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Energy and Technology Review

Lawrence Livermore Laboratory

June 1977

MASTER

RESEARCH REACTOR

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THE COVER

This view from the top of the Livermore Pool-Type Reactor (LPTR) shows the operating core under 6.1 m of water. The blue glow around the core is Cerenkov radiation caused by high-energy beta rays. The core itself is a rectangular array of fuel rods held in a frame at a specified spacing. The dark trapezoidal shapes in the glow coming from the near and far sides are the nose pieces of the two graphite-filled columns for experiments with thermalized neutrons. Various water-filled curved pipes at different angles make it possible to expose experiments at known locations in and around the core and remove them without disturbing the shielding. The horizontal tubes are empty; they provide beams of neutrons for experiments outside the main shielding. The pair of tubes coming down from the top of the tank and ending in the upper left corner of the core array is one of several pneumatic "rabbit" systems for rapid insertion and removal of samples. The slim tubes ending near the center of the array hold up the control rods, cylinders filled with neutron-absorbing boron that are raised to start the reactor and lowered to stop it. The low reading on the hand-held radiation meter in the foreground indicates the effectiveness of the shielding. For further information on the LPTR, see the article beginning on p. 1.

ABOUT THE JOURNAL

The Lawrence Livermore Laboratory is operated by the University of California for the United States Energy Research and Development Administration. The Laboratory is one of two nuclear weapons design laboratories in the United States. Today nearly half of our effort is devoted to programs in magnetic and laser fusion energy, biomedical and environmental research, applied energy technology, and other research activities.

The *Energy and Technology Review* is published monthly to report on accomplishments in this energy and environmental research and on unclassified portions of the weapons program. A companion journal, the *Research Monthly*, reports on weapons research and other classified programs. Selected titles from past issues of the *Energy and Technology Review* are listed opposite the inside back cover.

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Energy and Technology Review

Lawrence Livermore Laboratory

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BRIEFS

PREDICTING FISSION CROSS SECTIONS

Reliable neutron-induced fission cross sections $\sigma(n,f)$ are essential in several important fields, both theoretical and practical. Breeder reactors, for example, will make large quantities of fissionable thorium or plutonium isotopes, but the rates at which they can do this depend in part on the fission cross sections of all the intermediate isotopes, and many of these cross sections are known poorly or not at all. Also, one way of disposing of the high-level actinide waste from power reactors might be to "burn" them in a reactor—convert them to short-

lived fission products—but the effectiveness of such a method would depend on these same, largely unknown, cross sections.

Recent studies at LLL suggest a relatively simple relationship between cross sections of different isotopes—of elements from thorium through californium—for neutron energies in the range 3–5 MeV, where the energy dependence is weak. Figure 1 shows the measured cross sections, relative to the cross section for uranium-235, as a function of the atomic mass, A , the proton number, Z , and the neutron number, N . The curves are based on measurements conducted at LLL (open circles) and elsewhere (closed circles). Symbols without error

Fig. 1. Systematic correlations among the high-energy neutron-induced fission cross sections of isotopes of the transactinide elements. All cross sections have been normalized by $\sigma_0(n,f)$, the cross section for uranium-235.

bars indicate measurements whose uncertainties are too small to register on this scale.

Attempts to find systematic relationships among the fission cross sections, and to use them to predict unknown cross sections, go back more than twenty years. The relationship we have found appears to correlate virtually all the data available on this group of elements. The close correlations we have found, and the ranges in mass, energy, and proton and neutron numbers over which they appear to operate, suggest, moreover, that we may be able to formulate a unifying theory of the fission process in this regime.

Contact J. W. Behrens (Ext. 8621) for further information on this subject.

IMPROVED FILTER PERFORMANCE FROM A SUPERIMPOSED ELECTRIC FIELD

High-efficiency particulate air (HEPA) filters are used at radioactive handling facilities to remove airborne contaminants. The annual usage rate, currently over 20 000 filters per year, is increasing, and the cost of the filters plus the cost of testing and replacement is considerable.

LLL has studied techniques to prolong the life of these fibrous filters and to increase their efficiency in removing suspended particles. In the past an increase in filter efficiency resulted in greater flow impedance. Recently, however, both theoretical calculations and experimental data have shown that an externally applied electric field can improve the performance of fibrous filters—increasing their filtering efficiency without increasing flow impedance.

In typical experiments using sodium chloride aerosols with average droplet sizes of about $0.8\text{ }\mu\text{m}$, filtering efficiency improved by more than a factor of five when the filter was suspended in an electric field of 10 kV/cm . At the radioactive materials handling facilities, actual aerosol diameters may be as great as $16\text{ }\mu\text{m}$. Since our test aerosols averaged smaller diameters in most cases, the improvement in filtering efficiency under field conditions may be even better.

