MICHIGAN STATE UNIVERSITY

CYCLOTRON LABORATORY

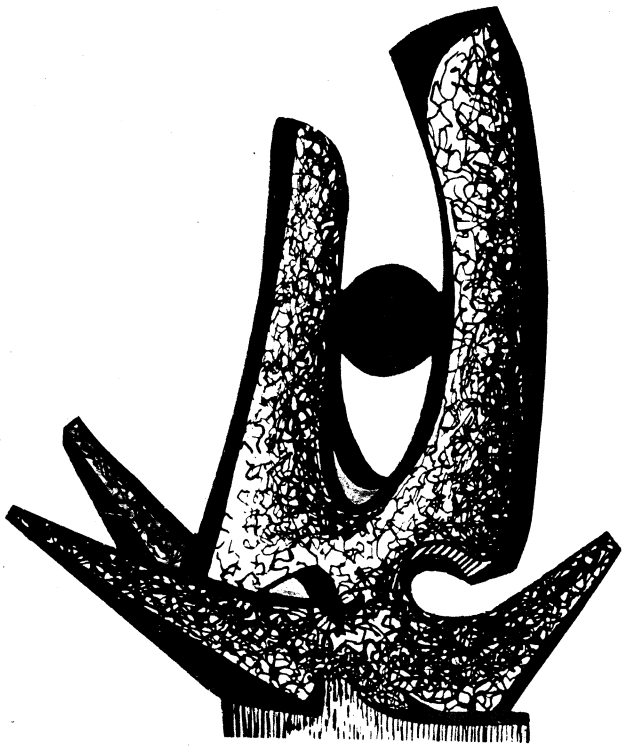
PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

for

BASIC RESEARCH RELATED

to

ENERGY and the ENVIRONMENT



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THE SUPPORT OF BASIC RESEARCH RELATED TO

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I. INTRODUCTION

During the past few years members of the Cyclotron Laboratory have been involved in basic research in a variety of fields bordering on nuclear physics, including nuclear astrophysics, the use of proton beams in cancer therapy, the fixation of nitrogen by blue-green algae and the mass analysis of materials by elastic scattering. To this date, however, such interdisciplinary programs have been a rather small fraction of the laboratory's efforts. In this document we propose to undertake a group of research projects related to the production or use of energy and its effects on the environment. Taken as a whole these projects represent a significant broadening of the research base of the Cyclotron Laboratory.

The justification for this expansion of the laboratory's interest is at least threefold. (1) The problems are intellectually stimulating, they appear ripe for exploration using the approaches and techniques of nuclear physics in which we have a broad expertise, and they promise to yield results of substantial interest. (2) We feel that our research effort, taken as a whole and in the long run, should be useful to society, and that at a time when technical solutions to specific problems are sought, part of our research effort should be devoted to these problems. (3) A majority of our Ph.D. students and a substantial fraction of our postdoctoral fellows now find positions in which they use the skills they have learned in nuclear physics in applied

research in other areas. These students would be better trained for such work if they could be exposed to and participate in basic research in these fields during their graduate careers.

Since the research proposed here is substantial in scope, we have considered its prospective impact on the continuing program of the Cyclotron Laboratory. It appears that with the exception of the optical model studies, which could eventually consume substantial cyclotron time, none of the projects would make large additional demands on either the cyclotron or computer facilities.

In the remainder of this Introduction we provide a brief overview of the five proposed research projects. These projects will be discussed in more detail in Section II.

1. Theoretical investigations of a Migma fusion device.--The Migma device for the attainment of fusion power using accelerator and storage ring techniques, incorporates a number of novel and ingenious ideas. However, it has not yet been possible to examine many of the necessary assumptions in detail. Much of the expertise in beam dynamics developed in this laboratory during the design of the MSU sector-focused Cyclotron is directly applicable to studying the Migma device. Such studies have already begun. The funds sought would make it possible to continue this program, but at an accelerated pace in an attempt to establish from rigorous calculations whether the Migma device could actually be a workable candidate for a fusion reactor.

2. Optical model studies with neutrons.--During the evaluation of cross sections necessary for the design of nuclear reactors and related projects, it is often necessary to refer to the nuclear optical model, either to check the consistency of various data sets or to supply the cross sections themselves when data is lacking. While the optical model has been remarkably successful, substantial questions remain as to the detailed radial shape of the potential and its isospin character. It now appears that perhaps the least ambiguous resolution of these questions would follow from a careful comparison of elastic neutron and proton scattering at energies of 20 MeV and above. The high intensity and exceptional time resolution of the MSU Cyclotron beam make possible,for the first time, high accuracy measurements of neutron elastic scattering at such energies. We propose to measure elastic scattering cross sections at neutron energies between 20 and 45 MeV for a group of nuclei in the A=40-208 range and to analyze them using "model-independent" techniques originally developed for the analysis of elastic electron scattering data.

3. Predictions of level densities with the nuclear shell model.--In predictions of cross sections for neutron induced reactions in reactors it is sometimes necessary to have estimates of level densities in cases where there are no measurements and at excitation energies too low for a statistical model to be applicable. The shell model is the only available instrument for making such predictions,

though it has not often been studied with this purpose in mind. The program of shell model calculations at MSU is perhaps unique in its scope and in its experience in obtaining semi-empirical effective two-body interactions well matched to reproducing the lower lying energy levels for a chosen configuration space. We intend to apply these techniques to reproduce the levels at higher excitation energy (typically the 10th-100th levels) for well known nuclei, thus allowing the prediction of the relevant level densities in less well understood cases. The evolution of the effective Hamiltonian as one attempts to describe level densities at higher excitation energies should also be of value in understanding the fundamentals of the nuclear shell model.

4. Studies of nitrogen fixation with radioactive nitrogen (^{13}N).--Since nitrogen containing fertilizers are costly, both in terms of the energy necessary for their manufacture and in their environmental side effects, attention has been focused on systems which naturally fix nitrogen from the air (e.g., legumes, the blue-green algae) in the hope of eventually adapting their processes to crop fertilization. We have developed a technique for producing specific activities (disintegrations per unit volume) of ^{13}N which are substantially higher than those available elsewhere, and have used this technique in an autoradiographic study of sites of nitrogen fixation in the blue-green algae. We propose to collaborate with C.P. Wolk of the AEC Plant Research Laboratory at MSU to further elucidate the nitrogen-fixation process in these

fundamental organisms by studying the metabolic pathway which fixed ^{13}N follows through various chemical substances in the alga. Following ^{13}N fixation and extraction from the algae these substances will be separated by a combination of thin layer electrophoresis and chromatography and the abundance of the fixed ^{13}N in each substance obtained from its ^{13}N radioactivity. It appears that the combination of the ^{13}N production technique we have developed and the expertise available to us at the AEC Plant Research Laboratory could make MSU one of the centers of research in nitrogen fixation.

5. Analysis of the effluent from the MSU Water Management Project.--In an attempt to study the feasibility of recyling the chemical contents (e.g. nitrates and phosphates) of sewage, the Institute of Water Management at MSU has instituted a pilot program of water quality management. A portion of the effluent of the E. Lansing sewage treatment plant will be moved through a series of artificial lakes where its contents will serve as nutrients for harvestable plants. The lake water will also be used for spray-irrigating various fields, woodlands, etc. A fundamental requirement of these research projects is the measurement of trace-element abundances in the lake water, in the irrigated land and in the vegetation harvested from them. We propose to collaborate with researchers in the Institute of Water Management in the measurement of these abundances. For a number of reasons, chief among them high sensitivity to a large range of atomic number, x-ray fluorescence seems the method of choice. Since the techniques are similar to those of high resolution γ-ray

spectroscopy in which we have substantial expertise, development of the computerized data acquisition and analysis procedures should be straightforward.

II. RESEARCH PROGRAMS

II. RESEARCH PROGRAMS

In this section more detailed descriptions (including budgets) of the individual projects are presented. In the lists of investigators, senior personnel are underlined and collaborators from outside the Cyclotron Laboratory are marked with an asterisk.

A. THEORETICAL INVESTIGATIONS OF A MIGMA FUSION DEVICE (M. M. Gordon).

During the past three years, a group at Rutgers headed by B. C. Maglich has been working on the development of a practical fusion power source using accelerator and storage-ring concepts. A detailed report on this work has been presented in an article entitled "The Migma Principle of Controlled Fusion",[1] in which Maglich describes the theory and design of the "Migma Cell", a complete reactor unit having an estimated power output between 10 mW and 10 W. The power output is limited by space charge effects, and a recently proposed solution to this problem has led Maglich to conclude that a Migma Cell 40 cm in diameter might produce 0.1 megawatts.[2]

On the surface at least, the Migma Cell constitutes a very impressive array of novel ideas with intriguing possibilities. A careful examination of the published material indicates, however, that some important assumptions are questionable, that too many of the necessary calculations are oversimplified, and that some of the resultant conclusions are therefore not fully justified.

