USE OF A HIGH-CURRENT ACCELERATOR (CWDD) FOR NEUTRON RADIOGRAPHY

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Abstract

Recent improvements in the current handling capability of linear accelerators has raised the possibility that an accelerator radiography system can be competitive with a nuclear reactor system. We review the status of the physics and engineering databases in high-current accelerators, high-power target design, and neutron reaction rates. It is concluded that while accelerators are attractive, the necessary system tradeoff studies cannot be made reliably without additional research, particularly in target design and neutron production rates. Since the high-current deuterium accelerator being built at Argonne can play a key role in developing this database, a brief description of this accelerator is provided.

I. INTRODUCTION

A review of neutron radiography literature[1-3] shows that nuclear reactors have been the dominant source of neutrons for use in high-quality neutron radiography. This was a natural consequence of the ready availability of research reactors with high thermal-neutron fluxes as well as development of small, compact, and relatively simple reactors. While there has been a low-level interest in accelerators and radioactive sources because of their small size[4], low neutron fluxes from these devices has limited their radiographic capability.

Recent public concern over the safety of nuclear reactors and the siting of reactors in an industrial or medical environment has lead to a renewed interest in accelerators because of their portability, relative licensing ease, and inherent safety. While these features give accelerators a certain appeal, they will still have to be competitive in terms of neutron flux, cost, and size. Evaluation of these issues involves a complex series of system tradeoffs between the parameters of the high-current accelerator, the power handling capability of the target, and the neutron production and thermalization characteristics of the target and moderator.

This paper indicates that the database of physics and engineering properties of an accelerator radiography system require additional information before a defensible system evaluation can be performed. Since the Continuous Wave Deuterium Demonstrator (CWDD) being constructed at Argonne can play a key role in providing this information, a brief description of this device is given in Section V.

II. HIGH-CURRENT ACCELERATORS

Figure 1 shows the exposure time as a function of neutron flux at the entrance of a collimator for a range of accelerators and reactors. The L/D ratio is the length of the collimator relative to the collimator aperture and is indicative of the spatial resolution that can be obtained in a radiograph. An L/D ratio of 400 corresponds to a high-quality image with few microns resolution, while an L/D of 25 reduces the resolution by a factor of 8.

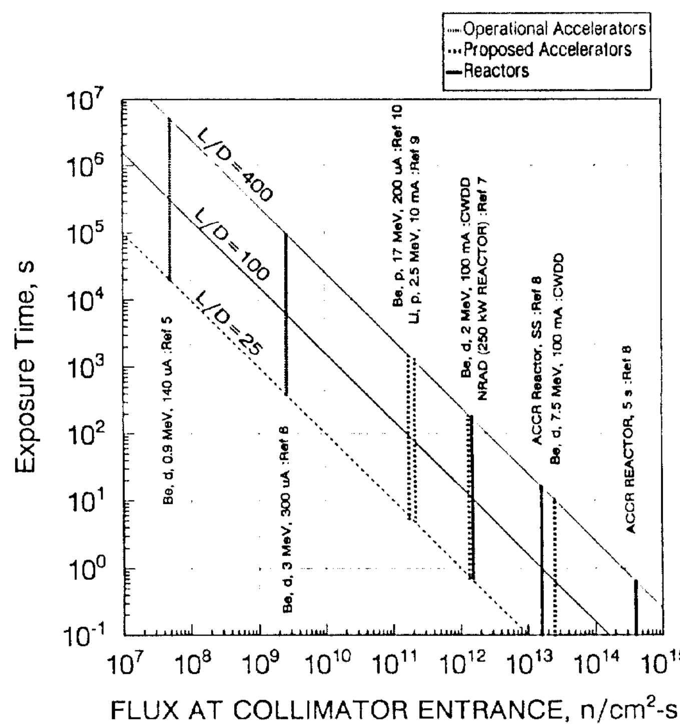

Fig. 1. Exposure Time Versus Incident Neutron Flux for a Range of Accelerators and Reactors . The lines assume a flux at the exit of the collimator of 10^8 n/cm^2 as in Ref. 4.