The enhanced filtration due to the electric field can transform a filter of low efficiency and low flow resistance to the hypothetical ideal filter charac-

terized by high efficiency and low flow resistance. This transformation is accomplished with negligible power consumption since the electric field is maintained below the corona discharge level.

We are conducting theoretical and experimental investigations to isolate the electric field mechanism that enhances filtration. The results will be used to develop a prefilter for prolonging the life of HEPA filters currently used in nuclear facilities.

Contact W. Bergman (Ext. 3920) for further information on this subject.

NEW DIGITAL CURSOR SYSTEM FOR TELEVISION DISPLAY OF COMPUTER DATA

A continuing problem for users interacting with computer-generated data on a television screen is the difficulty of easily and accurately pinpointing a specific piece of displayed data. A movable cursor—a small pattern such as an arrow or circle—can be generated on the screen to point out a feature or encircle an area. But present cursor systems have several shortcomings:

- Systems with analog controls are not always accurate.
- Most systems have only a single cursor pattern which restricts cursor usefulness. For example, in an extremely complicated display, such as a hydrocode mesh, the cursor may be difficult to pick out visually. Or the cursor may be unsuited for a given task. A circle, for example, can't clearly indicate a point on the edge of the television screen.
- Most systems are limited to a single type of operator control to position the cursor pattern.

We have greatly alleviated these problems by developing an all-digital cursor system with eight selectable cursor patterns plus a full-screen crosshair. The patterns include a dot and various types of crosses, circles, and pointers. They can be set to blink or remain steady, and they can be white on a dark screen or dark on a predominantly white area of the screen.

The new system is run by a microprocessor and has an accuracy of ± 1 line (vertical) and ± 1 space (horizontal) over the full 512- by 512-element grid of the television display. For convenience, a hand-held modified calculator case houses the operator controls. With these controls (Fig. 2) the cursor is

Fig. 2. Cursor pointing out a salient feature on the television display. Controls are housed in the modified calculator case at right.

easily positioned on the screen. Also, by pressing *one* of the function keys, we can automatically encode the x-y coordinates of the cursor position and record them in the computer for easy future retrieval. The system's versatility has been enhanced by permitting additional standard x-y coordinate input devices—such as a tracking ball or graph table—to be used.

Contact Henry H. Bell, Jr. (Ext. 8153) for further formation on this subject.

NATIONAL SECURITY

The Livermore Pool-Type Reactor

The Livermore Pool-Type Reactor (LPTR) has served a dual purpose since 1958—as an instrument for fundamental research and as a tool for measurement and calibration. Our early efforts centered on neutron diffraction, fission, and capture gamma-ray studies. During the 1960's we performed extensive calibration work associated with radiochemical and physical measurements on nuclear-explosive tests. Since 1970 the principal applications have been for trace-element measurements and radiation-damage studies. Today's research program is dominated by radiochemical studies of the shorter-lived fission products and by research on the mechanisms of radiation damage. Trace-element measurement for the National Uranium Resource Evaluation (NURE) program is the major measurement application today.

The LPTR is a pool-type research reactor cooled and moderated with light water, H_2O . Radiation shielding is provided by the tank water and by 1.83 m of heavy concrete. The fuel elements are enriched

to 93% uranium-235. To dissipate the power we circulate the tank water through a heat exchanger cooled by water from a forced-draft cooling tower. Figure 1 shows the reactor when it was new, before it was surrounded by experimental equipment.

The LPTR was first put into operation late in 1957 and has operated more or less continuously ever since. It was originally designed to operate at 1 MW but with shielding adequate for five times that power. It has since been upgraded twice and now operates at 3 MW.

The LPTR exists to make neutrons, and it has a wide variety of neutron-irradiation facilities. The phantom view in Fig. 2 shows many of these facilities and illustrates the geometry of the core and shielding. Six tubes radiate horizontally out through the tank wall and concrete shield to provide collimated beams of neutrons.

In addition, a 102-mm-diam (4-in.-diam) "through tube" passes through the entire shielding structure and near the core. This makes it easy to observe prompt gamma rays from a sample; we locate an instrument such as a bent-crystal spectrometer at one end and bring in samples from the other.

Contact Lloyd G. Mann (Ext. 7321) for further information on this article.

