ESTABLISHMENT OF A PULSE RADIOLYSIS FACILITY ON THE SRS LINAC AT DARESBURY LABORATORY

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Abstract

Pulse radiolysis is a technique for studying short-lived free radicals and excited states using short pulses of electrons. Following the closure of the linac at the Paterson Institute in Manchester [1,2] the electron beam pulse radiolysis detection equipment was transferred to the SRS linac at Daresbury Laboratory and a new facility established. The linac is only used for approximately one hour per day to refill the SRS, leaving the remaining time for pulse radiolysis experimental work. Improvements to the SRS linac have included computer control of pulse length and additional focussing quadrupoles. Extensive modifications to the personnel safety system were required to allow convenient access to the Linac Hall. Measurements of linac performance and initial commissioning results are presented. As the UK synchrotron light source centre, Daresbury also provides wider access to users from a range of research areas and enhanced support laboratories, as well as opportunities for synergy with synchrotron radiation and laser facilities, and has recently received an award of EU funding for international user access to the new radiolysis facility.

1 INTRODUCTION

Free radicals are highly reactive molecules that can wreak havoc, or confer benefits, on a wide range of biological and chemical systems. Understanding how they produce their effects requires knowledge of their structure, reactivity and thermodynamics. Such free radicals are usually short-lived with lifetimes of micro- or nanoseconds. A new facility capable of providing these measurements has opened at Daresbury Laboratory. In pulse radiolysis, bombarding a sample with a single short pulse of high-energy electrons creates a high transient concentration of free radicals. This pulse is provided by the electron linac of the injector complex for Daresbury's Synchrotron Radiation Source (SRS), the first dedicated high-energy synchrotron radiation source in the world.

Until June 2000, the UK's leading centre for this type of research was at the Paterson Institute for Cancer Research at the Christie Hospital in Manchester. When the centre closed, Daresbury was chosen as the obvious future home, with its existing accelerator facilities.

Although a thoroughly established technique, pulse radiolysis continues to be a versatile experimental approach with a remarkable range of applications across the physical, material, biological and biomedical sciences.

2 SRS LINAC

The SRS is a 2 GeV synchrotron radiation source that supports nearly forty experimental stations. The 2 GeV beam is produced by a three-stage acceleration procedure; a thermionic RF gun and 12 MeV linac feed a 600 MeV booster synchrotron at up to 10 Hz which itself then feeds the main storage ring. When sufficient current has been accumulated (usually about 250 mA), the energy in the storage ring itself is ramped to 2 GeV, at which point the X-ray shutters are opened for users. Because the lifetime in the storage ring is of the order of twenty-four hours, this process is undertaken only once a day. This means that the linac is available for pulse radiolysis for at least twenty-two hours per day. Table 1 shows the key linac parameters under normal operating conditions, i.e. for SRS refilling.

Table 1: SRS Linac Parameters.

Parameter	**Units**	**Measured Value**
Energy, *E*	MeV	~12
Macro Pulse Length, *t*	μs	~1
RF Frequency, *f*	GHz	3
Peak RF Power, *P*	MW	4
Accelerator Length, *L*	m	~1.4
Attenuation/length, α	Np/m	0.28
Shunt Impedance, *R*	MΩ/m	60

Figure 1 shows the measured relationship between the linac energy and beam current, while Figure 2 shows measured energy spread variation with gun voltage.

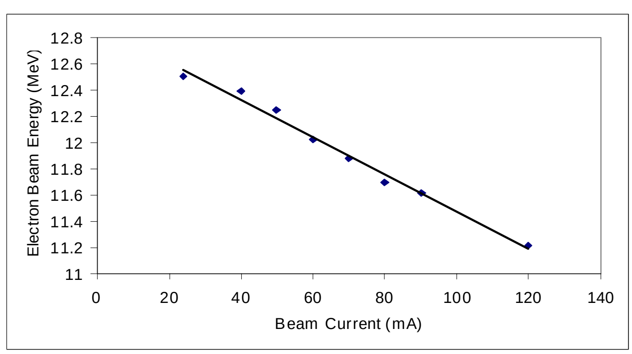

Figure 1: Energy and beam current relationship.

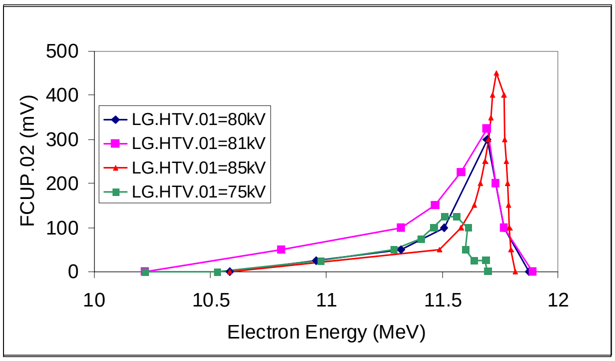

Figure 2: Energy spread with gun voltage.

