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MEASUREMENTS OF LOW ENERGY NEUTRON SPECTRA

By

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INTRODUCTION

Clearly, one of the most outstanding problems remaining in the field of reactor physics is that of understanding neutron thermalization. Not only must one acquire an understanding of the fundamental physics of how slow neutrons interact with a nucleus, but proven techniques for using these fundamental data to make reliable predictions of reactor behavior must continue to be developed. Unfortunately at this point in time, our ability to predict energy spectra in the thermal neutron range is limited to the calculations for the infinite homogeneous system. This limitation is imposed partly by the complexity of many physical systems, the complexity of the mathematics required to describe these systems, the lack of accurately measured fundamental constants needed in the mathematical analysis, and more important, the lack of definitive experiments which can serve to check theoretical predictions and point the direction for further exploration.

A year ago it seemed to us that an integrated experimental and theoretical program should be started which would have as its objectives the extension of our present knowledge on neutron thermalization and the development of generally applicable techniques for predicting these spectra. In part, to provide a versatile experimental facility for this work and in part, to satisfy other research needs of the laboratory, a high current traveling wave electric linear accelerator was purchased by General Atomic and is in the final stages of testing at the Applied Radiation Corporation in Walnut Creek, California.

II. ACCELERATOR AND FACILITIES

The characteristics of the General Atomic linear accelerator will be as follows: variable energy from 2 to 32.5 Mev; peak currents of about 0.3 amperes; pulse width variable from 0.5 microseconds to 15 microseconds, and repetition rates variable from 7.5 pulses per second to 720 pulses per second. The electron energy for maximum efficiency is about 18 Mev at which energy 5 Kw of beam power will be delivered.

Slide 1 is a line drawing of the accelerator indicating the major components. The injector for the accelerator is a high current version of the Stanford pulsed anode injector. A klystron cavity bunches the beam and phases it properly for injection into the first section of wave guide. Two VA820 klystrons will supply 5 MW peak power to the two 6' sections of wave guide used for accelerating the electrons. The machine has been designed so that it can be easily expanded, when our program requires, by adding higher peak power klystrons, more sections of wave guide, or increased average power capability.

Slide 2 is a plan view of the buildings we have erected to house our accelerator in San Diego. The accelerator is located at one end of the earth-shielded underground vault. The experimental set up area where the various assemblies will be constructed is separated by a thick concrete block wall from the accelerator room. The accelerator room will be able to hold additional sections of accelerator and will also house various switching magnets to be used for piping the beam to the targets. Water cooled vacuum plumbing must be used throughout the entire accelerator and target systems. Initially, we will place our neutron target at the intersection of the first two drift tubes which lead to a large outdoor area for the detector stations for time-of-flight experiments. The underground building is located about 100 feet from the General Atomic critical facility and it is planned to pipe the electron beam to this area for use with critical or nearly critical assemblies. The first neutron target will be water cooled bismuth to minimize the radiation hazard in handling the source after continued use. The accelerator control building is unshielded and provides area for the accelerator console, accelerator power distribution system, and the experimental electronics required for the research programs on the machine.

III. RESEARCH PROGRAMS

A research program of major importance on our linear accelerator will be the study of thermal spectra which we will conduct with the support of the AEC Division of Reactor Development. First let us briefly review the experimental techniques available for these investigations.

Existing Experimental Techniques

In recent years, two time-of-flight techniques have been developed for the detailed study of low energy neutron spectra and the dependence of these spectra on temperature, composition, and geometry of reactor cores.

Poole[1] at Harwell has developed a method using a pulsed accelerator as a source of neutrons. With this technique, a series of thermal spectrum measurements have been made on light water moderated, boron loaded assemblies. These data have been compared with spectra calculated by Amster[2] using a formalism developed by Wigner and Wilkins[3]. In general, these comparisons are extremely good. However, there may be some discrepancy in the range from 0.1 to 0.3 electron volts where the slowing down spectrum joins the thermal or low energy spectrum. In this region, Poole's data consistently indicate a relatively higher flux than the Wigner-Wilkins theory would predict.

A second method of measuring spectra has been developed by Stone and Slovacek[4]. This method utilizes a mechanical shutter to chop a neutron beam which is emerging from a subcritical assembly of the desired composition. The assembly is excited by fast neutrons derived from a fission plate mounted in a reactor thermal column.