Fig. 1. The Livermore Pool-Type Reactor (LPTR) when it was new (1958), before it was surrounded with experimental equipment. The extension of the shielding to the left, behind the stairs, houses experiments connected with the east thermal column. The west thermal column is behind the movable shielding wall on the right. The square opening beside the control box is the port for one of the neutron beam tubes. The cylindrical object between the two men on the floor is one plug for the horizontal through tube. The long, T-handled rods leaning against the upper rail (right) are tools for inserting and removing fuel elements in the reactor.

FIG-2. A schematic of the reactor showing the core; the east and west thermal columns; the curved, water-filled tubes for activation experiments; the horizontal neutron beam tubes; and the ship pneumatic "rabbit" tubes. The tank is shielded with heavy concrete all around except on the top, where 6.1 m of water provides the shielding.

Fig. 3. Plan view of the reactor core and irradiation facilities in the east and west thermal columns. The fast-neutron irradiation facility (FNIF) in the east thermal column provides a fission spectrum of neutrons from two plates of uranium-235. The neutron radiography facility provides highly collimated neutrons for imaging experiments. The deuterium oxide tube in the west column provides a long passage where the neutron flux and degree of thermalization as a function of position is well known, and in which experiments may be positioned, manipulated, and removed without the necessity of shutting down the reactor.

Two large graphite moderators, the east and west thermal columns, provide environments of well-thermalized neutrons into which we can insert experimental assemblies. There is also a boron-shielded cavity in the east thermal column (labeled FNIF—fast-neutron irradiation facility—in Fig. 3), where two thin slabs of uranium-235 exposed to the thermal neutron flux generate the fast-neutron spectrum characteristic of uranium fission.

Another feature of the east thermal column is its facility for high-quality neutron radiography. The neutron beam has a diameter of 51 cm at the object

plane. Its collimation is 0.4 mrad. In the familiar x radiography, materials made of light elements (flesh, wood, plastics, rubber) are transparent; only heavy elements cast a strong shadow. Neutron radiography, on the other hand, is sensitive to a different set of elements, including most of the light ones. Potential applications of neutron radiography include inspecting explosive subassemblies enclosed in metal cases and checking for gasket damage inside a metal valve (Fig. 4).

The west thermal column contains a 51-mm tube filled with heavy water. Inside this tube the flux of

neutrons is high, and the neutron energy distribution is predictable. Experiments may be moved along this tube to their optimum position and may be inserted and removed without shutting down the reactor.

Yet another set of irradiation facilities consists of four water-filled tubes that curve down into the neighborhood of the core from the mezzanine of the reactor shield (Fig. 2). These tubes provide access to radiation fluxes of about 5×10^{12} neutrons per square centimetre per second while the reactor is at power.

In all of the above irradiation facilities the samples or experimental equipment must be inserted and removed by hand. This presents few problems when the irradiation lasts for hours or days, but it can be difficult when irradiations of a few seconds are involved. For such irradiations we need a fast mechanical insertion system.

This need is filled with "rabbit" tubes, pneumatic delivery systems that can place a small capsule in

the core and retrieve it within seconds. The LPTR was designed with three rabbit systems: one large and slow (10-second retrieval) and two small and fast (2- to 3-second retrieval). All three place their capsules in corners of the core array where the thermal flux is about 2×10^{13} neutrons per square centimetre per second.

The highest neutron flux, 7×10^{13} neutrons per square centimetre per second, occurs in the center of the core. This position in the array is left vacant to provide space for measurements and irradiations. To place samples in this spot we lower them through the pool from the top of the tank.

NURE PROGRAM

Our newest irradiation facility is the special fast-rabbit system for the NURE program,¹ where we will be using the LPTR as a sophisticated trace-element analyzer to look for uranium. Stream sediment samples collected from numerous locations in

Fig. 4. X-ray and neutron radiographs of the same valve. In general, light areas on the x-ray plate (left) indicate the presence of heavy elements. On the neutron plate (right), light areas indicate the presence of neutron scatterers, mostly light elements such as hydrogen and carbon. The flat rubber gasket is invisible in the x-ray picture; it shows up clearly in the neutron picture, with all its cracks. The differences between the two views is also strikingly evident in the chevron seal on the central shaft, where the x rays show up the brass parts and the neutrons show the rubber seals.

seven western states will be activated by brief exposure to neutrons and then checked for induced radioactivity. We had to build a whole new system for this purpose, however, to be sure that any uranium detected is really in the sample and not just contamination left behind by some previous experiment.