3 PULSE RADIOLYSIS REQUIREMENTS

The technique of pulse radiolysis does not place stringent requirements on electron energy or energy spread; the main requirement is to deliver a sufficient dose of electrons to the sample in the shortest (but controllable) duration possible. In addition, this must be done repeatably.

The following modifications were made to the linac:

- Instead of operating at 10 Hz, a new timing module was designed and built which allowed single-shot firing of the linac, controlled from the pulse radiolysis laboratory.
- The existing analogue control of pulse length was replaced with fully-calibrated digital control via the SRS Control System, in the range 220 ns to 2.2 µs.
- The room in which the linac is situated required extensive modifications to the personal safety system, to allow convenient access by experimenters.
- As an alternative option to the electron beam passing down the flight path to the booster, a new transport line was designed to take the beam to the sample. The beam is initially allowed to pass undeflected through the first dipole magnet of the existing line before arriving at the sample. Figure 3 is a schematic diagram of the layout.
- To maximise the dose, two new quadrupole magnets are provided to focus the diverging beam onto the sample, which is typically 15 mm by 25 mm (FWHH). Figure 4 shows the beam size without additional focussing, assuming the linac has a one sigma emittance of 10 mm mrad, and the beam size (sigma) at the exit of the linac is assumed to be 5 mm, in both planes.

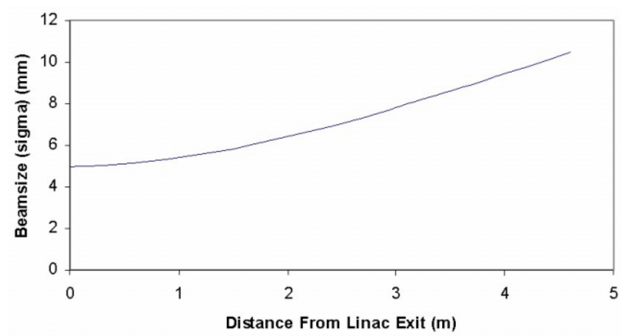

Figure 4: Beam size without additional focussing.

Figure 5 shows the beam size achievable with this design assuming a 15 MeV beam energy, the maximum energy the linac could realistically provide.

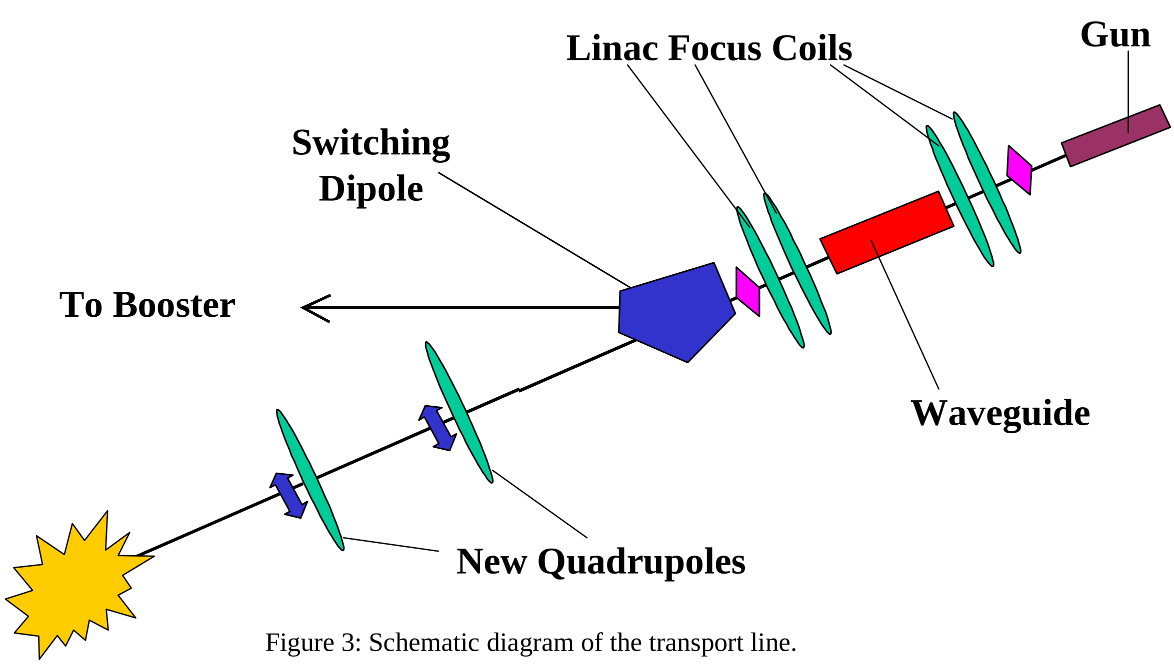

Figure 3: Schematic diagram of the transport line.

