A VERSATILE COOLING-WATER SYSTEM FOR RADIOISOTOPE PRODUCTION TARGETS IN TANDEM

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ABSTRACT: Depending on the exact configuration being used, targets for the production of radioisotopes may have completely different water-cooling requirements. Production targets employing high velocity water cooling of their surfaces together with thin entrance and/or exit windows on the target holder, for example, require a high flow rate at the lowest possible back pressure, while both high flow rates and high pressures are needed for swirl-flow cooling techniques. This paper describes a closed-loop cooling-water system for radioisotope production targets, characterized by its flexibility in terms of the independent control of each of three parallel cooling lines. The system, in operation at the National Accelerator Centre, enables up to three target holders of widely different water-cooling design to be irradiated in tandem. A flow rate of up to 180 ℓ/min at a maximum delivery pressure of 65 bar can be achieved, while the possibility of evacuating the reservoir also permits operation at ultra-low back pressures. Since the cooling water can become highly activated during irradiation of the targets, the system includes remote monitoring and control of flow rates and pressures, as well as remote monitoring of cooling water temperatures and electrical conductivity.

1. INTRODUCTION

The accelerator production of radioisotopes ideally requires intense beams of light ions. The irradiation of targets with such beams however calls for sufficient cooling of the targets to prevent thermal failure during irradiation. Depending on the exact target and beam configuration being used, this may require completely different water-cooling characteristics.

At the National Accelerator Centre (NAC) the routine radioisotope production irradiations are carried out with an external 66 MeV proton beam at intensities of up to 100 μA (66 MeV protons being regularly available for neutron therapy treatments). The separated-sector cyclotron facility has, however, been designed to deliver proton beams of this intensity up to an energy of 100 MeV for special (non-routine) radioisotope production sessions. In order to effectively utilize these powerful beams, a closed-loop cooling-water system, with independent water pressure and flow rate control over wide ranges in each of three parallel cooling lines, was designed and installed. This system enables up to three targets of widely different water-cooling requirements to be irradiated in tandem in a multi-purpose target station designed and built for this purpose.$^{1)}$

2. FLOW RATE AND PRESSURE CONSIDERATIONS

When a (non-gaseous) target is bombarded with a well-focussed beam (typically <5 mm diameter) of high intensity, the heat is deposited in such a small volume of the target material, especially towards the end of the range of the incident particles, that heat flux densities in excess of 1 kW/cm^2 are easily achieved at the interface between the target and cooling water. Removal of such high flux densities requires sub-cooled nucleate boiling at the interface. However, a catastrophic failure of the target will occur if this local boiling of the cooling water should develop to the stage where a steam layer isolates the heated target surface from the main body of the cooling water ("burnout"). In order to shift this critical point of departure from the subcooled-nucleate boiling regime to as high a heat flux density as possible, one or more of the following techniques may be employed at the cooled surface:$^{2)}$

- high water velocity
- high static pressure
- promotion of turbulence
- provision of adequate nucleation sites.

High velocity water cooling is usually achieved by forcing the water to flow in a thin layer (~1 mm thick) over the target surface at the maximum flow rate - and therefore also the maximum pressure - possible under the specific circumstances. Maximizing the water pressure is, of course, also as such (and in general) beneficial, since an increase in pressure raises the boiling point of the water layer directly against the heated surface, with the result that the critical heat flux density is also considerably increased.

The thin-layer cooling technique can be applied at either the front or rear surfaces of the target (2π-cooling), or both surfaces (4π-cooling). If applied at the front surface, however, the entrance beam energy is reduced by energy degradation in the water layer, as well as in the beam entrance window of the target holder needed to contain the water. This is not a problem when sufficiently high primary beam energies are available. In many cases, however, it may be essential to keep this energy degradation to a minimum, especially when the optimum entrance energy with regard to the production of the specific radioisotope is close to or higher than the available beam energy. Thin beam entrance and/or exit windows (in the case of tandem targets) then have to be used. In such cases sufficiently high water flow rates at the lowest possible back pressures are required.

With normal water cooling techniques, such as those described above, the maximum heat flux density which can be handled is of the order[3] of 3 kW/cm^2. This can be further improved by a factor of about two by employing swirl flow techniques,[4] in which cooling water is forced through a tubular cooling channel with a twisted tape insert to give it an angular velocity component perpendicular to the cooled surface. Both high flow rates and high pressures are needed for this technique.

3. SYSTEM DESIGN AND CONSTRUCTION

The lay-out and operation of the cooling-water system for radioisotope production targets at the NAC are shown schematically in Fig. 1.