Neutron activation analysis is not new; we adopted it in 1970 for detecting trace elements—such as airborne lead, bromine, and vanadium—in the environment. We are still performing such analyses, documenting the environmental impact of nuclear and fossil fuel plants and mining and smelting operations, and measuring trace elements transmitted through the dairy food chain and the marine environment. The NURE program is simply an extension of this effort, on a very large scale. Previous programs produced a trickle of samples, a few hundred a year; the NURE program is tooling up to handle 40 000 to 50 000.

Because of the large numbers, sample handling for the NURE program is completely automated. Each sample capsule receives an individual, machine-readable identifying number. Automatic machines sort the capsules, fire them one by one into the reactor, and retrieve them after 30 seconds. They are then shunted into a delayed-neutron counting station, then into a holding station where the more unstable nuclides decay away, next into a gamma-ray spectrometer to measure the energies of the remaining emissions, and finally into a storage bin. A week later, when only the longer-lived nuclides remain, we return the samples to the gamma spectrometers for yet another count, and then package them for long-term storage. Even here the samples can still be retrieved for further automated counting if desired.

The computer that runs the automatic system also performs data analysis on the information gathered by the counters. It examines the delayed-neutron counting record and the early and late gamma spectra for each specimen, and it deduces which of about 35 elements are present and in what

concentrations. It records this information in a data file separate from the file containing the geographical information on each sample. Only when we are ready to make a report will the two files be merged to produce maps of mineral concentrations. This is to prevent any premature leakage of information that might give someone an unfair advantage in the search for uranium resources.

RADIATION-DAMAGE RESEARCH

The NURE program, large though it is, is not the only program at the LPTR. We are simultaneously providing neutrons for research on radiation damage and on nuclear chemistry. Most of our work on radiation damage is motivated by the need to predict what will happen to materials in the fusion power reactors we expect some day to build.

In normal operation, the inner walls of a fusion reactor are expected to sustain during its operating lifetime a total neutron fluence of 10^{21} to 10^{23} neutrons/cm², together with proton, deuteron, electron, and gamma-ray irradiation. We anticipate severe radiation damage because of the high dosage and the extremely high average kinetic energy of the fusion-produced neutrons.

Unfortunately, there is not yet a reliable way to reproduce accurately either the flux or the neutron energy distribution of a fusion reactor. We must therefore fall back on simulation experiments and fundamental theoretical understanding to predict material behavior under such conditions. The LPTR provides reference neutron spectra; we predict as best we can what will happen in the LPTR and adjust our theories in light of the differences between prediction and experimental measurement.

There is one way to achieve the actual damage levels anticipated for fusion-reactor materials with thermal neutrons: we irradiate alloys containing small amounts of uranium-235. The thermal neutrons do no damage, they only trigger it. The recoiling fission fragments from the uranium do all the work.

The difficulty then is in correlating this fission-fragment damage with what would occur with 14-MeV neutrons from fusion. Experiments that compare the effects of bombardment with fission fragments, unmoderated fission neutrons from our FNIF (Fig. 5), and 14-MeV neutrons from our rotating-target neutron source (RTNS-1) are beginning to provide this correlation.

Recently, we collaborated in an important international experiment dealing with the fundamental parameters of radiation damage. Researchers at the Danish University of Aarhus measured displacement cross sections for light and heavy ions impinging upon dilute alloys of niobium, vanadium, and molybdenum. Using the same materials, researchers at Oak Ridge National Laboratory measured the cross section for displacements caused by unmoderated fission neutrons. Still other workers at the German Institute for Solid State Physics simultaneously measured cross sections for electron-induced displacements. Here at LLL we measure similar cross sections with slightly moderated neutrons from the LPTR and with 14-

MeV neutrons from the rotating-target neutron source. We also conducted similar measurements at the Crocker Cyclotron in Davis with neutrons of varying energy produced by deuterium-beryllium reactions.

These are extremely difficult and precise experiments in which the materials being bombarded must be kept at the temperature of liquid helium, 4.2 K. We measured the extent of damage as a function of neutron fluence by continually monitoring the electrical resistances of the samples.

FISSION-PRODUCTS STUDIES

Over the years the LPTR has also been an important source of radionuclides for studying nuclear radiations and energy levels.^{2,3} We still provide this service, but our emphasis has shifted toward the more unstable nuclides, those whose half-lives are so short that their study requires rapid handling and on-line instrumentation. This work will contribute basic knowledge about these little-known and hard-to-study nuclides. The main objective of this study,

Fig 5 A transmission electron micrograph (magnification, 150,000 $\times$) showing radiation damage in bulk copper bombarded with fast neutrons, 10^{18} neutrons cm^{-2} , energy ~ 100 keV. An undamaged specimen would produce a uniform gray picture. Each black and white dot is the image of a structural defect resulting when a neutron knocks a copper atom out of its place in the crystal lattice. The net effect of these defects is to make the copper harder and more brittle.

however, is to get data that are important to reactor safety calculations.