Because of our long experience in the field of accelerator beam dynamics and orbit computations, we are therefore proposing to carry out a program of theoretical studies aimed at systematically correcting some of these deficiencies.

1. The Migma concept. We begin with a brief outline of the basic Migma concept. Consider an axially symmetric magnetic field whose component $B_z(r)$ normal to the median plane falls off with increasing radius r. Suppose now that a continuous beam of mono-energetic ions (e.g., deuterons) is injected into the median plane so that the ions pass through the field center (r=0). The ions will then follow a precessing orbit such as that shown in Fig. 1. Because the field falls off with radius, the resultant vertical focusing will tend to maintain the ions close to the median plane.

Assuming for the present that the ions avoid striking the inflector, then after many precession periods the resultant ion distribution, called a "Migma", will be axially symmetric. Moreover, the ion number density $\rho(r)$ will be very high at the center (r=0), and will fall off rapidly with radius. In a volume element dV at a given radius r, the reaction rate dI between those ions moving outward (density ρ_1) and those moving inward (density ρ_2) will be given by:

$$dI = \sigma(v_{12})v_{12}\ \rho_1(r)\ \rho_2(r)\ dV,$$

where $\sigma(v_{12})$ is the cross section, $v_{12} = |\vec{v}_1 - \vec{v}_2|$ is the relative velocity, and $\rho_1 = \rho_2 = \rho/2$.

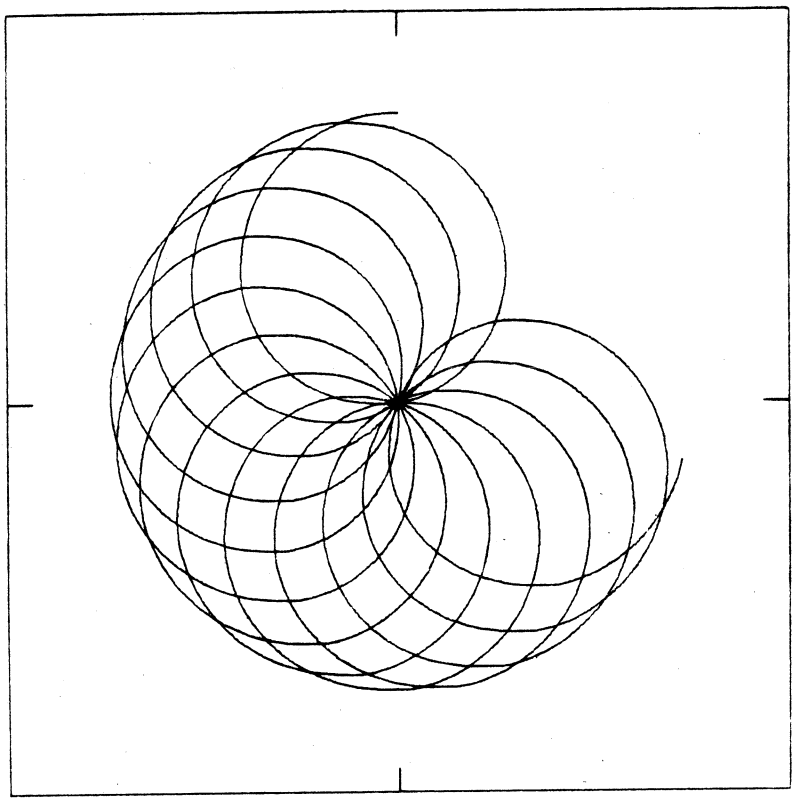

Fig. 1.--Example of precessing orbit which loops through the center of an axially symmetric magnetic field. The precession angle here is θ_p = 21.6 deg per loop. The scale of this figure is arbitrary.

Since the factor $\rho_1(r)\ \rho_2(r)$ is very sharply peaked at r=0, most of the scattering and reactions will occur in the "central core" of the Migma. Moreover, those ions which are elastically scattered in the central core will return to this region along similar precessing orbits. Thus, as a first approximation, Coulomb scattering will not alter the high ion density at the center. This is a crucial feature of the Migma.

The relative velocity v_{12} is given by: $v_{12} = 2v_o\sin(\alpha/2)$, where v_o is the velocity of the injected ions, and α is the angle between $\vec{v}_1$ and $\vec{v}_2$. Under ideal conditions, where the injected beam has a very small emittance and energy spread, the value of α will be a relatively well defined function of radius. In this case, $\alpha \to 0$ for $r \to r_{max}$, while $\alpha \to \pi$ for $r \to 0$. Thus predominantly head-on collisions will occur in the high density central core, and this will greatly enhance the fusion reaction rate. Although $\sigma(v_{12})v_{12}$ for Coulomb scattering diverges for $r \to r_{max}$, the low density in this peripheral region is assumed to reduce the resultant scattering rate to negligible proportions.

With the above arguments as justification, Maglich uses the initial (idealized) Migma density to calculate fusion reaction rates. However, the initial density will differ from the eventual steady-state density not only because of Coulomb scattering in the region $r>0$, but also because of space charge effects. That is, as the space charge builds up in the central core, it will tend to prevent the ions which are subsequently injected from reaching the r=0 point. The steady-state density in the central core may therefore be significantly lower than the initial density. As

noted by Maglich,[1] this question certainly requires further investigation.

2. Basic orbit properties. The design of a Migma fusion device requires, first of all, accurate information regarding the dependence of basic orbit properties on magnet parameters and on ion energy. These properties include, in particular, the precession angle θ_p, and the frequency ν_z of the vertical oscillations. Since these important properties have been treated rather casually by Maglich et al.,[3] we have undertaken a more thorough investigation.

Using equilibrium orbit and transfer matrix techniques, we have developed a computer code which, for a given magnetic field, calculates as a function of momentum, all the important properties of the median plane orbits and of the vertical oscillations. The structure of this code together with some preliminary results have been described in a paper entitled "Basic Orbit Properties of Ions in a Migma Fusion Device", which has been submitted for publication.[4]

The most important results we have obtained concern vertical focusing. These results show that inherent alternating-gradient effects increase the vertical focusing, but beyond a critical momentum value, the vertical oscillations become unstable because of over-focusing. This behavior is displayed in Fig. 2 where the focusing frequency ν_z is plotted as a function of momentum for the same magnetic field as used by Maglich, namely:

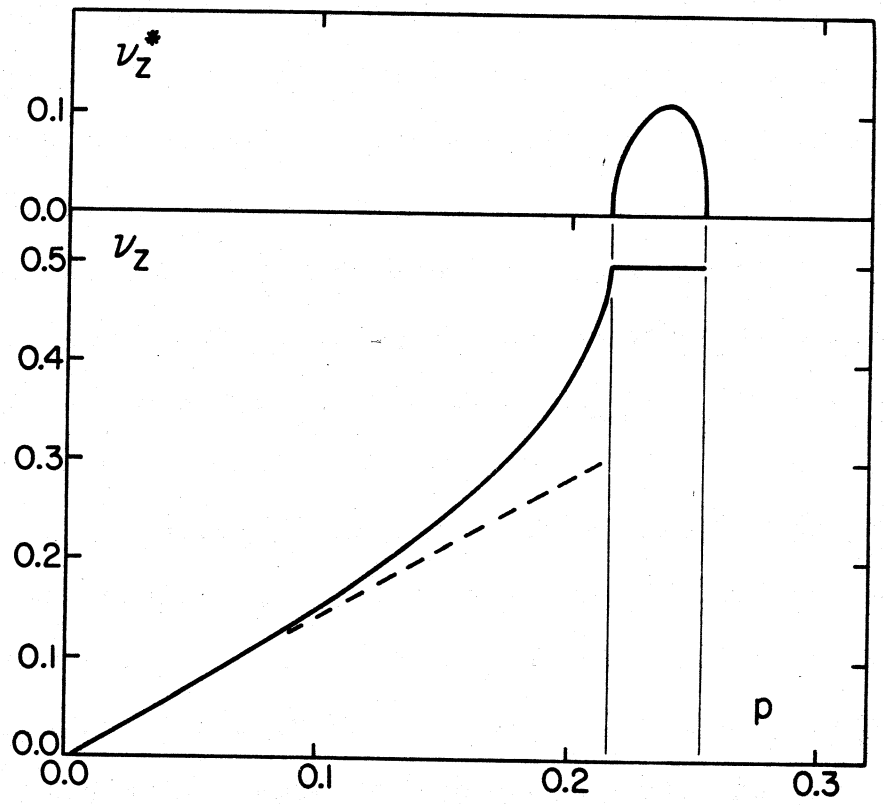

Fig. 2.--Plot of vertical focusing frequency ν_z (oscillations per loop) versus momentum p for orbits like that shown in Fig. 1 in the field: $B_z(r) = B_o(1 - r^2/R_o^2)$. Here, $p = mvc/qB_oR_o$. Lower curve shows real part of ν_z, while upper curve shows imaginary part, ν_z^*.

$$B_z(r) = B_o(1-r^2/R_o^2).$$

As momentum variable, we use $p = mvc/qB_oR_o$, so that our results will apply to any ion and for any values of B_o and R_o.