Nuclear reactors operate in the range of 10^{12} to 10^{15} n/cm^2-s, and require relatively short exposure times for high resolution. The accelerator facilities that are currently operational cover the range of 10^8 to 10^{10} n/cm^2-s and usually sacrifice spatial resolution to reduce the exposure

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time. The remaining systems in Fig. 1 consist of a series of proposed accelerators that have considerably higher output fluxes. These are typically obtained by operating at higher currents and CW duty factors, although one of the proposed systems obtains the higher fluxes by going to higher energies (17 MeV). Clearly the upper end of these proposed accelerators as represented by the CWDD accelerator are competitive with reactors in terms of neutron flux.

The fact that these accelerators can be constructed with a reasonable confidence of successful operation does not imply that they can compete with reactors in terms of size, cost, reliability, and operational simplicity. These issues depend on the projectile type, beam power, and maximum beam energy, which in turn are related to target power handling capabilities and neutron production and thermalization rates.

III. HIGH-POWER TARGETS

Section II indicates that a reactor competitive accelerator system will produce beam loading on targets of several megawatts for a few tens of seconds. In addition, the low energy of the projectiles results in most of this energy being deposited in a thin layer near the surface. (A 4-MeV deuteron has a range of 0.2 mm in Al.) Finally, this power dissipation must be accomplished using a target geometry that does not compromise the production of neutrons. The two possible techniques for handling this power are a solid target with the beam expanded to reduce the heat load on the target material, and a flowing liquid target.

In CWDD the high power dissipation is handled by spreading the beam over a large area (approximately 2 m^2) and allowing the temperature of the carbon tiles to reach a maximum of 1700 ^{o}C between the 20 s beam pulses. This results in a large-diameter beam transport section that has higher costs associated with the vacuum equipment. The extended geometry will probably degrade the thermalization efficiency of the moderator.

A flowing molten target would produce the most compact target and beam transport design, but with the complications of a liquid-target vacuum interface. It is expected that the small target geometry will improve the thermalization efficiency. The requirement of a molten target can also affect the neutron fluxes by limiting the choice of target materials, although lithium is competitive in terms of neutron production.

The power dissipation requirements of the target will have a significant impact on the accelerator operational parameters as well as on system size and cost. There has been considerable engineering design work on high-power targets, especially for the fusion program. Clearly CWDD could be useful in conducting benchmarks for various codes and in demonstrating prototype target operation for low-energy beams.

IV. TARGET NEUTRON PRODUCTION

Figure 3 is a sketch of the radiographic process. The production of thermal neutrons is a two step process involving the production of fast-neutrons (energies greater than a few keV), and their subsequent thermalization via scattering in the surrounding moderator. In general, the fast-neutron production will increase with incident projectile energy, while the thermalization efficiency will decrease because of the higher neutron energies. Near threshold the neutron production usually increases faster than the thermalization decreases and there is a net gain in thermal flux. Typical values of ε_T range from 1/2 to 2% (K values of 50 to 200). An ideal target would produce a high yield of low-energy neutrons, and few gamma rays, at a low incident projectile energy to reduce the length of the accelerator and the external shielding.

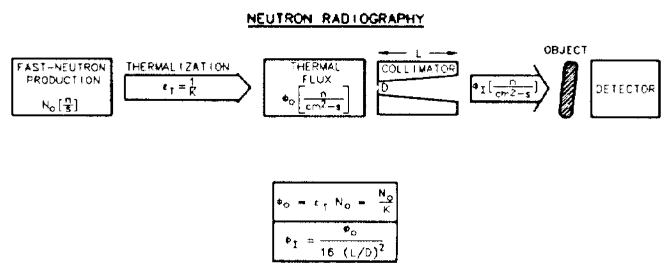

Fig. 2. Radiography System Components

The optimum accelerator/target combination can be found by using reaction data to determine the neutron source term for a given target, projectile, and geometry. This source term is used in a neutron transport code along with the target and moderator geometry to obtain the thermal flux. An alternative method is to perform integral measurements with the target/moderator system.

The knowledge of the cross sections for production of neutrons at low beam energies is relatively limited, with even less information available on the neutron energy and angular distributions. Broad trends have been identified but the optimum particle, target, and energy are still a matter of debate.

