AN OVERVIEW OF THE RELIABILITY AND FAULT TRENDS OF THE SYNCHROTRON RADIATION SOURCE

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Abstract

The Synchrotron Radiation Source (SRS) at Daresbury Laboratory is a 2GeV 2nd generation synchrotron radiation source. The SRS has been an operating light source for 27 years and is scheduled for closure in December 2008.

This paper will present details of SRS reliability throughout its lifespan focussing on fault trends and particular emphasis will be placed on how the fault profile has changed as the accelerator has aged.

During the 27 years of operation there has been a continual drive to not only maintain the reliability of the SRS, but to improve it. There have been a number of methods used to maintain and improve reliability including capital investment, preventative maintenance, redundancy and risk analysis, each of these methods will be discussed.

INTRODUCTION

The SRS is a 2GeV, 2nd generation light synchrotron light source operating in the UK. The SRS was built between 1975 and 1980 and was the first accelerator specifically designed to use x-ray synchrotron radiation. The SRS began scheduled operations for users in 1981 and has been an operational user facility for 26 years.

The SRS Facility produces synchrotron radiation for users and has been scheduled to operate between 4500 – 6000 hours per year throughout its life. In addition to the number of user hours scheduled the SRS has agreed Operational Targets in place with our funding bodies, which require the reliability of the source to be in excess of 90%. This places significant demands the reliability of accelerator components and systems, particularly as some SRS systems are in excess of 25 years old and others such as some injector components were salvaged from a previous accelerator and predate the SRS.

Diamond Light Source has now been commissioned and will provide synchrotron radiation for the UK in the future. The SRS is scheduled for closure in December 2008 following 27 years of user operations. During the operational period of the SRS the synchrotron radiation community has changed considerably and some experiments require only a single shift to collect data. As a result, the focus on accelerator reliability has significantly increased since the early days of SRS operation.

The constant drive to improve and maintain reliability of the SRS and more recently addressing the issues of ageing and obsolete hardware has been the focus of the Operations and Engineering Group throughout the lifetime of the SRS. Preventative maintenance, risk analysis and capital investment have all played a part in ensuring reliable operations.

SRS OPERATIONAL STATISTISTICS

A greater focus has been placed on reliability throughout the years the SRS has been operating due to a changing and increasing user community. Initial experimenters spent a large amount of time at the SRS setting up their experiments and collecting data. More recently large proportions of the user community using current state of the art detectors and techniques can collect data in a single shift and only book a single access day on the SRS. As a result the focus on reliability and how the statistics are collated has changed over the SRS's 26 years of operation.

Prior to 1984, development of the source and experimental techniques were developed in parallel, as a result operational efficiency figures were not recorded in a comparable way, although significant faults and accelerator system failures and issues were recorded.

The efficiency data on the chart from 1984 shows refill compensated efficiency, which is raw efficiency (delivered hours / scheduled hours) with a one hour allowance for each scheduled refill.

Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) were only introduced to the published data in 2003.

Figure 1shows SRS Reliability data from April 1984 to March 2007.