Maglich uses the value: $\nu_z = p\sqrt{2}$, which is shown by the broken line in Fig. 2. Evidently, ν_z increases faster than $p\sqrt{2}$, and reaches the value $\nu_z = 1/2$ at p=0.215. Above this critical momentum, the vertical oscillations become unstable and the resultant complex value of ν_z is given by: $\nu_z = 0.5 \pm i\nu_z^*$. The values of ν_z^* are also shown in Fig. 2. (Note that for the orbit shown in Fig. 1, p=0.2 and ν_z=0.385.)

For the sake of clarity, Fig. 2 does not show the rapid variation in ν_z in the narrow range between p=0.253 and p=0.272, the maximum momentum which can be confined by this field. Between p=0.253 and p=0.268, the value of ν_z becomes real again and rises from ν_z=0.5 to 1.0; above p=0.268, the vertical oscillations are again unstable. The results of Fig. 2 apply specifically to orbits which pass through the center (r=0), since these orbits are the most important for a Migma device. Very similar results have been obtained for other sets of orbits which pass close to but not through the center.

Since a Migma device must contain ions with a range of momenta, it should be designed to operate in the primary region of vertical stability, namely, ν_z<0.5 or p<0.215. In his design of the Migma Cell, Maglich uses 2.2 MeV deuterons in a field with B_o=200 kG and $R_o \simeq 5.6$ cm.[1] In terms of our momentum variable, these parameters correspond to p=0.27, so that Maglich is (unknowingly) proposing to

operate in the region of vertical instability for motion close to the median plane. This means that the vertical focusing observed by Maglich results entirely from a nonlinear coupling resonance, and under these conditions, the focusing is centered on an equilibrium orbit which corresponds to one of the "stable fixed points" associated with the nonlinear resonance. Unfortunately, the field used by Maglich contains terms only to order z^2 which severely limits the validity of his calculations of nonlinear effects.

We plan to extend our study of basic orbit properties to other magnetic field shapes appropriate to a Migma device, particularly those fields which can be generated by a simple coil configuration. We also plan a systematic study of nonlinear vertical motion in order to establish the basic properties of the phase space diagrams such as fixed-points and separatrices. These properties (which have been treated only sketchily by Maglich) are important for determining the fate of ions which are scattered vertically through relatively large angles. Also, as hinted by Maglich, stable fixed point orbits which pass through the center may be particularly useful for beam injection.

3. Beam injection. Beam injection poses difficult problems for a Migma device. The injection scheme proposed by Maglich depends for its success on a "self-ensnaring" mechanism.[1] Using a conventional inflector, the ions would be injected into precessing, self-colliding orbits (such as that shown in Fig. 1), and the random Coulomb scattering which then ensues would prevent (or at least inhibit) the ions from returning to strike the inflector. Thus, the ions would be "self-ensnared". Maglich proposes two variations of this scheme: one in which deuterons themselves are

B. OPTICAL-MODEL STUDIES WITH NEUTRONS (S.M. Austin, A. Galonsky, J.H. Hetherington*)

1. Introduction

For the design of nuclear reactor cores or of reactor shielding one needs the cross sections for many reactions involving neutrons. It would be ideal to have accurate measurements for all important reactions but in practice it is often necessary for those involved in cross-section evaluations to combine rather scanty and inconsistent experimental data with the results of nuclear-model calculations.[1] The models are used, for example, to normalize the data, to interpolate between data points, to check various sets of data for consistency and of course, to provide the cross sections themselves when data is lacking.

Nearly all of these model calculations involve the nuclear optical model in some fashion. Calculations of reaction cross sections such as (n,2n), and of elastic or inelastic scattering when the compound-nucleus mechanism is dominant, are usually done in the Hauser-Feshbach approximation with transmission coefficients calculated from the optical model. At higher energies where direct reactions may contribute, the optical model is used to generate the elastic waves for Distorted-Wave Born-Approximation calculations and in the case of inelastic scattering to supply also the necessary form factor. Finally, of course, the model gives directly the elastic scattering cross sections.

While the optical model has been remarkably successful in reproducing and correlating large amounts of scattering data, especially for protons, there are still ambiguities in the model,

especially regarding the detailed radial shape of the potential and the differences between potentials for proton scattering and for neutron scattering.[2-4] [The latter point is particularly relevant to the needs of the reactor designers, since a knowledge of the differences would permit one to obtain neutron potentials from the much more accurately known proton potentials.]

We ~~propose~~ intend to study the fundamental properties of the optical model both experimentally and theoretically. We intend to measure the elastic scattering of neutrons from isotopic targets covering a substantial range of mass (primarily ^{40}Ca to ^{209}Bi) at several neutron energies in the 20 to 45 MeV range, in order to establish the energy dependence of the potential and to obtain data for comparison with accurate measurements of proton scattering such as those available near 30 MeV. Such comparisons seem the least ambiguous way to extract differences between the neutron and proton potentials (see below, section 3). We also intend to adopt the "model independent"[5-7] techniques originally developed for the study of elastic electron scattering to investigate possible deviations of the radial shape of the optical-model potential from the commonly used Woods-Saxon form. We will examine first the available proton scattering data and later, that obtained from our neutron scattering experiments.

In most applications of optical-model cross sections to problems of fission or fusion reactor design, etc., energies below about 15 MeV are of dominant importance.[1] However, to determine the basic properties of the optical models for use below 15 MeV, studies at higher energies seem more appropriate

above holds for the imaginary potential

$$W(r) = W_o(r)+W_E(r)E\pm W_1(r)\varepsilon+W_{corr}(r)$$

A more general way of writing U is in terms of an isovector coupling[2]

$$U(r) = U_o(r) + \frac{4U_1(r)}{A}\vec{t}\cdot\vec{T}$$

where $\vec{t}$ is the isospin of the projectile and $\vec{T}$ that of the target nucleus. This prescription contains the previous results; for example, $U_o = V_o+V_EE+i(W_o+W_EE)$ and in addition implies the existence of a particularly simple (p,n) reaction which leads from a target nucleus (N,Z) to its analog in the (N-1,Z+1) nucleus.

In what follows we shall concentrate our attention on the asymmetry terms $W_1\varepsilon$ and $V_1\varepsilon$, since these quantities contain the essential difference between neutron and proton scattering.

3. Measurements of V_1

Perhaps the most obvious way to obtain $V_1(r)$ is to measure proton and neutron scattering at the same energies on the same nucleus. The difference ΔV in V for protons and neutrons is just $2V_1\varepsilon + V_{corr}$, and since the geometry and energy are the same, the only ambiguity is the necessity to estimate V_{corr}.[†] In

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[†] It has been suggested[8] that this ambiguity might be reduced by comparing neutron and proton scattering at energies related by $E_n=E_p-\bar{V}_c$, where $\bar{V}_c$ is the average Coulomb repulsion felt by the proton. To obtain this result we note that V_{corr} accounts for the effect of the slowing of the protons by Coulomb repulsion and the velocity dependence of V. Thus $V_{corr}\simeq -V_E(r)\bar{V}_c$ and for protons $V=V_o(r)+(E_p-\bar{V}_c)V_E(r)+V_1(r)\varepsilon$ while for neutrons $V=V_o(r)+E_nV_E(r)-V_1(r)\varepsilon$. Further developments of these ideas may affect our choice of the energies chosen for these comparisons.

practice however, accurate proton and neutron data have not been available at the proper energies and on the same nuclei and this method has been little used.[2] Instead, it has been necessary to compare potentials derived from scattering of nucleons on nuclei with different values of ε, plot the potential against ε and thereby determine V_1.[2-4] The major disadvantage of such studies is that in order to avoid large fluctuations in the extracted value of V_1 many parameters must be held constant. Specifically, the geometrical parameters (a,r_o) are normally held fixed and it is normally assumed that the radial shapes of V_1, V_o and V_E are identical. A number of such analyses have been done for both protons and neutrons and are summarized refs. 2-4. Perhaps the most complete of these is the analysis of Becchetti and Greenlees (BG)[9] based primarily on proton data, where it is found, as is typical for these analyses, that V_1=24 MeV, with no apparent energy dependence. In general for neutrons it is found that V_1 is somewhat smaller, though the data are much less accurate.[2] This difference may indicate that part of the asymmetry dependence is due to a geometrical effect, e.g. the fact that $R=r_o A^{1/3}$ is not precisely valid.

In this section we have, for purposes of simplicity of presentation, restricted ourselves to discussions of V_1. Information about W_1 is obtained by similar techniques (see refs. 2-4,8).

