days would be 22 compared to 26 or a loss of 48 hours of available beam time. This corresponds to 1.3% of the total hours scheduled for the APTW station per year.

More Aggressive scenarios – Variant C/D

1. **Variant C – Fast recovery**
    a. Assume that the fresh target can be replaced on the Thursday day shift so that beam conditioning can occur on Friday (AM/PM) with beam tuning on Saturday AM and yield is on Saturday night
    b. In this case beam production would start Sunday AM – also assume the TDS shift is canceled to reduce load on yield staff and gain back production time
    c. In this scenario 3 shifts out of the 30 shifts available for AETE/APTW targets would be lost accounting for 27 shifts and with the standard 4 procedural days would be 23 compared to 26 or a loss of 36 hours of available beam time. This corresponds to 1% of the total hours scheduled for the APTW station per year.
2. **Variant D - Early start**
    a. Assume an early knowledge scenario that relies on a 1 shift target exchange (Monday AM with shielding to be placed on Tuesday AM) the failure mode would be discovered on Tuesday and the defective fresh target could be exchanged on Wednesday. The shielding could be replaced on Thursday morning and beam conditioning could commence soon after with yield on Friday night and beam delivery on Saturday morning. Assuming TDS is canceled this recovery accounts for 1 shift lost or 0.3% of the total hours scheduled for APTW station per year.
3. **Variant E – Automated exchange**
    a. Assume there is a mechanism to get the target exchanged and under vacuum with shielding in place in 1 shift. In this case the beam could be applied (after 12 hours standard non-beam conditioning time) sometime early Tuesday so the fault could be identified and the target exchanged on Tuesday with no time lost

Analysis

The analysis above shows that for all cases the extra expert RH tasks would occur during the regular week and during day shifts with (in the most pessimistic case) the expert staff required from Mon-Friday. Other scenarios show that this could be reduced to Mon-Th or even Mon-Tuesday. This means that there would be little impact on the other target stations with the exception of some possible reschedule of work in the ISAC target hall if there is an overlap in expert personnel.

The impact to yield experts, beam delivery experts and OPS is the same as in the previous case.

Variant A reduces the total yearly scheduled hours by 2% per failure while Variant B would reduce the target up time by 4 shifts or by 1.3% of the yearly scheduled shifts per failure. By having expert RH personnel ~~HR staff~~ complete the recovery in one day reduces this impact from 4 shifts to 3 shifts or 1% of the yearly down time. Variant C could reduce this to 0.3% if the target could be replaced on Monday (without shielding) and to almost zero if the target exchange can be ultra-fast so that fault could be discovered early Tuesday.

Conclusions: Planning for non-routine recovery from infant mortality events is advised in order to meet the top level requirements concerning reliability. Analysis shows that beam operation can be recovered with acceptable impact as long as 1. A fresh target of similar type is readily available 2. The target can be replaced during the same week as the failure 3. Yield staff are flexible (or trained operators) 4. The TDS shift is canceled 5. RH staff can extend their work to We/Th.

Steps 3-5 do not seem overly burdensome especially considering that infant target failure should be an infrequent occurrence due to TISA. The small perturbation to the factory approach seems acceptable. Step 1 needs further analysis. The target canister is characterized by both the target material and the source configuration so there will be many flavours of target canisters. Though having a back-up target on the shelf for every target seems a reasonable goal given the factory approach the requirement would place demands on the fresh target storage infrastructure. It may be that for more rare combinations we choose to tolerate the risk of early failure or we keep subassemblies available that can be quickly turned into canisters. This latter risk mitigation makes the turn-around significantly longer as assembly then conditioning would be required until the part could be installed. This would certainly push start-up into the second week with an increased chance of delay from activities in other stations.

The above analysis does indicate that significant efforts to reduce the target exchange time are not strongly motivated based on infant mortality issues alone.

Action \ Failure mode	**Fails during non-beam checks**	**Fails with beam**
Routine – no mitigation	26 shifts lost (8.5% of year)	26 shifts (8.5% of year)
Non-routine A	6 shifts lost (2% of year)	6 shifts (2% of year)
Non-routine B	3 shifts lost (1% of year)	4 shifts (1.3% of year)
Non-routine C	1 shift lost (0.3% of year)	3 shifts (1% of year)
Non-routine D	0 shifts lost	1 shift lost (0.3% of year)
Non-routine E	0 shifts lost	0 shifts lost

Table 8: Shifts lost due to a single target infant mortality failure assuming various mitigation variants (see text for description).