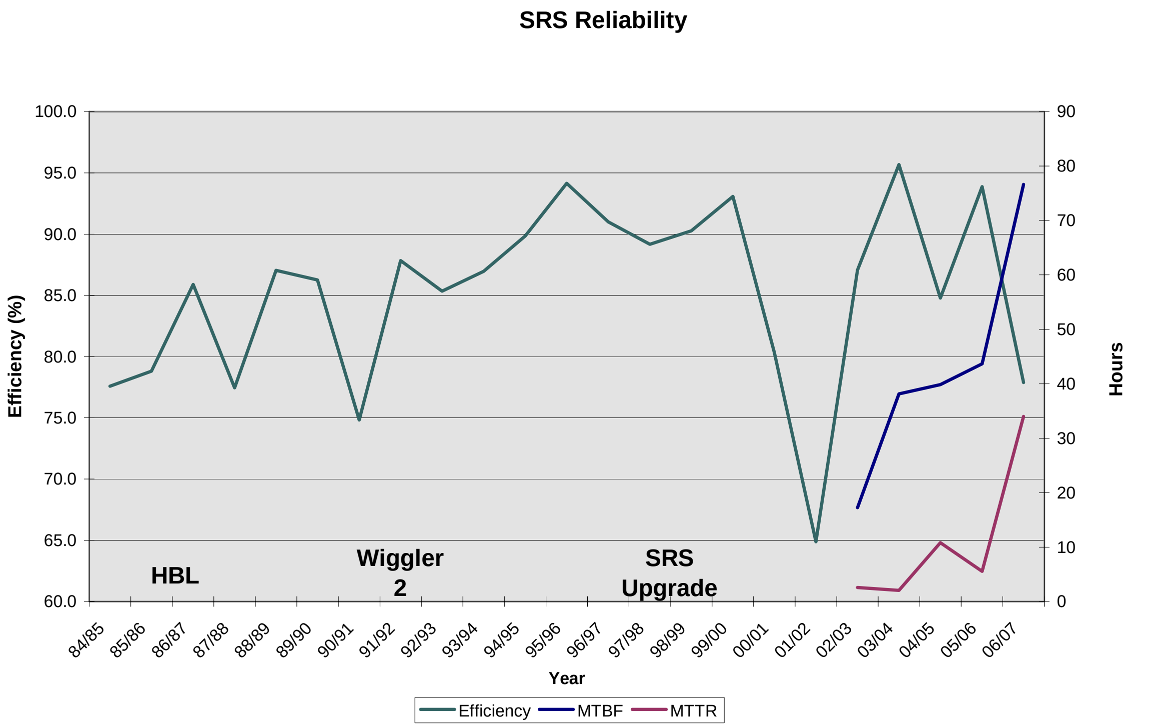

Figure 1: SRS Reliability Data

As with efficiency, MTBF and MTTR, the recording of how each of the technical systems have contributed to SRS fault time has changed over the life of the SRS to reflect the increasing emphasis placed on light source reliability.

The recording of each systems attribution to the fault hours were first published in 1998/99. Figure 2 below shows, for each year since 98/99, the five systems which contributed the most lost user beam time in that particular year.