An initially more appealing way of obtaining V_1 and W_1 is through measurements of the cross sections for (p,n) reactions leading to analog states, since these cross sections depend quadratically on $2\sqrt{2T}\ U_{1/A}$ (Here V_1 is often taken to be a volume

C. PREDICTIONS OF LEVEL DENSITIES WITH THE SHELL MODEL (B.H. Wildenthal)

1. Introduction

We propose to use the techniques of the nuclear shell model to calculate the densities of levels in light-and medium-mass nuclei in regions with less than ~100 levels/MeV. Specific results of such calculations are a presently needed input for the evaluation of the response of various isotopes to bombardment with ~0.1 to ~15 MeV neutrons. These evaluations are an integral preliminary aspect of reactor (particularly fusion reactor) development and design, and are being actively pursued by several groups.

Modern applications of the shell model of nuclear structure have been quite successful in accounting for the properties of nuclei in the first few MeV of excitation. This has particularly been the case when careful and systematic studies of the model Hamiltonians and basis spaces have been carried out, as has been the case in the MSU-type investigations.[2-7] Although it is usually said in a humorous vein, it is none the less true that at our present level of theoretical understanding of certain regions of nuclei, a qualitatively serious disagreement between a new experimental number and a stable theoretical prediction is usually evidence for an error in the experimental datum or analysis.[8,9] The point is that the nuclear shell model, properly and appropriately applied, is now a serious predictive tool.

We propose here to apply this tool to a problem of nuclear reactor technology, namely estimating the density of levels in certain nuclides. When the idea was first broached to us we were surprised that the problem even existed and skeptical that our shell-model techniques could be very pertinent to its solution. Our initial assumptions were that (1) all such data would have long since been experimentally measured and (2) that statistical level-density formulae would be more appropriate than shell-model predictions where recourse to theory was necessary. However at the level of investment in reactor development projected for the remainder of the 20^{th} century, the properties of even trace elements in a reactor wall, ^{30}Si for example, deserve and are in fact receiving, attention which in absolute terms is substantial. Essentially any isotope may turn out to be one whose properties need to be evaluated, and many of these may present prohibitive difficulties for accurate, prompt experimental study. The simple fact is that scientists now actively engaged in developing neutron-interaction evaluation profiles for various elements recurrently find it necessary to turn to theory for assistance.

The pertinence of the shell model for this problem lies in the predictions it can make about level densities in the region, say, of the 10^{th} excited state to the 100^{th} excited state. In this region, and particularly for light nuclei, the shell model does not just give the most accurate numbers, it gives the <u>only</u> numbers that have any foundation at all,

and is the necessary and appropriate bridge between the lowest few levels, which are typically experimentally known, and the high excitation region where the statistical level density formulae presumably become valid.

The use of the shell model to solve these problems in basic reactor design was brought to our attention by a former MSU student, Duane Larson, who is now engaged in neutron-interaction data evaluation at ORNL. Two of the problems on which we initially worked in conjunction with his evaluations involved the levels of ^{30}Al and the relative level densities of ^{19}O and ^{19}F. In the A=19 case, for example, the dominant processes by which neutrons interact with ^{19}F are (n,n'), (n,p), and (n,α). The magnitudes of the (n,n') and (n,p) yields ultimately depend upon the densities of levels in the residual systems, ^{19}F and ^{19}O. Quite different conclusions result from assuming one or another estimate for the level densities in the 5-15 MeV range of excitation in these nuclei. A close study of the problem led to the conclusion that extensions of the results for A=19 presented in Ref. 7 yielded the most realistic estimates of the requisite level densities presently obtainable. In Fig. 1 we indicate the degree to which the theory reproduces the known level densities at lower excitation energies in ^{19}F. Even in this relatively well documented nucleus there is a strong indication of deficiencies in the experimental count of levels above 9 MeV.

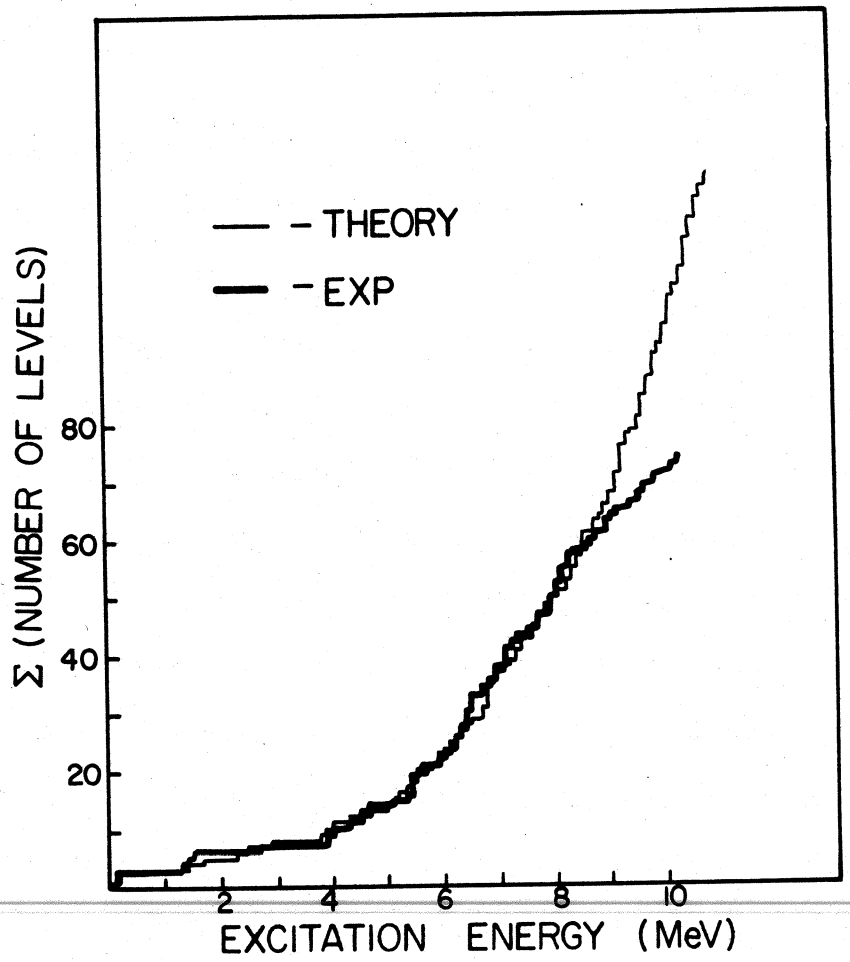

Fig. 1.--Level densities in ^{19}F. Above 9 MeV the calculated density ($\frac{d\Sigma}{dE}$) continues to increase strongly, while the experimental density actually decreases, presumably indicating "missed" levels.

The consequent necessity of accurate theoretical predictions obviously follows. For ^{19}O, a system much less amenable to experimental study than ^{19}F, recourse to theory is even more essential.

At present we are able to offer definitive assistance to a problem concerning level densities in only a few cases. Our attention has previously been directed towards an ever more complete understanding of the lowest few levels rather than towards the best accounting for the structure of the intermediate-level-density region, where little detailed information about the levels is available. It is an example of the power of the shell-model approach that our extant results have already proved useful in an application for which they were not developed. By a very slight reorientation of emphasis, we would be able to treat the problems of intermediate level densities much more fully and consistently than in our previous work and thereby provide a substantial and needed service to the overall program of reactor design.

2. Proposed research

The project we specifically propose is to develop matched Hamiltonians and model spaces for the nuclei from A=6 to 64, such that the density of levels below approximately 10-15 MeV excitation is systematically and accurately reproduced. Emphasis will be placed upon using model spaces as large as possible, both to extend the range of excitation over which realistic predictions are possible and to smooth out discontinuities in the

transitions across major shell closures. We would use tightly circumscribed Hamiltonians, such as the modified surface delta interaction, which yield a good qualitative reproduction for spectra, and which can be specified by a very small set of parameters. Concurrently with blocking out this general attack we would propose to widen our contacts with neutron-interaction evaluation projects so as to insure that current topics of interest in that area are those nuclei for which we obtain the earliest results.

We are presently running, with modifications and improvements, all the significant main and auxilliary shell model codes in existence. Our experience in this area is such that we would very quickly be able to get usable and accurate results.