ANL has extensive experience in measuring cross sections using the Fast Neutron Generator (FNG)[11]. Figure 3 shows an example of the zero-degree energy distribution of neutrons from Be(d,n) as a function of incident beam energy. Work is currently in progress to measure the absolute yields as a function of energy as well as the angular distributions at a limited number of angles. We are also evaluating the potential use of CWDD to supplement some of the FNG work.

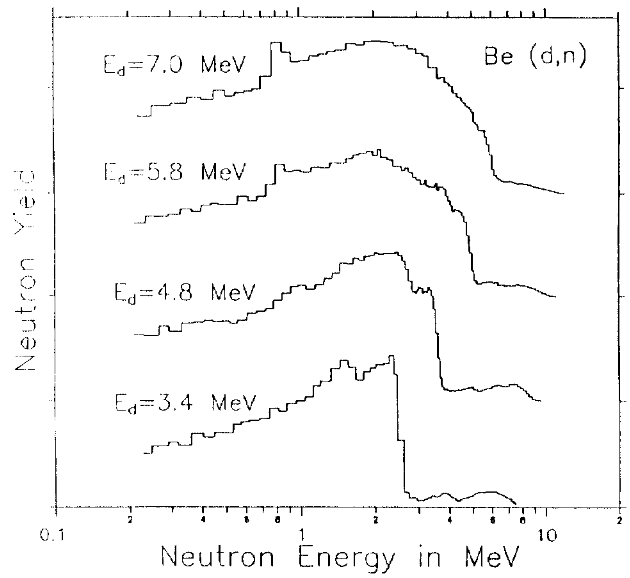

Fig. 3. Neutron Energy Distributions as a Function of Incident Deuteron Energy.

IV. CONCLUSIONS

The preceding showed that design of an optimized accelerator/target system for neutron radiography is a complicated process involving a wide range of parameters. At present the database of physics and engineering information does not appear adequate to make the necessary system tradeoffs required to design an accelerator radiography system that is competitive with reactors in terms of neutron flux, size, and cost.

The physics design of high-current accelerators is in reasonable shape but operational costs and reliability need to be better understood. The use of new technologies such as superconductivity also need to be evaluated. High power target designs from fusion need to be reviewed in terms of radiography requirements, and then tested under actual beam conditions. Finally, additional low-energy charged-particle data must be acquired and incorporated into neutron transport codes to better understand the effect of tradeoffs in other system parameters on the thermalized flux. Since many of these tests can be done using the CWDD accelerator, a brief description of this device follows.

V. CWDD

The CWDD device and facility are currently undergoing fabrication and testing by a team involving Grumman Corporation, Culham National Laboratory, and Argonne, (among others) . Current plans are to have a 2-MeV d^- beam available by the end of 1992, and a 7.35 MeV beam by 1993.

A layout of the facility is shown in Figure 4. The device consists of a volume ion source capable of producing 10's of milliamperes of d^-. The beam is extracted at an energy of 200 keV and focused into a radiofrequency quadrupole (RFQ) by a magnetic solenoid. The RFQ accelerates the beam to 2 MeV. An RF cavity then matches the beam into a ramped gradient drift tube linac (RGDTL), which accelerates the beam to a final energy of 7.35 MeV.

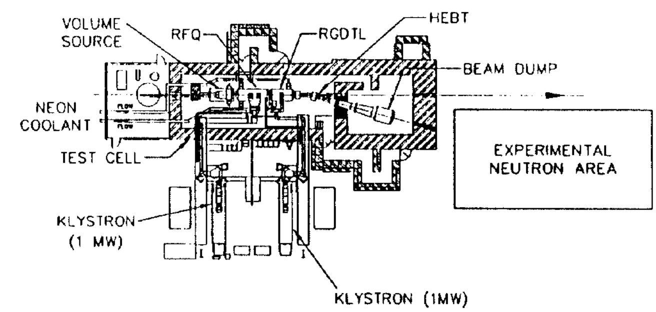

Fig. 4. Sketch of the CWDD Accelerator Facility

The RFQ and RGDTL are cryogenically cooled to reduce power requirements. The engineering design is capable of CW operation, but external cooling constraints will limit operation to a 20-s pulse every 90 minutes or a 1-ms pulse at 10 Hz rate in a steady state mode.

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