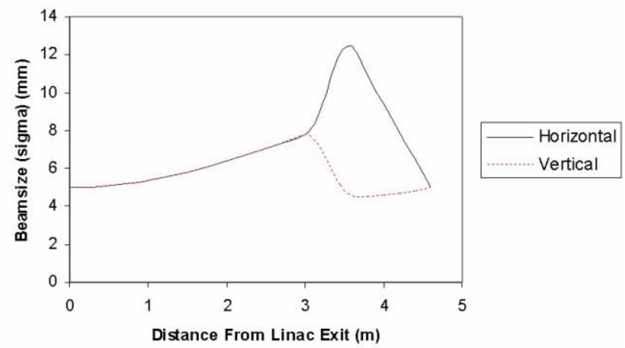

Figure 5: Beam size with additional focussing at 15 MeV.

Figure 6 shows the pulse radiolysis beam line and sample stand.

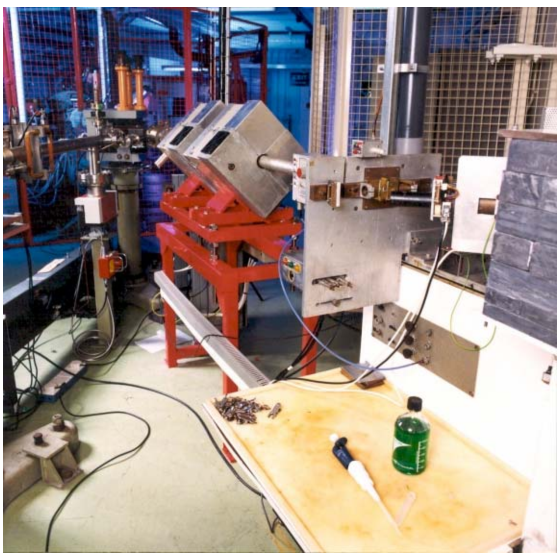

Figure 6: Pulse radiolysis equipment.

4 INITIAL RESULTS

Initial commissioning measurements, using a simple Faraday cup to measure the charge in the pulse, were very promising. This was then followed by user experiments with chemical detection methods, in which doses up to 20 Grays were recorded.

A number of chemical investigations are now underway with the equipment. Single-shot firing of the linac from the pulse radiolysis laboratory, along with pulse length control via the SRS Control System, is now routine. A secondary emission chamber (SEC) is provided to monitor the dose reaching the sample for each pulse. Figure 7 shows the variation of the charge collected in the SEC with pulse length.

5 OPERATIONAL IMPLICATIONS

The development of the pulse radiolysis facility has produced a number of changes to how the accelerator complex at Daresbury is operated. Following the daily refill of the SRS, control over the operation of the linac is devolved from the main control room to the pulse radiolysis users.

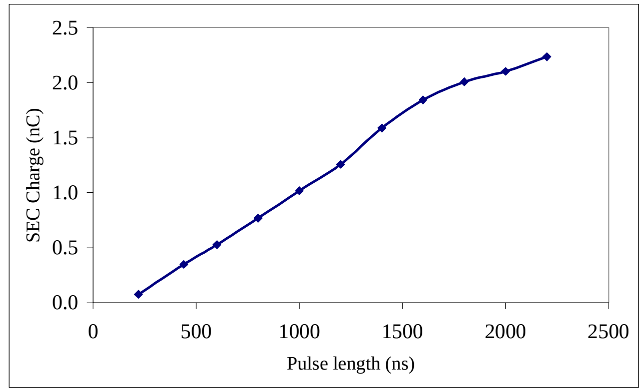

Figure 7: SEC charge with pulse length.

This is achieved by the transfer of a key, providing a hardware interlock that also enables the changes to the personal safety system. However, if at any time the linac is required to refill the SRS, due to an unexpected beam loss, this always takes priority over pulse radiolysis.

Some reduction in reliability of the linac could also be expected due to increased workload; however there has been no evidence of this yet.

The SRS traditionally operates one or two major shutdowns each year, when the whole accelerator complex is turned off for maintenance work. It is envisaged that in future, the linac will continue to operate for pulse radiolysis through some of these periods, requiring a change in operational planning – it can no longer be automatically assumed that maintenance work on the accelerators can be fitted in at any point during a shutdown.

6 FUTURE DEVELOPMENTS

Various improvements in detection systems for the free radicals reactions are planned. In addition, the proposed fourth-generation light source at Daresbury, based on an energy recovery linac, will provide a 10 to 20 MeV dump beam following its second pass through the linac. The high charge and short length of these pulses, along with the fact that they would otherwise go into a beam dump, mean that they are ideal for pulse radiolysis.

7 ACKNOWLEDGEMENTS

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[2] J. Butler et al, “Experimental Studies of Some Moderately Fast Processes Initiated by Radiation,” Radiat.Phys Chem. Vol 34, No. 4, pp. 633-646, 1989.