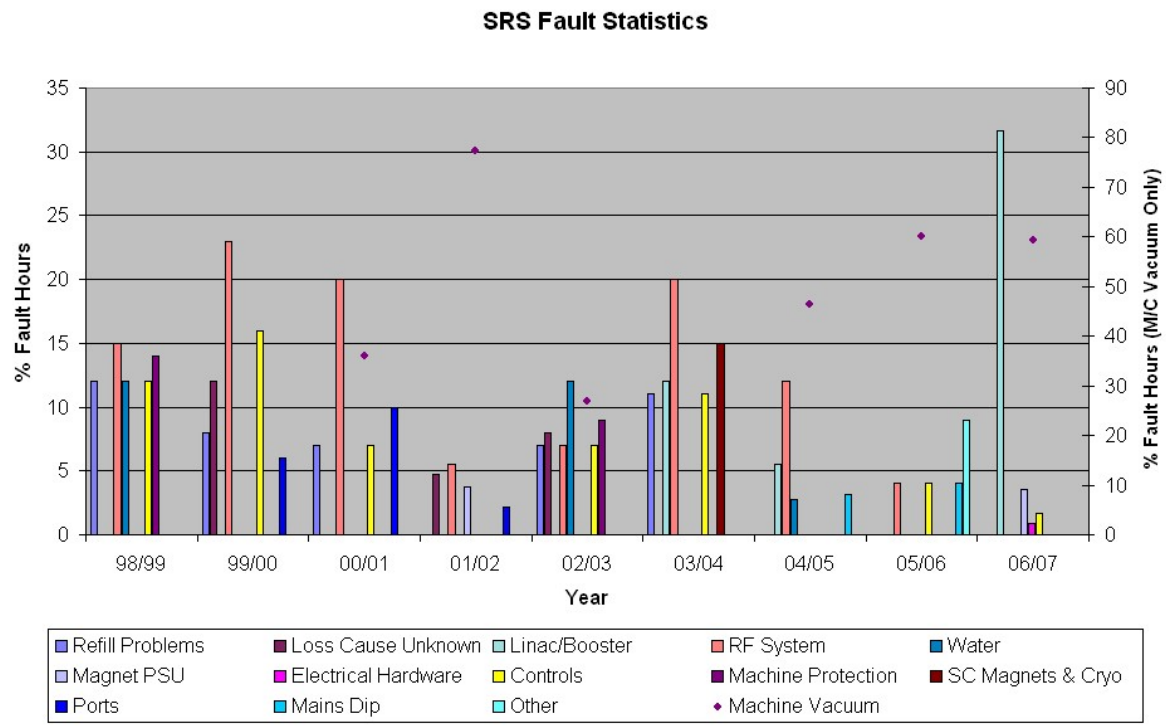

Figure 2: SRS Fault Statistics

ANALYSIS OF THE OPERATIONAL DATA

Annual Operating Efficiency

During the first 3 years of accelerator operation, operational efficiency, although monitored was not recorded. Much of the activity being carried out involved collaboration between the university user groups and accelerator physicists at Daresbury to develop experimental techniques. Following initial commissioning of the SRS, the accelerator underwent a number of upgrades to improve the source for users, the installation of the superconducting wavelength shifters, the High Brightness Lattice (HBL) and installation of an Undulator. This resulted in a rather erratic efficiency profile until 1993, as new systems were commissioned and teething problems eliminated the accelerator source then entered, a relatively stable period of operation with no major developments planned.

Throughout the 1990's, the efficiency of the SRS continued to improve, as experienced operations teams became familiar with established systems. Efficiency stabilised in excess of 90% for a number of years and was only marginally effected by the SRS Upgrade, this was an exceptional achievement given the disturbance to the accelerator lattice.

However, in 2001/2002, the efficiency of the SRS fell dramatically, this was due to a water to vacuum leak, caused by a failed vessel absorber. The failure of the absorber occurred during a shutdown and was due to a heat leak between the SC wavelength shifter cryostat and its vessel, this resulted in standing water inside the absorber being frozen, which subsequently ruptured the absorber. A four month unplanned shutdown was required to return to operations, as a large sub-sector of the accelerator and two ports needed to be removed and reinstalled following vacuum processing.

Following this incident, efficiencies rose again. However, this was disruptive year due to two planned shutdowns, to replace the Klystron Power Supply Unit (PSU) and also the installation of two new ports and beamlines. During the year there were a number of losses due to RF trips, which occurred immediately before the replacement of the PSU. There was also another vacuum incident this year when a ceramic feedthrough failed on a Residual Gas Analyser (RGA). Fortunately this did not have a major impact on accelerator operations.

The next significant drop in efficiency occurred in 04/05 and was the result of two vacuum incidents, the first was the loss of an RF Cavity Window, this was the first window to break in over 20 years of operation. In order to reduce to effect on the users, the cavity was taken off tune and the SRS operated with three rather than four RF Cavities until a suitable shutdown later in the year. The second incident had a greater effect on SRS efficiency and was the result of a water to vacuum leak from a Quadrupole vessel absorber.

Reliability was again seriously effected in 05/06 by a water to vacuum leak, this time it was the failure of a cooling circuit in a Tungsten Vane Monitor (TVM). Reliability figures for 05/06 were improved by converting shutdowns later in the year to user operations increasing the achieved hours.

The year 06/07 started with the continued recovery from the water to vacuum leak. Unfortunately start-up did not go smoothly due to faults on the Linac High Power systems, both the high power transformer and the Linac RF Klystron failed, both having been in service for 15 years. This had the effect of delaying user operations by one month. The second major impact on efficiency occurred later in the year and followed a routine change of the Gun Cathode. Unfortunately what is normally a routine operation did not go as planned and a number of cathodes failed to show any emission at all. Following thorough investigation of procedures and equipment, the source of the problem was found to a faulty batch of the thermionic valves used to make the Cathode.

MTBF and MTTR

MTBF and MTTR could be used to determine whether the number of faults are increasing on the SRS. Unfortunately the overall annual figures are skewed in years where there has been a major failure, as the MTBF increases (due to non operation) and the MTTR increases considerably due to long repairs. These figures are more useful when individual systems looked at to determine if a system is showing an increasing number of faults as the machine ages and combing the results with the fault statistics.

Fault Statistics

Analysing the fault statistics, there have been periods of time when a particular system has shown a significant number of fault hours due to start-up issues following the installation of a new or upgraded component in the system. These areas will not be focussed on and the paper will concentrate on profiles and trends which appear or have appeared routinely in the fault statistics.

One of the major issues facing the operations teams during the last few years have been several machine vacuum incidents, which have dominated the fault statistics and skewed the MTBF and MTTR figures. This type of incident is usually an isolated single failure, which is difficult to predict and has significant consequences.

