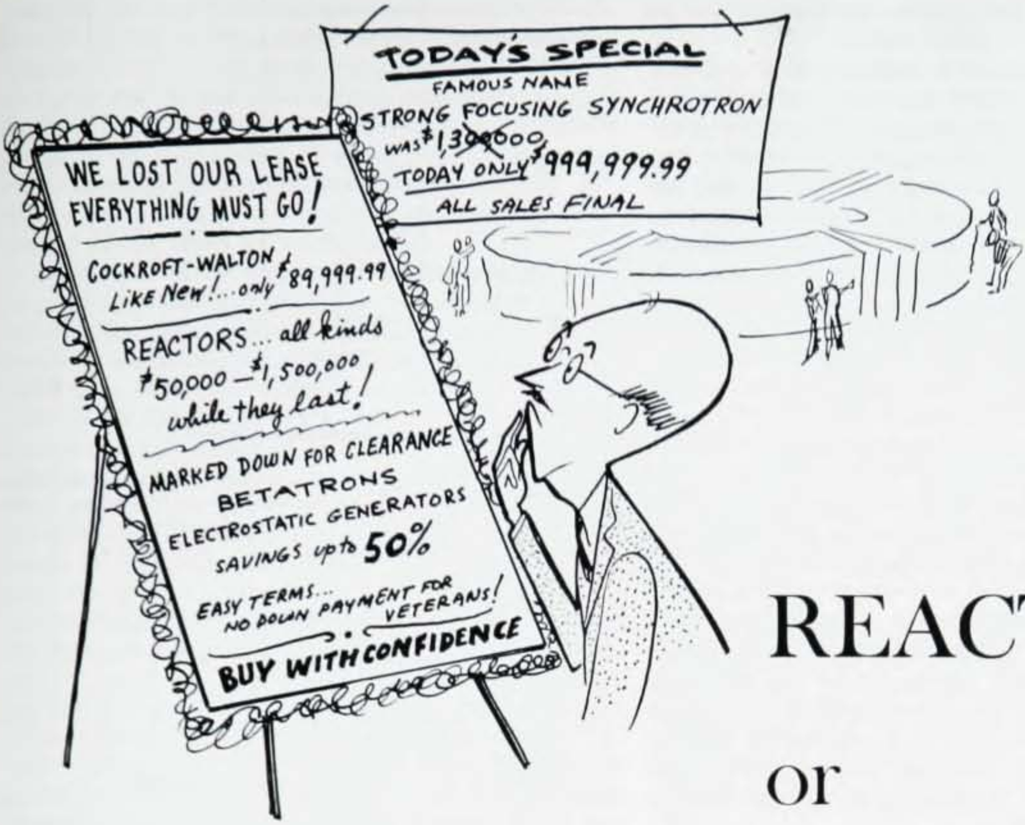

REACTORS or OTHER NUCLEAR MACHINES?

*By **Arthur H. Snell***

PLEASE consider with me, if you will, the problem presented by Professor Diddle. Professor Diddle is, of course, a fictitious person; he is chairman of the physics department of the equally fictitious East Yaphank University. East Yaphank U at present has no nuclear machines, but the physics department wants to start some experimental nuclear physics, and Professor Diddle has appeared asking for advice as to what kind of a machine they should acquire. There seems to be no preconceived determining factor in the choice; that is, there is no betatron man on the staff and nobody who particularly wants a cyclotron or reactor. The feeling in the department is neutral.

I asked Professor Diddle, "How about your biology department? Are they interested in some particular machine?"

He said, "Well, they are getting along fine so far as gamma rays are concerned by using a cobalt source, but they would like a source of neutrons. They are much concerned about the purity of their radiation source, and for this reason their inclination is toward a Cockcroft-Walton D-T generator or a cyclotron."

"And your chemistry department?" I asked.

"They get most of their isotopes from the AEC," he answered. "If we have a local radioisotope producer, it will be useful mainly for only short-lived materials, and here the choice of the radiochemists leans toward a cyclotron because with it they can make the positron emitters as well as the negatron emitters. The radiation chemists also use a cobalt source and, as a particle machine, they would prefer an electron accelerator."

"And what about your engineering faculty? Are they interested in training reactor engineers?"

"If they were," he replied, "I wouldn't be here with these questions because their choice would settle the matter and we would build a reactor." Then he added

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as an afterthought, "And besides, the students can go to Brookhaven to learn about reactors."

At this point, he sensed a definite stiffening in my attitude and realized that I was from Oak Ridge and that at Oak Ridge we pride ourselves particularly on our reactor training, so he added hastily, "Proximity, you know!" I let him get away with that one, but this was the start of increasing personal difficulties between us.