There are two requirements to implementing the program described: computer time and manpower. While most of the developmental work can be done on a relatively small computer, a fact which is implicit to a significant extent in the present (unpublished as well as published) body of our research program, the final, definitive, calculations should be done on the largest possible computer so as to encompass the largest possible model space. The MSU cyclotron computer facilities are already taxed to the limit by the present experimental and theoretical research programs. Hence, not only the production runs but also substantial further developmental work would necessitate obtaining additional, alternate, computer capability. While enlarging our in-house capabilities has much in its favor, the necessary time-lag causes

us to omit that possibility from this present proposal. We would propose to obtain the computer time both by traveling to various installations where large computers are available for collaborative use between staff members and visitors and by direct purchase from facilities which rent computer time commercially. Specific places under consideration at present for collaborative programs are ORNL and BNL. Since the calculations contemplated have a multiplicity of ultimate uses, it should not be hard to find physicists interested in "sponsoring" such research. The primary costs here are for travel and the primary handicap is the unreliable and sporadic nature of the access to the computer. The present investigator is experienced in such operations via previous collaborations at ORNL. (Parenthetically, the extension of collaborations to foreign laboratories, some of which have comparatively under-used computing facilities, is another aspect of the travel-collaboration aspect of getting access to a large computer.) The other avenue to getting time on a large computer is simply to rent it. Berkeley, for example, now sells time on a CDC 7600 at a very reasonable rate, and a tie-in via the cyclotron input-output devices should be feasible and convenient.

The manpower requirements we propose to be met initially by 1/2 of one research associate and 1/2 of one graduate student. As noted, there is a close relationship between this application of the shell model to a specific problem of the national energy program and intrinsic scientific merit. All that is involved is a reorientation of part of our prevailing

interests. Hence, the project should yield scientific publications of high quality, and work on it should contribute in very positive ways to the student's and research associate's careers. Given the other responsibilities of the senior investigator, and his desire to personally supervise the quality of this program, two people is as large an effort as is desired at this time.

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D. STUDY OF NITROGEN FIXATION WITH RADIOACTIVE NITROGEN

(A. Galonsky, S.M. Austin, C.P. Wolk*)

1. Introduction

Since most plants do not fix atmospheric nitrogen, the use of artificial nitrogen fertilizer has greatly expanded man's food production. This great boon to civilization is now used on such a vast scale, however, that it is creating two serious problems. First of all, the commercial production of fertilizer consumes large quantities of energy. For example, the energy used to produce nitrogen fertilizer for an average acre of corn in 1970 was 940,000 kilocalories, compared to only 800,000 kilocalories in fuel used to work that same average acre.[1] Secondly, eutrophication of our natural waters, which is proceeding at an alarming rate, is overwhelmingly the result of run-off from agricultural land using nitrogen-loaded chemical fertilizer. From 1945 to 1970 our use of nitrogen increased from 7 to 112 pounds per acre of corn.[1] With an increasing world population and with virtually all arable land already in use, this does not seem the time to conserve fuel or to stem the tide of "green pollution" by curtailing our use of nitrogen fertilizer. Yet, sooner or later we must do so.

Unlike most plants, leguminous crops and blue-green algae have the peculiar ability to fix nitrogen from air. A legume acquires its nitrogen through a symbiotic relationship with nitrogen-fixing bacteria attached to root nodules of the plant. The bacteria supply nitrogen to the plant; the plant, through its leaf structure and photosynthesis, produces and supplies carbon compounds to the bacteria.

If nitrogen fixation was sufficiently understood it might be possible to develop strains of wheat, corn, or other nutritious crops which also could fix nitrogen. Another possibility is the creation of a strain which would have its nitrogen needs satisfied in symbiotic existence with a blue-green alga.

Blue-green algae and other photosynthetic bacteria are the only organisms which are known to be self sustaining, in the sense that they can assimilate directly from the natural environment both N_2 and CO_2. That they also have an extremely simple structure marks them as ideal candidates for study in research aimed at elucidating the mechanism of nitrogen fixation. For a combination of reasons blue-green algae are also uniquely suited to serve as a model for prospective nitrogen fixation by higher plants: (1) in the test-tube, nitrogen fixation by the purified biological catalyst is inactivated by oxygen, so that it must be protected in oxygen-producing organisms such as the higher plants; and (2) blue-green algae are the only nitrogen-fixing, oxygen producing microorganisms.

2. The site of nitrogen fixation in blue-green algae

The structure of a common form of blue-green algae is a long filament of cells. Filaments which fix nitrogen aerobically consist of two kinds of cells called vegetative cells and heterocysts. The vegetative cells predominate, typically outnumbering the heterocysts by around 20 to 1. As an alga grows, by normal division of the vegetative cells, the number of vegetative cells between heterocysts increases from ~13 to ~26, at which point a

vegetative cell differentiates into a heterocyst, thus maintaining the average heterocyst spacing of ~20. In blue-green algae the phenomena of cell differentiation and of nitrogen fixation may be related. The work proposed here bears on both phenomena.

Although inconclusive, a great deal of biochemical evidence points to the heterocysts as being major sites of fixation of nitrogen. In collaboration with C.P. Wolk of the M.S.U. Plant Research Laboratory, we have examined the location of nitrogen fixation by performing autoradiography of algae immediately following their fixation of ^{13}N-labeled N_2. We concluded[2] that heterocysts, numbering only 5% of the cells, performed at least 25% of the fixation. Although we saw tracks originating in vegetative cells, we could not rule out the possibility that all nitrogen entered at a heterocyst and migrated down the filament during the few minutes of fixation time allowed in our experiment.

3. Proposed research--The early products of nitrogen fixation in blue-green algae

The next stage in our work should be a study of the intracellular metabolism of nitrogen and the intercellular movement of particular nitrogenous substances between heterocysts and vegetative cells. If we could follow the biochemical pathways by which nitrogen, after fixation, becomes incorporated into the alga, and--in whole or in part--transported from heterocysts into vegetative cells we should have made great progress in understanding how a plant gets nitrogen. We know of no way to

do this without the use of ^{13}N, and we propose an entirely feasible way of doing it with ^{13}N.

In our previous work[2] we developed a technique for producing ^{13}N by the $^{13}C(p,n)^{13}N$ reaction and extracting ^{13}N in diatomic $^{13}N^{14}N$ molecules. In spite of decay during processing ($T_{1/2} \cong$ 10.0 min.) we were able to expose algae to 10 mCi of ^{13}N in a 1 cc vial. The algae assimilated 0.02% of this or 7×10^7 ^{13}N-^{14}N molecules per minute. We propose to use this technology in combination with thin-layer electrophoresis and thin-layer chromatography to obtain the distribution of ^{13}N amongst various amino acids and other products of fixation as a function of time after fixation.

Radioactive algae will be extracted with methanol and the extract deposited in a small spot on an electrophoresis plate. Ions formed on this plate will migrate under the action of an electric field and at a rate mainly proportional to the time-averaged charge on the ion. All ions of a given species will have the same average charge, will have approximately the same drift rate, and will be grouped together in a single spot when the drift is concluded, physically separated from those molecules having different average charges. By counting the ^{13}N radioactivity of each spot we will determine the abundance of each molecular species. It is important to remember that the distribution of nitrogenous molecules assayed here relates only to the nitrogen fixed during the time of ^{13}N fixation, a time which is completely under our control. All other nitrogen is rendered invisible by the tracer technique. This is an essential

feature because the distribution of old nitrogen in an alga must be quite different from that of, let us say, nitrogen fixed during the last minute of an alga's existence. Since algae grow exponentially with a doubling time of around one day, the nitrogen fixed during the last minute is less than 10^{-3} of the total nitrogen present. (^{13}N would be approximately 10^{-10} of the total.)

To follow in time the assimilation of nitrogen during ^{13}N fixation we can perform something akin to time-lapse photography. We partition the activated algae--perhaps into 5 parts. After a brief fixation time (e.g. 1 min.) one part is extracted with methanol and fractionated by electrophoresis. The same is done to each of the other parts after assimilation times of, for example, 1 min, 2 min, 5 min and 10 min. The practical range of time will be determined at the lower end by finite handling times and by the sensitivity of our ^{13}N detector. Because of the 10-minute half life of ^{13}N, detector sensitivity will also determine the upper end. We should, with the thermoluminescent detectors discussed below, be able to cover the range 0.1 min to 10 min.

A significant complication of the separation procedure described thus far is the problem of degeneracy in electrophoresis. It is known that three important amino acids--asparagine, citrulline, and glutamine--drift at the same rate. The standard technique, which we can also use with radioactive nitrogen, is to follow thin-layer electrophoresis with chromatography on the same plate but dispersing the molecular species in a direction perpendicular to the electrophoretic drift.

Chromatography, depending upon adsorbtion and solubility, does not exhibit the same degeneracies as electrophoresis.

The result of the two dispersions should be an area containing spots of radioactivity. In a 15-minute electrophoresis at 50 volts/cm we have obtained a 5-cm separation between ammonia and some amino acids. Chromatography is slower and, because of the 10-minute half life of ^{13}N, we do not expect to obtain as great a dispersion with it as with electrophoresis. Thus far we have produced separations of 2 cm in 35 minutes, and have separated asparagine, citrulline and glutamine. We can expect to produce a 5 cm x 2 cm area containing radioactive areas 2 mm to 3 mm in diameter. A detector with 1 mm^2 resolution would seem appropriate. With 1,000 mm^2 to scan and with the 10-minute radioactivity to assay, only gross information could be obtained in a "single-channel", sequential counting scheme. A parallel device would be much better. There are a number of possibilities--photographic film, image intensifiers, multi-wire proportional counters and thermoluminescent dosimeters (TLD).