One of the incidents, the failure of the ceramic feedthrough falls into this category. However, the other incidents are all water to vacuum leaks and although on the surface very different lessons can be learned.

In the case of the Quadrupole absorber, thorough investigation determined that the cause of the failure was due to thermal cycling of the absorber after a flow meter interlock failed to prevent operation when there was no flow through the absorber. This induced a small stress fracture in the absorber. The other two incidents, the wavelength shifter absorber and TVM have very different failure mechanisms but share a common theme. The presence of both devices was historical and both devices were no longer required in the current configuration of the SRS.

If the vacuum incidents are removed form the statistics, there are a number of systems which have routinely featured highly in the fault statistics, the RF System, Beam Loss Cause Unknown and Controls.

The main area of concern and focus for a number of years was the beam loss cause unknown statistics, unless faults and losses are diagnosed it is impossible to prevent reoccurrence. A drive to reduce the number of these undiagnosed losses started in 1998, with the introduction of beam loss checklists and investment in improved beam monitoring hardware and software. This reduced the number of undiagnosed losses until 02/03, when a significant number reappeared together with losses on machine protection. The setting up of further diagnostics eventually traced the fault to high voltages tracking through an insulation board in the original Klystron PSU. Replacement of this device was already scheduled and its installation removed beam loss cause unknown as a notable feature in the fault statistics.

Controls is an area where there have been significant changes throughout the lifetime of the SRS, with upgrades to servers and also hardware upgrades to the accelerator and beamlines. The result is a control system with beamlines operating on mk1, 2 or 3 control systems depending on their installation. Although controls feature prominently in the statistics, repairs are undertaken quickly, as most only require a module change.

An area which does not yet feature highly in the statistics, but has been increasing noticeably, are water leaks on pipework external to machine vacuum. The leaks occur on elbow joints - not at the brazed joint, but at the apex of the elbow. The failure mechanism appears to be wear due to the turbulent water flow around the elbow. Mostly these are discovered during shutdowns, as a result they tend not to impact on the operating efficiencies and repairs are quick. If these leaks are not discovered quickly a significant amount of water can be sprayed on to sensitive electrical equipment and accumulate on the floor of the tunnel, increasing local humidity significantly. Fortunately, this type of water has only once resulted in the failure of other equipment, which on that particular occasion was the Injection Septum PSU. The result was 30 hours of lost beam time.

Ageing and Obsolete Equipment

Ageing and obsolete equipment has been an issue for the SRS for a number of years.

The SRS has been providing beam for users for 26 years and although there has been modernisation throughout the lifetime of the SRS, there is equipment in routine operation which is over 20 years old. At the time the SRS was designed and constructed there were no commercially available accelerator systems. As a result, many systems were designed and built in house. This has the effect that many repairs need to be carried out in situ, rather than be replaced with a commercially available spare. Although this increases repair times, it has also to some degree saved some of the problems of obsolescence. Many of the early systems were constructed from scratch using relays, valves, capacitors, etc. which are still available today, so units can still be repaired. However, modern solid state systems are designed to be replaced and returned to manufacturers for repair, rather than repair in house. These modern devices go out of production quickly and become unsupported by their manufacturers. This can lead to greater problems than the time taken to repair older equipment, such as the availability of spares.

Inevitably there comes a point where the unreliability of the ageing hardware dictates that it must be replaced, with a modern unit. Careful attention is paid to fault statistics to evaluate areas where modernisation would make a significant improvement to SRS efficiency. This was the case with the original Klystron PSU, which was replaced with a commercially available unit in 02/03.

During the last four to five years of operation, a significant area of concern has been the condition of in vacuum water pipes and whether they have suffered erosion over 26 years of operation, particularly following the failure of an in-vacuum water cooled absorber. In order to assess the risk, sections of 17 year old SRS absorbers removed from the storage ring, Figure 3, were examined and it was confirmed that erosion and change in wall thickness was negligible.

Figure 3: Milled Away Absorber

However, external water pipes are now proving to be an issue, with cavitation and erosion causing failures on the apex of the elbow joints. Although, most are relatively straight forward and easy to repair they do cause significant disruption to users, with delays to refills. In a number of cases these elbows are close to ceramic feedthroughs and therefore repair poses a risk to machine vacuum. In unfortunate circumstances these leaks can also lead to failure of sensitive electrical equipment, due to ingress of water and high humidity. Figure 4, shows a typical elbow leak and it’s proximity to a ceramic feedthrough.