In their studies of pure water and of nearly homogeneous light water moderated multiplying assemblies, the spectra obtained by Stone and Slovacek do not evidence the discrepancy noted by Amster in Poole's experiments. There are, however, experimental uncertainties associated with the lack of homogeniety in the multiplying assemblies and in the effects of thermal leakage associated with the non-multiplying assemblies.

Initial Investigations

Initially, our interest in the program will be devoted to the study of homogeneous light water moderated assemblies with varying amounts of 1/v absorber added in the form of boric oxide. This type of assembly best satisfies the conditions outlined by Wigner and Wilkins in their thermal spectrum calculations.

The neutron spectrum emergent from a source tube inserted in this assembly will be measured by the method outlined by Poole and also by the method outlined by Stone and Slovacek. In this way, any systematic error that may be inherent to either method will be isolated.

A flexible experimental arrangement for these investigations has been designed so that all geometrical factors which might conceivably affect the measured neutron spectra can be varied. For example, assembly tank size and shielding and neutron source location can be altered drastically.

In the pulsed source method, the linear accelerator will irradiate an experimental assembly with a burst of fast neutrons, these neutrons will be slowed down and will establish a fundamental mode distribution. Neutrons emitted in the solid angle subtended by the BF_3 detector bank at the end of the source tube will be detected with a time delay after the fast burst. If the flight path is sufficiently long so that the neutron flight time is long compared to the neutron slowing down time in the medium, then the delay time between fast burst and neutron detection provides a measure of neutron energy. If one counts the number of neutrons as a function of time of arrival at the detector and makes corrections for relative detector efficiency as a function of energy, one can then obtain a measure of the spectral distribution of neutrons at the bottom of the source tube.

In the chopper experiment, the linear accelerator will be pulsed at a high repetition rate to provide a maximum average neutron flux in the experimental assembly. The same source tube and detector will be used; however, a neutron chopper will be inserted between the exit aperture of the source tube and the detector and will be run asynchronously with the accelerator. Present thinking indicates that we might be able to use the same flight path as with the pulsed source method. Neutron energies in this series of experiments will be determined from a measurement of the time required for a neutron to traverse the distance from the shutter to the detector. After making corrections for energy dependent shutter transmission and detector efficiency, one can obtain a measure of the neutron spectrum at the source point within the medium.

Direction of Future Experiments

The experiments just discussed should establish the validity and compatability of the two experimental techniques developed to date. Once this is done, there are a number of interesting experiments that will be undertaken.

Perhaps one of the more interesting is a study of the time dependence of the establishment of the thermal neutron spectra in a moderating medium. We feel that it should be possible to perform this experiment by using a combination of the two experimental methods previously outlined. If we use a graphite system, then the slowing down time is sufficiently long so that our instrumentation will be able to detect the growth of the thermal spectra after a fast burst. For this experiment, the rotating shutter will be operated in phase synchronism with the accelerator. A fast neutron burst can be introduced into the assembly and after a predetermined time, the neutron shutter will be opened. The spectrum of neutrons transmitted by the shutter at this time can be determined by the time of flight technique.

If there exists a range in time after the burst where the observed spectrum varies slowly with time, then it should be possible to obtain a large increase in counting efficiency by operating the machine and chopper synchronously. We calculate that for some experiments one can gain between a factor of two and ten in intensity by this new method. This is an important point when we consider the large cost of obtaining increased intensity by building larger accelerators.

Another problem that we plan to investigate experimentally is the spectral variations at interfaces between different media and also between media at different temperatures. This general problem has only recently been attacked theoretically by Kottwitz at Hanford and is worthy of much careful experimental study, since these situations are characteristic of many encountered in actual reactor design.

IV. CONCLUSION

Clearly, experimental and theoretical work on neutron spectra and the effect of spectra on reactor behavior is still in its infancy. At General Atomic, we feel that a fundamental investigation of these subjects will provide definitive experiments to check the theoretical work that has been done. The development of newer experimental techniques promises to provide a firm base for further theoretical work and basic understanding of reactor processes.

References

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[3] Wigner, E. P. and Wilkins, J. E. Jr. - AECD 2275

[4] Stone, R. S. and Slovacek, R. E. - KAPL 1499