"There is really no environmental factor determining our choice of machine," Professor Diddle continued, "and we think the choice has to be made on the basis of what can be done in the physics department with nuclear machines of the various kinds."

"How much money do you have to spend?" was my next question.

"What does it matter?" he asked.

"Look," I replied crushingly, "a $20 wheel barrow is a much more functional object than a $20 pick-up truck, but if you go to the $2000 range, then things are different—the same applies to nuclear machines."

SO Doctor Diddle went back to the president of East Yaphank U for further details as to how much money he could count on spending. The president would not let himself be pinned down. It seems that negotiations just then were in a particularly delicate stage . . . Finally the president said, "Prepare your plans for anything in the price range from $50 000 up to $1 500 000."

When Doctor Diddle reported this to me he added, "But, you know, I have an idea about this cyclotron thing. One of our trustees of the University is on the Board of Directors of the Bethlehem Steel Corporation and maybe we can . . ."

I interrupted him—"There are two ways of financing these things. Either you can do it on a commercial cost basis or you can do it on a scrounge basis. On the commercial cost basis you will certainly pay a lot more money for nuclear machines than you would on the scrounge basis if you can use graduate students for design labor and use whatever help you can get in the obtaining of materials, but the scrounge basis is extremely variable and an uncertain thing to count on, so, in any comparison, let's take the commercial values—off the shelf wrapped in cellophane and usually fixed with a breath-taking price tag."

We agreed that there is no point in cutting things too fine cost-wise, so we divided the president's price range into four broad bands. We further agreed that the various nuclear machines can be compared only on very general grounds, deciding finally on four bases of comparison. In the first place, we would consider the versatility of the machine as a nuclear research tool. Secondly, we would consider the mechanical reliability, because nobody likes to spend much of his research time fighting the machine. Thirdly, we would ask if certain machines have pedagogical advantages over others, that is, whether one machine more than another would introduce, or, shall we say, *force* graduate students into a greater variety of experimental techniques.

NUCLEAR MACHINES: $50,000-$100,000 PRICE RANGE

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORM DEPENDAB RATIN
TRANSFORMER-RECTIFIER "COCKCROFT-WALTON"	SEVERAL ma AT 600 Kev	NO	A	A	B
ELECTROSTATIC GENERATOR	1.5 TO 2 mv ELECTRONS OR + IONS	NO	A	A	B
CYCLOTRON	18-in. 3 Mev H^+ OR D^+	NO	B	A	B
BETATRON	25 Mev	NO	C	B	B+
LINEAR ACCELERATOR	12 Mev ELECTRONS	NO	C	B	B
REACTOR	1 kw CONTINUOUS 10 kw FLASH 10^{10}-10^{11} SLOW FLUX	YES	C	B	A

Table 1

NUCLEAR MACHINES: $100,000-$300,000 PRICE RANGE

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE RATING
ELECTROSTATIC GENERATOR	3 mv POSITIVE IONS	NO	A	A	B
CYCLOTRON	6 Mev H^+ OR D^+	MARGINAL	A	A	B
BETATRON OR SYNCHROTRON	75 Mev ELECTRONS	YES	B	B+	B
REACTOR	10^{12} SLOW FLUX (Swimming Pool)	YES	B	B	A
LINEAR ACCELERATOR	INSUFFICIENT EXPERIENCE				

Table 2

NUCLEAR MACHINES: $300,000 – $750,000 PRICE RANGE

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE RATING
ELECTROSTATIC GENERATOR	5-6 mv	VERT: YES HOR: MARGINAL	A	A	B
CYCLOTRON	40-in. 10 Mev D^+ 15 Mev H^+	PREFERABLE	B	A	B
SYNCHROTRON	200 Mev ELECTRONS	YES	B	B	B
REACTOR	10^{12} SLOW FLUX (water boiler)	YES	B+	B	A
LINEAR ACCELERATOR	INSUFFICIENT EXPERIENCE				

Table 3

NUCLEAR MACHINES: $750,000-$1,500,000 PRICE RANGE

MACHINE	"RATING"	SPECIAL BUILDING?	VERSATILITY RATING	PEDAGOGICAL RATING	PERFORMANCE RATING
ELECTROSTATIC GENERATOR	9 mv	YES	A	A	B
CYCLOTRON	60-in. 20 Mev H^+ OR D^+	YES	A	A	B
SYNCHROTRON	350 Mev ELECTRONS	YES	B	B	B
REACTOR	10^{13} SLOW FLUX LITR OR NAA DESIGN	YES	A	B	A
LINEAR ACCELERATOR	INSUFFICIENT EXPERIENCE				
STRONG-FOCUSING ELECTRON OR PROTON SYNCHROTRON	INSUFFICIENT EXPERIENCE				

Table 4

Fourthly, we would rate the machines according to the number of simultaneous experiments which they could support. Then we did some enquiring and looking up of costs, and Mister Diddle drew up Tables 1 to 4. In doing so you will note that he omitted a comparison according to the number of simultaneously supported experiments. I reprimanded him severely for this, but, as it is, we will have to weave this aspect into the discussion of the tables as we go along.