A constant area of debate is can anything or should anything be done to prevent this. There are hundreds of similar joints on the SRS and to replace them all would require a significant amount of resources, in addition to the danger of creating more leaks and a possible loss of machine vacuum.

Figure 4: Elbow Water Leak

As a result water leaks are being repaired as and when they occur. One action that has been taken is, over several years of operation cooling water flow rates have gradually been increased, to err on the safe side. The result of this is the possibility of turbulent flow and increased cavitation. Careful setting of appropriate flow rates throughout the cooling system has now been carried out to reduce cavitation to an absolute minimum.

Another aspect of an ageing machine is not necessarily the equipment, but the loss of design knowledge and experience as those who were involved the original design, build and commissioning retire. This causes particular problems with older systems and equipment, as the requirement for documentation and maintenance schedules was not the same 20 years ago as it is now. This can result in a failure of equipment after a key person has retired, because newer members of staff do not have the same operational experience to know when there is a fault developing, how to rectify it before failure occurs and the complete maintenance requirements of a piece of equipment. Succession planning is carried out and is extremely important, however it is not a complete substitute for over 20 years experience of fault finding and operation of a piece of equipment. On a very small number of occasions this has led to a lapse in maintenance and an increase in fault rectification time.

MAINTAINING RELIABILITY

A number of strategies have been used to maintain and increase reliability on the SRS.

Capital Investment and Redundancy

The most obvious way to combat ageing equipment and obsolescence is by modernisation with capital investment. Unfortunately this money must be bid for along side other high priority programme lines. Therefore, only the most essential systems and components, which would significantly increase SRS efficiency, can be addressed through this route.

A key aspect in bids for capital investment is to ensure adequate provision of spares for long lead time items. In some cases for critical systems, such as Storage Ring Magnet PSUs and the high power klystron, these are hot spares and can be brought on-line quickly through a series of switches.

Another area, where spares have played a key role, is the storage under clean conditions of processed vacuum vessels and pumps. The availability of these spares has significantly reduced the length of time required to return to user operations after a vacuum incident. Following the use of these spares, the processing of the vessels removed from the storage ring, to replenish the spares stock, is considered to be a priority activity.

Risk Analysis

Risk analysis has been carried out on the SRS at a number of levels with varying degrees of success.

At the top level, starting from the cathode and systematically moving through the entire accelerator, it is very difficult to assess and compare the risks. How do you compare the risk of something which trips frequently, but can be repaired easily to a piece of equipment which, although difficult to repair and expensive with long lead times, has not failed for 15 years? However, this exercise does highlight major issues. For example, the SRS Linac RF Klystron had been in service for 15 years, this meant that the spare for this device had been stored for 15 years without use. This exercise highlighted a potential problem in that, how did we know that the spare would operate if required. As a result of the risk analysis, the spare was sent back to its manufacturer to have its acceptance tests repeated, which it passed, before being returned to the Laboratory. This proved to be worthwhile, as the Linac RF Klystron did fail two years later and the repeated tests gave us confidence that the spare was still usable.

The most beneficial area for risk analysis is within individual technical engineering groups. This has been used to great effect over the last three years by the Electrical Engineering and Power Supplies Group, who have used risk analysis, shown in Figure 5, to set up a programme of modernisation based on risk to SRS operations and safety. The result has been an improvement in fault statistics in the areas addressed and faster repair times due to the introduction of on-line spares.

Location	Equipment	Likelihood of Failure	Impact	Risk Exposure				Resources man weeks	Cost	Comments
				09/06	**10/05**	**09/04**	**01/03**			
Booster Accelerator	Temperature Interlock Panel	1	1	**1**	**1**	**1**	**3**	0	£0K	Replaced Aug 04 and drawings updated
	Septum Extraction	1	1	**1**	**1**	**2**	**6**	0	£0K	Replaced Sept 04, drawing updated.
	Septum Injection	1	2	**2**	**4**	**4**	**6**	2	£0K	Spares available, Drawing need updating
	Kickers Extraction	1	1	**1**	**2**	**6**	**6**	0	£0K	Replaced Oct 05, drawing updated.
	Kickers Injection	1	2	**2**	**4**	**4**	**6**	2	£0K	Spares available, Drawing need updating

Figure 5: Excerpt from EE&PS Risk Analysis

This type of risk analysis has also been carried out within the other technical groups to the same effect.