4. Thermoluminescent dosimetry

We have chosen TLD[3] as the most appropriate detector for this investigation. We will cover the 5 cm x 2 cm area of interest with a sheet of TL phosphor [dysprosium-doped CaF_2 or $CaSO_4$] until most of the ^{13}N has decayed, cut the sheet into small squares, and measure with a photomultiplier the light heated out of each square in a standard, commercial TLD reader. Although we will count, or more appropriately, interrogate, each square in sequence, we will satisfy the parallel require-

ment by recording the information in parallel when the entire TL sheet is activated by the ^{13}N positrons. This detector integrates the ^{13}N radioactivity and stores the information as long as one wishes. Its response is linear over many orders of magnitude. As used here the detector solid angle will be about 2π.

TL dosimetry is a tried-and-proven, simple-to-use, relatively inexpensive technique. We have tested its suitability for this project by substituting ^{32}P (end point 1.73 MeV) for ^{13}N (end point 1.15 MeV) and using the TL dosimetry instrument (Teledyne model 7300) of our university health-physics group. We exposed 0.4 mm thick disks of 28% $CaSO_4$ in teflon to ^{32}P for 49 minutes. The ^{32}P was deposited in small spots which had activities ranging from 10^{-3} μCi to 1μCi; the corresponding exposures ranged from 5×10^4 betas to 5×10^7 betas. Our results are shown in Figure 1. The large deviation of one point from the 45° line is most likely the result of error in preparing the ^{32}P activity.

The exposure range 10^4 to 10^6 betas would reveal much, but not all, of the information we seek. In the example already cited, where the algae assimilated 7×10^7 ^{13}N-^{14}N molecules in 1 min and each fifth part of that separately underwent electrophoresis and chromatography (requiring 50 minutes=5 half lives of ^{13}N) the TL phosphor would receive an exposure of $(7\times10^7)(0.2)(2^{-5})(\frac{2\pi}{4\pi})=2\times10^5$ positrons. With the type instrument used

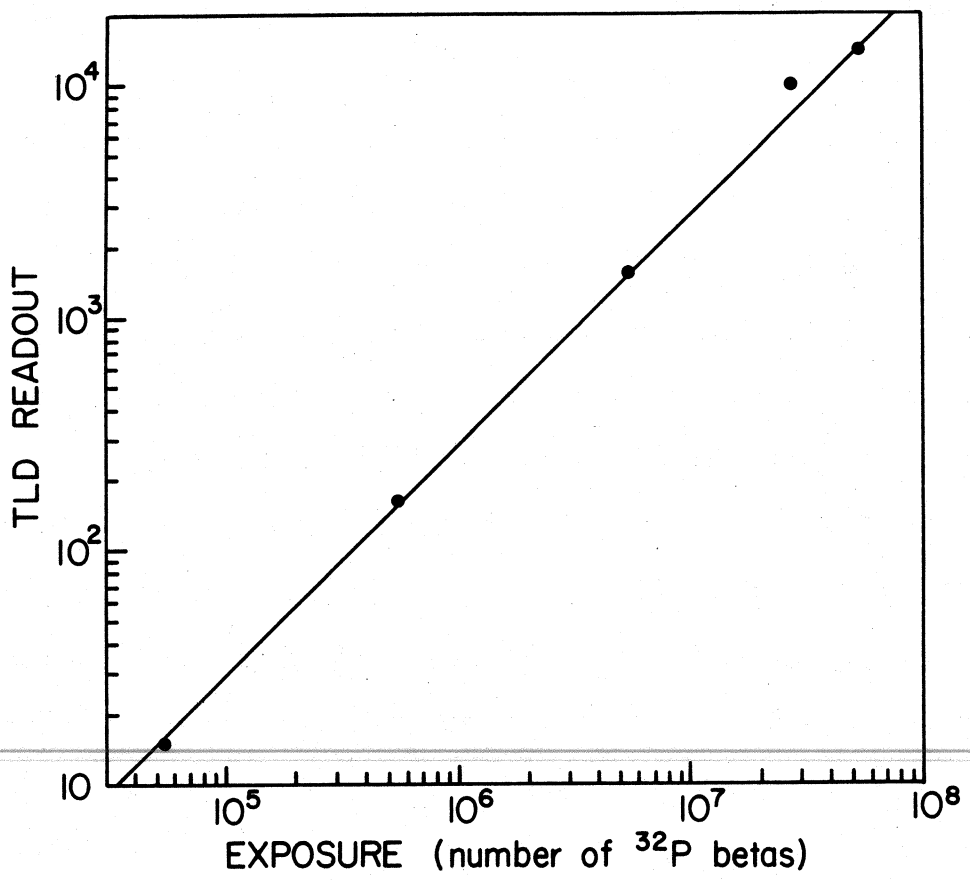
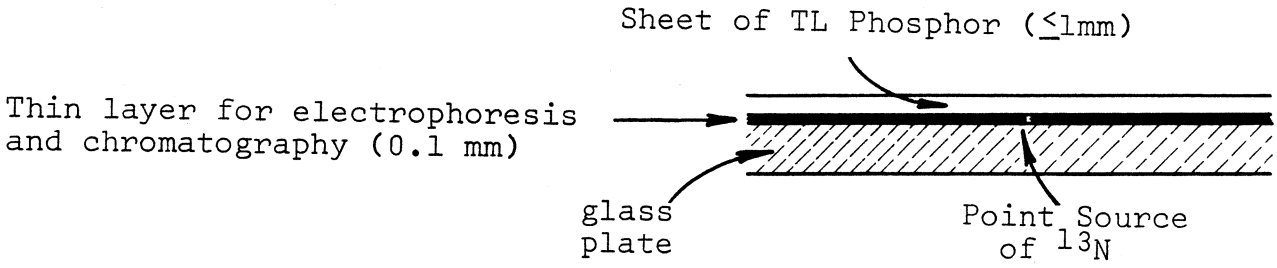


Fig. 1.--Response of $CaSO_4$-in-teflon TLD to exposure to betas from ^{32}P.

here, whose sensitivity limit is about 10^4 positrons, we could see fixation products down to about 5% abundance which is sufficient for most purposes. With a fixation time of only 0.1 minute the detection sensitivity required for 5% abundance is 10^3 positrons. Instruments with this sensitivity are available. If one counts individual thermoluminescent photons with a photomultiplier, on the average there are about 1.5 photomultiplier pulses for each beta ray or positron that originally passed through the TL phosphor.[4] As an ultimate sensitivity this leaves little to be desired. In practice, there is a background near 500 counts during the time interval in which the light is cooked out of a TL phosphor, resulting in a sensitivity limit of $\lesssim$100 positrons[5] and permitting a very detailed investigation in the present instance.

In addition to low counting sensitivity it is desirable to have good position resolution, perhaps as low as 1 mm^2. Can this be achieved with TLD?



There are two problems to consider. One, a point source of positrons irradiates an area, not just a point, in the phosphor above it (see sketch). Two, when a positron stops in the phosphor or glass its annihilation radiation excites adjacent regions of phosphor via Compton scattering.

The first effect has a natural limit determined by the range of ^{13}N positrons in the phosphor. A positron having the average energy of 0.55 MeV has a range of ~0.6 mm in the TL phosphor CaF_2. Although the highest energy positrons have ranges over 1 mm, most of the positron energy from a point source will be deposited in an area of about 1 mm^2 in the sheet of phosphor. A smaller area can be achieved at some loss of TL excitation by reducing the thickness of the phosphor or by inserting a few mils of dense absorber, say gold, between the electrophoresis layer and the phosphor.

The second effect, Compton scattering, is less important. Consider the energy deposited in a mm^3 of CaF_2 by a source of annihilation radiation at the center of an adjacent mm^3. The mean free path of 0.511-MeV γ rays is 30 mm in CaF_2; the mean Compton electron energy is 0.15 MeV; and the solid angle subtending the source is about $(.05)(4\pi)$. Since there are two γ rays per positron, the average energy deposited is $(\frac{1}{30})(.15\ \text{MeV})(.05)(2) = 5\text{x}10^{-4}$ MeV. This energy is only 10^{-3} of the average energy deposited directly by the positron. Hence, two point sources 1 mm apart could be distinguished even if their intensities differed by as much as a factor of 10^3. This is not much of a limitation.