10.3 Other target failures

Besides infant mortality the targets could also fail during operation. The underlying principle governing any recovery action plan is that the mitigation should not impact the operation in the other two target stations. This may mean that beam operation on the particular target station would be canceled until the next target cycle. However it is possible that an action plan to recover at least some of the lost time could be considered that still meets the `no impact' requirement.

In this case the actual recovery action plan would depend on several issues.

- The time in the cycle where the fault occurs

- The availability of key personnel
- The activities in the other parts of ARIEL

A probable cause of target failure is beam aging. This failure mode would most typically occur near the end of the target life cycle. If this occurred in the last week of operation no immediate intervention would be expected and the beam from that station would be off until the start of the next cycle. If the fault occurred early in the run it is conceivable that a target exchange later in the week (after the early week standard procedures) could be considered if RH personnel could be made available. Some thinking of the day to day activities of RH personnel during a three week cycle would help shed light on recovery scenarios.

11 Summary

An operational model has been proposed for ARIEL/ISAC with a three-week interleaved target schedule for ITE/ITW, APTW and AETE. The rotating three-week model is consistent with a 'RIB factory' paradigm. The model is characterized by a schedule where a new target is launched every week. A consequence of the RIB factory paradigm is that the facility schedule trumps maximum flexibility in beam delivery to a much greater degree than in the single user mode. The model shows that for the cyclotron operating 35 weeks of the year and the e-Linac operating 43 weeks of the year the top level requirement of ≥9000 RIB hours is a reasonable goal in the steady state with a balanced use of operations and technical resources.

The model predicts that six operators/shift in two control rooms (*i.e.* three per shift in each of the MCR and ICR) could efficiently deliver three simultaneous beams. The model depends on reliable, standardized operation – designing for maximum flexibility and extreme cases is expensive and operationally inefficient.

The model shows that the present design where only one path is available from ARIEL to either one of the low energy areas does not impact RIB hours. It does mean that in the three-simultaneous-beam scenario the ISAC target areas will not be used for accelerated beam experiments.

A ramp-up model for the intervening years between now and full production is presented. The model also presents a target waste management strategy utilising the target hall storage vault and the hot cell for target decay and target separation/packaging.

Alternatives to the three-week cycle are presented showing that target/source combinations customized for shorter life cycles could be scheduled in one target location with the proviso that another target run longer in another location so that only one target starts up per week to keep the start-up weekly work load the same. It should be emphasized that the strength of the factory paradigm is that the technical staff have a weekly rhythm to their activities that helps to optimize efficiency.

This model in the present form can help inform design choices particularly in the target hall. Further work is required to determine the cost of operations and the number of technical staff required to support the expanded facility both during operation and during maintenance and shutdown periods. The RIB factory operational model will also need to be tested against shutdown maintenance scenarios to ensure that resource loading is similar to operation periods.

Some consideration has been given for dealing with infant mortality of targets. It seems feasible that the failed target could be exchanged within the same week. Such an action is warranted in order to meet the top level reliability requirement. This recovery could be completed without special RH equipment but assumes that a fresh target always be available to mitigate the risks associated with this low rate but likely eventuality.

It is clear that ways to improve efficiency, especially in target production, laser sources and beam delivery, and to increase the focus on reliability will have to be identified. The periodic regular rhythm of the Factory model will be essential to smooth peak demands on groups serving the RIB production areas and beam delivery. In addition beam delivery efficiency would benefit from an increased effort on high level applications. Additional work can be done to estimate the inefficiencies of scheduling and the impact of customizing experiments to the factory paradigm.

12 Acknowledgements

Special thanks to Colin Morton for extended discussions on beam delivery moving towards ARIEL operation. Thanks to Alex Gottberg for useful discussions, in particular on alternative models to the three-week cycle. Thanks to Anders Mjos for discussions on reliability issues. Thanks also to Marco Marchetto, Don Jackson, Grant Minor, Pierre Bricault, Joe Mildenberger, Yuri Bylinski, and Shane Koscielniak for useful discussions.