Post Incident Investigation and Modifications

Post incident investigation is one of the most valuable tools in ensuring that lessons are learned from any failure and solutions are put in place to prevent a reoccurrence.

Following any incident which results in a significant amount of lost time, either in a single period or frequent losses, a committee is formed to investigate what happened and to draw up actions to prevent a reoccurrence. Examples of actions which have resulted from recent incident investigations have included:

- Modification to all TVM cooling pipes
- Revised interlock testing schedule
- Development of a test rig to carry out our own on-site acceptance tests of thermionic valves

Preventative Maintenance and Scheduling

Regular preventative maintenance is a key aspect of keeping ageing and modern equipment operating reliably. Regular three day maintenance shutdowns are scheduled each month, with longer shutdowns scheduled at Easter, Summer and Christmas. In addition, contingency periods are included in the schedule which can be converted to user operations or shutdown depending on circumstances. Figure 6, shows a typical schedule.

2007/2008 SRS AP48 AGREED SCHEDULE & AP49 Draft 11 Dec 06

MB | MAINT | START-UP | SB | BS | Soak Beam for Station Set-up | Contingency | User Meeting | Holidays

EASTER SUNDAY 2007 8 APRIL; 2008 23 MARCH

Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08
1 Sun	1 Tue	1 Fri	1 Sun	1 Wed	1 Sat	1 Mon	1 Thu	1 Sat	1 Tue	1 Fri	1 Sat
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3 Tue	3 Thu	3 Sun	3 Tue	3 Fri	3 Mon	3 Wed	3 Sat	3 Mon	3 Thu	3 Sun	3 Mon
4 Wed	4 Fri	4 Mon	4 Wed	4 Sat	4 Tue	4 Thu	4 Sun	4 Tue	4 Fri	4 Mon	4 Tue
5 Thu	5 Sat	5 Tue	5 Thu	5 Sun	5 Wed	5 Fri	5 Mon	5 Wed	5 Sat	5 Tue	5 Wed
6 Fri	6 Sun	6 Wed	6 Fri	6 Mon	6 Thu	6 Sat	6 Tue	6 Thu	6 Sun	6 Wed	6 Thu
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	31 Thu		31 Tue	31 Fri		31 Wed		31 Mon	31 Thur		31 Mon

Figure 6: SRS Schedule

Maintenance has become an area of concern over the last 6 months. The SRS is due to close in December 2008 and the closure programme, rolls off the number of operational beamlines and staff numbers working on the SRS gradually over an 18 month period. This roll off is occurring at the same time as the development of other future accelerator programmes, such as ERLP. The reduced staff numbers and the additional work has caused prioritisation difficulties within the technical groups. The effect of this on SRS maintenance is that safety and essential work is being carried out, but more general maintenance work has to compete against high priority project work. This problem is likely to continue and possibly increase throughout the final 18 months of operations.

CONCLUSIONS

The SRS has provided reliable user operations for over 26 years, with the annual efficiency only occasionally falling below 85%.

Although there have been a number of vacuum incidents recently, these have been isolated incidents and are not the result of any systematic failure which would limit the lifetime of the SRS.

The greatest evidence of systematic failure due to ageing is the failure of copper elbows on cooling circuits. These have a relatively small effect on overall accelerator efficiency, but do have the potential to lead to more serious faults. On an accelerator with a longer period of operation it is possible to replace these elbows, however given the SRS closure date of December 2008, it is not feasible in the given timescales.

The operational efficiency of an ageing accelerator can be maintained by careful analysis of fault statistics and learning and implementing actions from failures.

In conclusion, following 26 years of user operations, there is no evidence to suggest that the SRS can not complete the final 18 months of operation with operating efficiencies in excess of 90%.

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The sustained high operational efficiencies at the SRS are the result of the work of a large number of dedicated staff past and present, the author would like to thank them for their contributions to the operation of SRS over the last 26 years.

REFERENCES

[1] Daresbury Laboratory Annual Reports, 1982 - 2007