The degree to which we will push for the ultimate sensitivity and resolution with TLD will depend upon the refinement to which electrophoresis and chromatography are developed by our biological collaborator, Dr. C.P. Wolk. He is carrying out this work under a separate NSF grant--number GB 43823. We propose to

E. ANALYSIS OF THE EFFLUENT FROM THE MSU WATER MANAGEMENT PROJECT VIA X-RAY FLOURESCENCE (E. Kashy, T.L. Khoo, F.M. D'Itri*)

A problem society now faces is the disposal of its municipal and industrial wastes in the most efficient fashion from both an energy and an environmental point of view. Traditionally, sewage is discharged after appropriate treatment into waterways and lakes, leading to their pollution and eventual destruction, if the process is continued unchecked. An alternative method consists of recycling the effluent with land disposal. Such a scheme should not only preserve the environment but also the available resources; the nitrates and phosphates in the effluent can be utilized for irrigation instead of being wasted into the nearest stream; and the eventual cost (in terms of dollars and energy) of reclaiming polluted rivers and lakes is obviated. The importance of reclamation is heightened by the awareness[1] that the supply of phosphorus is rapidly dwindling and that large amounts of energy are required[2] to manufacture the nitrogen fertilizers needed for food production.

1. Institute of Water Research pilot project

In response to this issue, the Institute of Water Research at MSU has initiated a unique pilot program of water quality management. The plan is to divert a portion (2 out of 15 million gallons per day) of the secondarily treated effluent from the East Lansing Sewage Plant to a 500 acre site on campus (instead of

into the Red Cedar River). Here the water will be moved through a series of artificial lakes over a period of about thirty days. The nitrogen and phosphorus in the effluent will be removed by aquatic plants, which will be periodically harvested and fed to farm animals or worked into the ground as fertilizer for crops. The final lake is expected to be clean enough for recreational use. Water from the lakes will also be used for spray irrigating fields, woodland and agricultural plots, and the effects of such irrigation will be studied.

The important and unique aspect of the MSU scheme is that it combines two methods of recycling wastewater--lakes and irrigation. It has been designed specifically to demonstrate the feasibility of such a scheme and for research in related areas such as soils science, entomology, botany, engineering, microbiology, fisheries, as well as the sociological and economic aspects of wastewater recycling. Further details of the program are given in an accompanying appendix.

An important facet of the whole project will be the regular monitoring of the total elemental content at each stage of the effluent flow. It will be necessary not only to ascertain the nitrogen and phosporus content but also the level of toxic heavy metals (Cd, Cr, Cu, Ni, Zn, Hg, and Pb to name a few) in the water, sediment and plants. Furthermore, it is imperative that the effects of the lakes and spray irrigation projects on the quality and quantity of underlying ground water be determined. As part of a collaborative effort with F.M. D'Itri we propose

to develop and apply the technique of x-ray flourescence to this specific problem.

2. Woodland irrigation with sewage effluent

In conjunction with the above mentioned Water Quality Management Project, G. Schneider and others at the Department of Forestry at MSU started a study in 1972 to evaluate surface soil and vegetation changes associated with irrigation of deciduous woodlands and coniferous plantations with municipal waste water. Small, replicated plots in pine plantations and in hardwood forests have been treated with measured amounts of effluent during the past two growing seasons and this process will be continued. There are two sources of waste water: (1) an oxidation pond at Middleville, a small (2,500) non-industrial community in South Central Michigan and (b) the sewage treatment plant at East Lansing. At the Middleville project, effluent is distributed on nearby plots at different monitored rates by sprinkler irrigation. For the MSU campus plots, effluent from the E. Lansing plant was trucked in during 1972 and 1973 and spread by trickle irrigation from storage reservoirs.

Vegetation parameters being measured include stem and height growth, leaf area, biomass distribution, changes in species composition and nutrient concentrations. Soil measurements include structure, organic matter, biological activity, infiltration, bulk density and nutrient levels. Water quality measurements have included phosporus, total nitrogen, ammonia-nitrogen, and

nitrate in effluent and soil percolate at various depths below the soil surface. To date, effluent irrigation has not resulted in significant stem biomass increases, except for pine foliage. A highly significant uptake of boron by the Middleville pine site raises the possibility of potential toxicity. High irrigation rates have resulted in important reductions in needle litter and increases in microbiological activity. Instances of high nitrate contents in soil water percolate have been recorded while the movement of additional phosphorus through the profile has been minimal.

In collaboration with Dr. Schneider x-ray fluorescence analysis will be applied to expand the scope of the project to monitor the presence of heavy elements in the effluent, the absorption of these elements by the vegetation, their flow through the soil, and their residual levels in the soil.

3. Details of the x-ray fluorescence technique[3]

For the purpose of this study x-ray fluorescence seems the method of choice. This technique is based on the emission of characteristic x rays by elements when they are excited by higher energy radiation (gamma rays, x rays, or energetic charged particles). The energies of the x rays provide a unique fingerprint of the element and their yields are a direct measure of the quantity of the element in a sample. The x rays are detected by a Si(Li) detector, capable of <180 eV FWHM photon energy resolution, which is sufficient to resolve the characteristic x rays of neighboring elements for $Z \geq 11$. The resultant signals

are electronically processed and sorted according to energy in a pulse-height analyzer.

Although x-ray spectroscopy has only recently been recognized as and developed into an extremely powerful elemental analysis technique, there are already wide applications--measurement and monitoring of pollutants in our environment, material analysis for quality control in industry, detection of art forgeries, assay of archaeological objects and other applications requiring a knowledge of the elemental composition of materials. It is now recognized as an accurate, rapid, versatile, quantitative, non-destructive and inexpensive analysis technique. It is also extremely sensitive: quantities of the order of parts per million (ppm) or smaller may be detected. When compared to other commonly used techniques for elemental analysis (e.g. atomic absorption spectrophotometry, mass spectroscopy), x-ray fluorescence offers the following advantages: (a) a wide range of elements (Na-U) may be simultaneously detected; (b) sample preparation is usually easier; (c) measurement periods are short (of the order of 1-60 minutes); (d) data reduction may be performed in a matter of minutes with an automated system including a computer; and (e) as a consequence of items (c) and (d), the turn-around time for analysis is shorter.

4. Suitability of the MSU Cyclotron Laboratory as a site

At present no x-ray fluorescence equipment is available on the MSU campus or, to the best of our knowledge, in the Lansing metropolitan area. The Cyclotron Laboratory seems well suited

as a site for such a facility for a number of reasons. We are familiar with the measurement and analysis techniques involved, which are essentially similar to those of high resolution gamma-ray spectroscopy. Furthermore, sophisticated data acquisition and computer systems already exist at the laboratory, considerably reducing the cost for setting up a complete system. In addition, the laboratory electronics and machine workshops will be valuable assets. Where necessary, we are also equipped to bring to bear on particular problems a variety of techniques of elemental analysis, e.g. x-ray or beam-induced x-ray fluorescence, elastic proton scattering,[4] and neutron activation analysis (utilizing the TRIGA reactor located on campus).

5. Other applications

While the development of the techniques and their application to the research described above will dominate our efforts during the initial phases of this program, the fact that the facility will be unique in this area has already brought other applications to mind. For example:

a. Heavy metals and plant growth.--B.D. Knezek and his collaborators of the Department of Crop and Soil Science at MSU have been studying[5] the effects of heavy metals upon agricultural product growth. They have found, for example, that Cd-treated soils retarded growth of corn plants more than Ni-treated soils. This research is related to the problem of municipal or industrial waste disposal since industrial effluent may contain toxic heavy metals which pose potential threats to

human food and water originating from areas used for waste disposal and water renovation. Dr. Knezek plans to continue studies on the effect of heavy metals upon plant growth and intends to use x-ray fluorescent spectroscopic techniques among others.

b. Pb poisoning in farm animals.--The Department of Veterinary Medicine at MSU handles numerous cases of Pb poisoning of animals which have ingested used motor oils or acquired Pb from emissions of combustible engines, for instance. Professor K. K. Keahey, of the Pathological Laboratory of Veterinary Medicine has expressed interest in utilizing an x-ray fluorescence system for analysing animal tissue for Pb and other heavy metals.

We intend to collaborate with these investigators and in other circumstances where this seems scientifically fruitful, and in addition to provide, on a limited basis, analysis service to units of the university whose needs are not sufficiently large to justify their own set-up.

6. Summary

We intend to collaborate on a number of energy and environment-related programs which are currently under study at Michigan State University and which depend on elemental analysis. As indicated above, x-ray fluorescence spectroscopy offers several advantages over the currently employed techniques and therefore should make a significant impact on these projects. We envision developing the x-ray system with these applications particularly in mind. It will be necessary to develop sample prep-

aration techniques and useful to study the possible enhancement of sensitivity for particular elements. The projects involve handling of a large number of samples, and it will be convenient eventually to develop automatic data acquisition and analysis techniques.