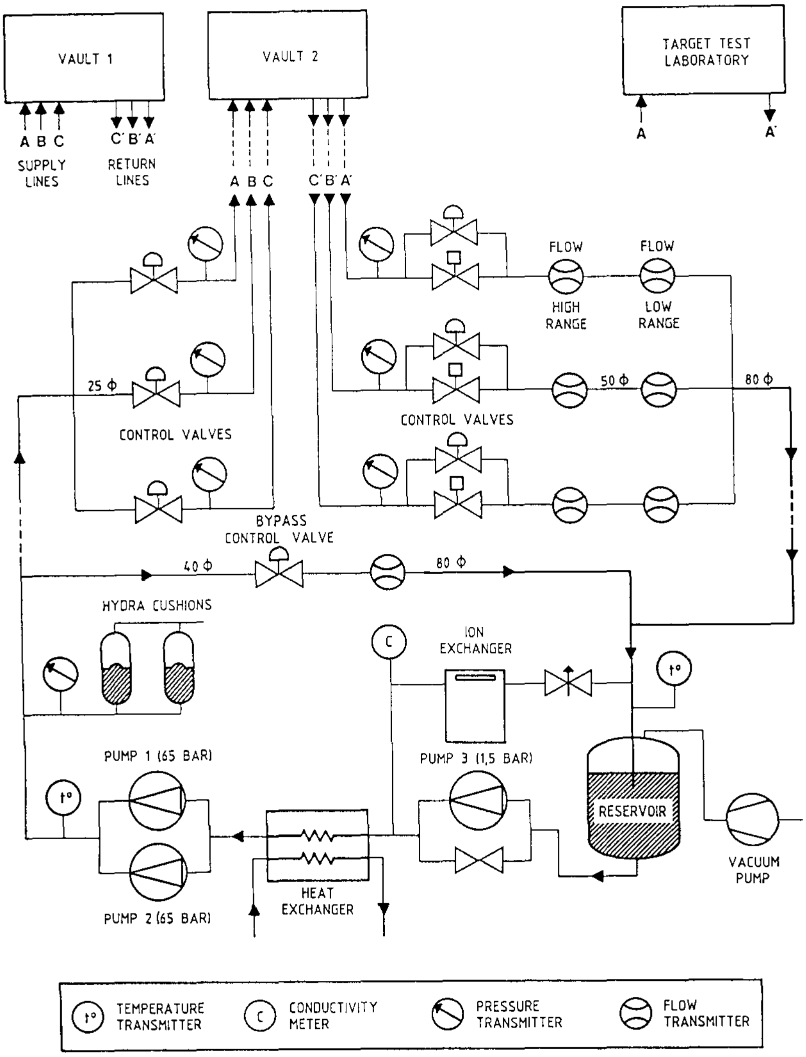

Fig. 1 Schematic diagram of the layout and operation of the cooling-water system.

It basically consists of four parallel cooling-water loops, one of which is a by-pass used for control of the maximum operating pressure of the system. This is achieved by proportional-plus-integral-plus-derivative (PID) loop control of the flow rate through the by-pass control valve. The individual pressures and flow rates in the three main lines are determined by the settings of the two control valves in each line, one upstream and one downstream of the target, allowing, to a large extent, the independent control of pressure and flow rate for three targets in tandem.

The cooling water is circulated in a closed loop by either one or two parallel positive-displacement helical rotary pumps, each having a capacity of 90 ℓ/min with a head of 65 bar. Each pump can be operated at one of two selectable speeds, the resulting main pressure being continuously adjustable by means of the by-pass control valve. A centrifugal pump maintains an input pressure of 1.5 bar on the suction side of the high-pressure pumps, preventing cavitation in the latter. In addition, it also maintains flow in a deioniser loop. Two hydra cushions, nitrogen pumped to 13 bar, serve to dampen the pulsations induced by the high-pressure pumps. The main reservoir can be evacuated in order to allow operation at ultra-low absolute pressures. An overall view of the pump station is shown in Fig. 2.

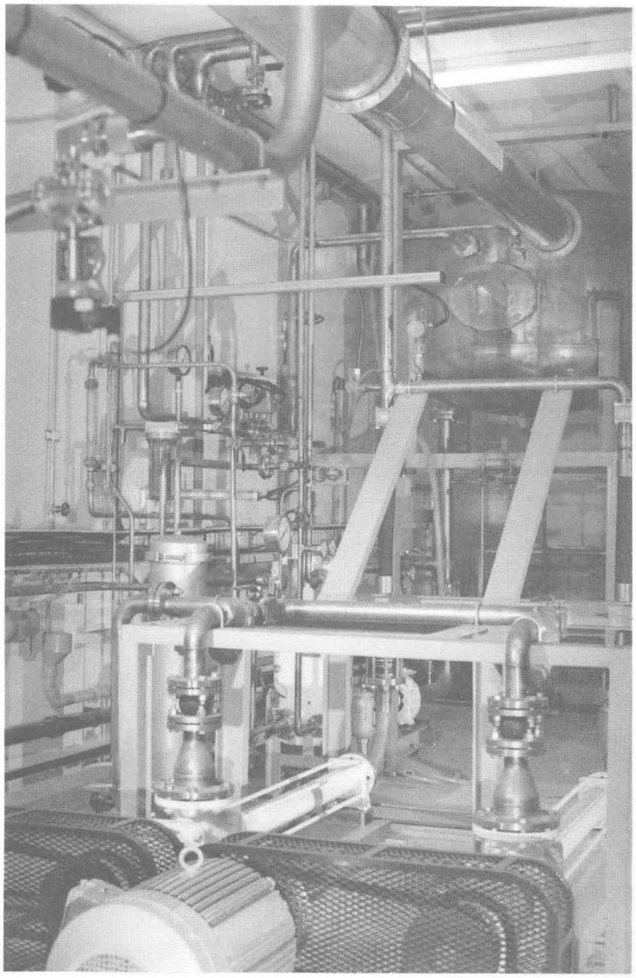

Fig. 2 Overall view of the cooling-water pump station.