Table 1 shows the approximate situation in the price range below about \$100 000. It is interesting to note in the first line that the classical nuclear machine still remains a useful and versatile object. Not only can it be used to clear up remaining details of nuclear reactions in the lightest elements, but also it can serve as a very powerful source of D-D or D-T neutrons. Furthermore, it can be used in the investigation of stopping powers and charge exchange cross sections for charged ions as they penetrate matter—currently an active field. Pedagogically it rates high because the student comes into contact with vacuum techniques, ion source design, ion focusing and deflection, penetration through thin windows, and the stopping powers of various thick and thin targets. The same considerations apply to the small electrostatic generator, the difference being merely that one trades intensity of current for extra voltage. The betatron is the commercial article which has been available in this country, and the linear accelerator is the English Mullard machine which can accelerate powerful pulses of electrons to the indicated energy, and can thereby be made to supply short pulses of photoneutrons. The reactor in this price range would probably be an uncooled affair which could supply some neutron activations of moderate intensity and support a rather limited amount of slow neutron physics. Any of the electrical machines could be placed in a vacant corner room in the main physics building at East Yaphank, but neither Mister Diddle nor I felt comfortable about placing the reactor in a classroom building because of the possibility of a blunder which would let the reactor run away. There is not much to choose between the machines of Table 1 with regard to the number of simultaneously supportable experiments.

In Table 2 we go to the next higher priced range and the machines become more powerful. In accordance with practice in this country, the electrostatic generator has displaced the Cockcroft-Walton machine, although it might have been wise to keep the Phillips transformer-rectifier set in the picture. The reactor is still rated below the positive ion accelerators because of its limitation to neutron physics. It will, however, be a highly reliable machine, and perhaps can support more than one experiment at a time. Shielding requirements begin to demand that these machines be placed in special buildings.

In the \$500 000 price range, Table 3, the electrostatic generator retains the high ratings for versatility and pedagogy for the reasons indicated in the discussion of Table 1. The cyclotron is given a slightly lower versatility rating because experience has shown that the electrostatic generators have given a greater wealth of accurate and detailed nuclear information than have cyclotrons. Both Diddle and I could point to brilliant exceptions to this, but we agreed that it was generally true. The cyclotron, however, might have been uprated slightly because at this size it becomes an important and unique source of the positron-emitting radioactive isotopes. The reactor is, of course, still limited to neutron physics, but in this range it can be expected to stand in a shield of its own with several beam holes, and can support a number of simultaneous experiments. Electron accelerators are limited to photonuclear reactions, and as such have been given a lower versatility rating throughout.

In the last table we come to the highest price range, and here we have guessed at 9 million volts for the electrostatic generator because the most advanced machines of this kind are nearing that energy. The postwar cyclotrons that were on the market were priced in the neighborhood of \$1 000 000 for a 60-inch job. The linear accelerator situation is pretty unclear. The several in this country that are under construction or in operation have involved rather serious development costs, and at the same time they have not yet proved themselves research-wise to the extent of the other machines. The strong-focusing machines are, of course, even less well known. I had some argument with Diddle about the versatility rating of the reactor in the 10^{13} slow-flux range. Diddle was plugging for a high rating and I still favored the charged-particle accelerators.

"Coulomb excitation!" I screamed, "Accelerate fancy ions!"

"Look here, bud," he said (you see, we had achieved pretty familiar terms with one another since our little tiff about the omission of data from the tables), "when I get up into the 10^{13} flux range with my reactor, I can set up spectrometers and get into the neutron diffraction business, which means a unique approach to solid state physics and to magnetic structure. I am no longer afraid of being in the shadow of the bigger reactors at the national laboratories. Does this not counterbalance the charged-particle business that you have been harping on so much in arguing for the positive-ion machine?"

I had to admit that it did. On these grounds we rated the reactor as equally versatile to the charged-particle accelerators. It is still a more reliable machine and can definitely support many more experiments at one time.

IN summarizing our conclusions, I would say that if one is considering a reactor for physical research, it pays very much to go to the high-flux range. If one cannot afford this kind of a tool, then some of the well-known positive-ion accelerators become very strong competitors. On the other hand, the high-flux reactor can support a number of people for their lifetime in research in induced radioactivity, solid state physics (mainly through neutron diffraction), and in neutron physics. In these conclusions, I may say that August * and I were in complete agreement.

* That was his first name.