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III. BUDGET SUMMARY

IV. APPENDICES

APPENDIX A: Members of the MSU Nuclear Research staff from the Departments of Physics and Chemistry. Those associated with the projects described herein are marked with an asterisk.

Sam M. Austin* — Ph.D., Univ. of Wisconsin (1960); Oxford Univ. (1960-61); Stanford Univ. (1961-65), MSU (1965). NSF Postdoctoral Fellow (1960-61), Sloan Research Fellow (1963-66); Guest, Niels Bohr Inst., Copenhagen (1970), Visiting Professor Univ. of Munich (1972-73).
Research interests: elastic and inelastic scattering, the optical model, the nucleon-nucleus interaction, nuclear astrophysics, nitrogen fixation.

Walter Benenson — Ph.D., Univ. of Wisconsin (1962); Univ. of Strasbourg (1962-63); MSU (1963). Visiting Fellow, Australian Natl. Univ. (1968), Visiting Prof., Univ. of Grenoble (1970).
Research interests: proton rich nuclei, inelastic proton scattering, fast neutron polarization, Doppler-shift lifetime measurements.

Fred M. Bernthal — Ph.D., Univ. of California, Berkeley (1969); Yale Univ. (1969-70); MSU (1970).
Research interests: nuclear chemistry, α-β-γ spectroscopy, nuclear lifetimes.

George F. Bertsch — Ph.D., Princeton Univ. (1965); Niels Bohr Inst., Copenhagen (1965-66); Princeton Univ. (1966-69, 1970-71); MIT (1969-70); MSU (1970). NSF Postdoctoral Fellow (1965-66); Sloan Research Fellow (1969-71), Guest, Weizmann Inst., Rehovoth (1972).
Research interests: theoretical nuclear structure.

Henry G. Blosser — Ph.D. Univ. of Virginia (1954); Oak Ridge Natl. Lab. (1954-58); MSU (1958). Visitor, CERN (1966-67), Guggenheim Fellow (1973).
Research interests: isochronous cyclotrons, high resolution nuclear spectroscopy, ion optics, high energy particle accelerators, nuclear reactions.

J. R. Borysowicz — Ph.D., Inst. for Nuclear Research, Warsaw (1965); Warsaw Univ. (1959-63); Niels Bohr Inst., Copenhagen (1963-64), Inst. for Nuclear Research, Warsaw (1965-67), MSU (1967). Research interests: diffractive deuteron scattering on nuclei, the few-nucleon problem shell model calculation for light nuclei, nuclear cluster model.

Gerard M. Crawley — Ph.D., Princeton Univ. (1965); Melbourne Univ. (1960-61); MSU (1965-66); Australian Natl. Univ. (1966-68); MSU (1968). Fullbright, Ford, and James W. Queen Fellowships, Princeton Univ.; Queen Elizabeth II Memorial Fellowship, ANU. Research interests: inelastic scattering, analog states, cluter transfer.

Aaron I. Galonsky* — Ph.D., Univ. of Wisconsin (1954); Oak Ridge Natl. Lab. (1954-59); Midwestern Univ. Research Assoc. (1959-64); MSU (1964). Research interests: compound nucleus, elastic scattering, β-ray polarization, (p,n) reactions, neutron scattering, nitrogen fixation.

Morton M. Gordon* — Ph.D., Washington Univ. (1950); Univ. of Florida (1950-59); MSU (1959). Visitor and consultant, Oak Ridge Natl. Lab. (1953, 1956, 1957-58), Naval Research Lab. (1964), Univ. of Maryland (1966), Indiana Univ. (1967, 72-73), Univ. of British Columbia (1971). Research interests: theory and design of isochronous cyclotrons, particle orbits in magnetic fields.

Charles R. Gruhn — Ph.D., Univ. of Washington (1961); MIT (1961-64); MSU (1964). Visitor, CERN and Univ. of Munich (1970-74). Research interests: inelastic scattering detection of high-energy particles, high-energy physics.

Edwin Kashy* — Ph.D. Rice University (1959); MIT (1959-62); Princeton Univ. (1961-64); MSU (1964), NSF Postdoctoral Fellow (1959-61), Guggenheim Fellow (1970); Visitor, Niels Bohr Inst., Copenhagen (1970-71). Research interests: direct transfer reactions, nuclear mass measurements, isospin multiplets.

William H. Kelly — Ph.D., Univ. of Michigan (1955), MSU (1955). Visitor, Naval Research Lab. (1965); Visitor, Oak Ridge Natl. Lab. (1964), Visitor, Lawrence Rad. Lab. (1962, 1968).
Research interests: nuclear structure via in-beam and off-line gamma-ray spectroscopy and particle transfer reactions.

Wm. C. McHarris — Ph.D., Univ. of California, Berkeley (1965); MSU (1965). Sloan Research Fellow (1971-73), Visitor, Lawrence Rad. Lab., Berkeley, (1971-72).
Research interests: nuclear chemistry α-β-γ spectroscopy, nuclear lifetimes.

Hugh McManus — Ph.D., Univ. of Birmingham (1947); Atomic Energy of Canada (1951-60); MSU (1960). Guggenheim Fellow, Nordita (1963-64), Physics Advisory Comm. NSF (1965-68), Research Assoc. MIT (1957-58; 1970); Visiting Professor Pittsburgh, (1962) and McGill (1968); Visiting Professor and Fellow of New College, Oxford (1969).
Research interests: scattering theory, nuclear scattering at high and intermediate energies, simple aspects of nuclear structure.

J.A. Nolen, Jr. — Ph.D., Princeton Univ. (1965); Princeton Univ. (1965-66), Argonne Natl. Lab. (1966-68). Univ. of Maryland (1968-70); MSU (1970).
Research interests: direct one-, two-, and three-nucleon transfer, Coulomb energies.

B.H. Wildenthal* — Ph.D., Univ. of Kansas (1964); Rice Univ. (1964-66); Oak Ridge Natl. Lab. (1966-68); MSU (1969). AEC Postdoctoral Fellow (1966-68). Humbolt Stiftung Fellow-Univ. of Munich (1973).
Research interests: experimental direct transfer reactions, shell model calculations of nuclear energy level observables, level densities in nuclei.

APPENDIX B.--PUBLICATIONS

In this appendix we list the publications since January 1972 of senior personnel associated with this proposal. Abstracts of contributed or invited papers are not included.

Published papers:

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(p,n) Isobaric Analog Transitions in Targets of ^{27}Al, ^{51}V, and ^{90}Zr at 22, 30, and 40 MeV, R.K. Jolly, T.M. Amos, A. Galonsky, R. Hinrichs, and R. St. Onge, Phys. Rev. C5, 1903(1973).

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Applications of a New Field Trimming Program to the MSU Cyclotron, M.M. Gordon and D.A. Johnson, Cyclotrons-72, pp. 298-307 (Am. Inst. Phys., New York, 1972).

An Optimized Multi-particle Central Region for the Michigan State University Isochronous Cyclotron, L.L. Learn, H.G. Blosser, and M.M. Gordon, Cyclotrons-1972, pp. 291-297 (Am. Inst. Phys., New York, 1972).

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An Ultra-Thin-Window Gas Cell, Helmut Laumer, C.N. Davids, Sam M. Austin and Lolo M. Panggabean, Nucl. Instr. Meth.

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APPENDIX C

Recycling sewage biologically

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Recycling sewage biologically

A novel use of nature's resources may effectively reclaim secondary effluent

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people). These

land and water systems will be combined with a community recreation project to provide complete recycling of the waste water.

Lake system

Raw sewage will be drawn from a trunk line of the East Lansing (Mich.) sewer system and will be treated by a conventional activated sludge process at the MSU-constructed sewage treatment plant. The waste solids will be returned to the city sewer system; the liquid, secondary-treated effluent, will be piped to the first of three lakes (construction to begin in March) with total surface area of 30 acres.

These three lakes (the first of five that will eventually be built) will be connected by an underground pipe, and the water will flow from lake to lake (by gravity) over a 30-day period. During this movement, the waste water will be stripped of most of its nutritional and polluting characteristics and will eventually, with additional treatment, be used in a swimming pool.

Michigan, like many other parts of the country, has soil that is sandy, which allows water seepage from lakes and ponds into the ground. In the MSU lakes, precautions are being taken to prevent infiltration or water loss into the soil. Many soil sealants are available, but few are effective and most are expensive.

A technique borrowed from agriculture will initially be utilized. An asphalt or clay emulsion will be injected under the ground to seal capillaries, providing greater water-holding capacity.

Rooted aquatic plants will be grown in these 6 to 8-ft deep lakes to maximize the removal of phosphates and nitrates from the secondary effluent. These aquatic plants, which are not algae, are selected for their adaptability to the climate, their high demand for phosphates and nitrates, and their food value. For this, plants have been collected from as far north as the Hudson Bay and as far away as New Zealand. Suitable plants have a growing season