The pipework is of 304L stainless steel pipe throughout, and the system serves two separate irradiation vaults. One of the three cooling loops has also been extended to a target test laboratory. Each line has a 25 mm I.D. for the supply side and a 50 mm I.D. for the return side. Common return piping has an 80 mm I.D., thereby keeping dynamic back pressure to a minimum. Fig. 3 shows some of the pipework and control valves of the three main cooling lines.

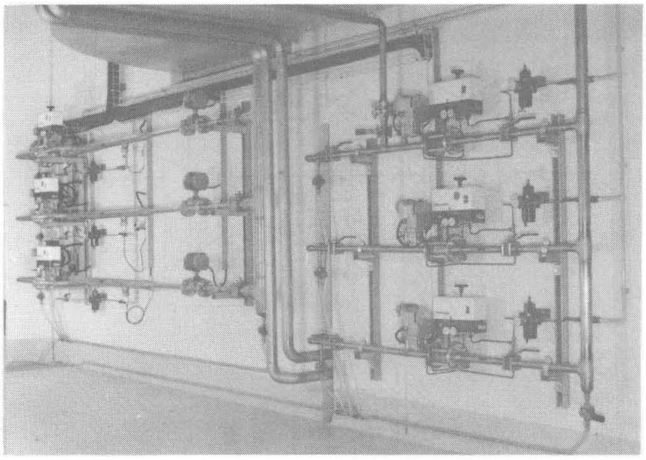

Fig. 3 Photo of the pipework and control valves just outside the irradiation vaults.

The main cooling-water system is connected to the previously-mentioned multi-purpose target station$^{1)}$ via a dedicated manifold, shown schematically in Fig. 4. This manifold is mounted inside the vault, in close proximity to the target station, and is connected to it by means of flexible, high pressure hoses. This ensures the free movement of the pusher arm which enables remotely-controlled coupling and decoupling of the water lines to the target holders. The manifold provides the following functions:

- Connection of the three main cooling lines to the exact target configuration being used (single target or tandem configurations).

- Connection of the target holders in series instead of in parallel, when desired.

- Provision to blow the highly-activated water inside the targets back into the main cooling system reservoir by compressed air prior to target unloading after irradiation. Only the short lines to and from the manifold are drained, ensuring that the minimum volume of the cooling system is vented and that radioactivity is contained as far as possible.

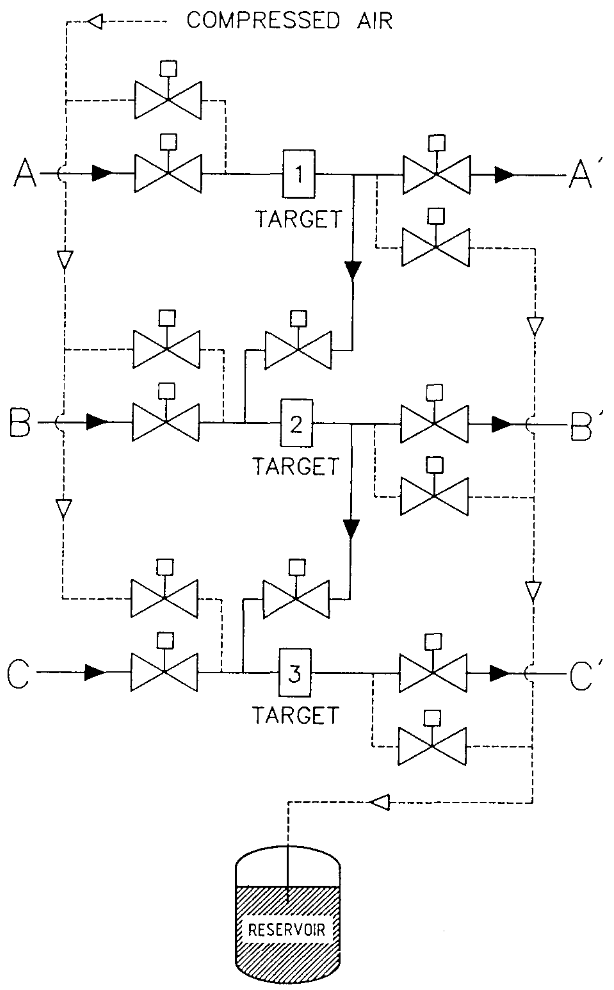

Fig. 4 Schematic diagram of the layout and operation of the cooling-water manifold for the multi-purpose target station.

During irradiation the cooling water is directly activated by the beam, causing radiation dose rates in excess of 10 mSv/h on the surface of the return lines. All the necessary valve control as well as monitoring of pressure, flow rate, temperature and electrical conductivity are therefore done remotely by means of a microcomputer. Two control panels have been provided: a master in the radioisotope production control room and a slave in the target test laboratory.

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