An important concern in power-reactor safety is the hypothetical loss-of-coolant accident, that is, what happens if the pumps stop or if a pipe breaks and spills the cooling water. In such a case, automatic relays would instantly drop the control rods back into the core, stopping the nuclear reaction. This would prevent the reactor from making any more radioactive nuclides, but it would have no effect on those already present. And hence the concern.

A lot of energy is tied up in those radioactive nuclides in a power reactor, and this energy will convert to heat at the decay rates of the radionuclides. The problem, then, is to dissipate that heat, to keep it from melting down the reactor core and possibly releasing radioactivity to the air. To plan effectively how best to prevent the heat buildup, we must know how much heat would be released and at what rate. And this rate would be dominated, in the early stages of a coolant loss, by the little-known nuclides we have been studying.

The study of short-lived radionuclides calls for some unusual techniques. The first essential is a fast transport system, such as a pneumatic rabbit, to place samples and retrieve them before the nuclides have decayed. Just as vital is a fast chemistry apparatus to single out the nuclide of special interest from among the swarm of others present. A uranium sample, after irradiation, contains scores of different radionuclides, each emitting its own characteristic radiation. In principle it might be possible to tune in one radiation and ignore the others. In practice, radiation detectors are nowhere near selective enough to do this. Instead we must separate the nuclides chemically.

Our fast irradiation facility has achieved a total time from irradiation to counting of separated samples of only 15 seconds, all but 2 to 3 seconds of which is separation time. We are developing a liquid-liquid separation technique that should provide separations in as little as 1 to 2 seconds.

The LPTR has come a long way in the nearly 20

years it has been in operation. It has contributed vital calibration and analytical techniques to the weapons program and has been the scene of much fundamental research. Its operating power level has increased from 1 to 3 MW, with the option of increasing still further to 5 MW. Its programs contain a healthy element of research while primarily addressing our national energy goals in enhancing reactor safety, developing thermonuclear power, and discovering nuclear fuel resources.

Key Words: Livermore Pool-Type Reactor; LPTR; materials—effects of radiation; National Uranium Resource Evaluation; NURE; nuclear chemistry; reactor safety; thermonuclear reactor.

NOTES AND REFERENCES

1. The NURE program has been the subject of several articles in *Energy and Technology Review*, most recently in the May 1977 issue (UCRL-52000-77-5), p. 23.
2. L. G. Mann, W. B. Walters, and R. A. Meyer, *Phys. Rev. C14*, 1141 (1976).
3. R. A. Meyer, J. H. Landrum, S. V. Jackson, W. H. Zoller, and W. B. Walters, *Phys. Rev. C13*, 1617 (1976).

CONSERVATION

Car for Tomorrow: A Quasi-Electric-Drive Vehicle

Highway vehicles account for 75% of the national energy need in transportation, consuming over one-sixth of the yearly energy demand. Almost all of our highway vehicles are powered by internal combustion engines that use petroleum, a commodity expected soon to be in short supply. Because of this, alternative vehicle propulsion methods are actively under development. This article presents a survey of some alternative concepts that was conducted by our Energy and Resources Planning Group.

One promising choice is the electric vehicle. Powered by batteries or a battery-flywheel combination, electric vehicles draw their energy from the nation's electric power network. Since the network's power can be generated by plants other than petroleum-burning plants, widespread use of electric vehicles could reduce transportation's use of petroleum. Electric vehicles cannot now match the range of conventional cars, although they can compete in performance and fuel cost. This range limitation should cease to exist by the early 1990's. Until then, one way to reduce petroleum use is to build elec-

tric vehicles with a small internal-combustion-engine adjunct—a transition vehicle. This car would be powered by battery most of the time and by the combustion engine when an extended range is required.

Electric vehicles have existed since before the turn of the century. In the early days of the automobile they competed favorably with internal-combustion-engine vehicles. In fact, in 1915 about four times as many electric vehicles were sold in this country as gasoline-powered cars. After 1915 electric-vehicle sales declined and sales of gasoline-powered vehicles steadily rose.

In recent years electric vehicles have come back into focus as a potential solution to transportation's heavy use of dwindling petroleum reserves. Research and development in battery technology has accelerated, and electric hybrid concepts have been investigated. One such concept, the modern battery-flywheel vehicle, can achieve acceptable performance, that is, sufficient acceleration and pulling power to satisfy today's driver. Because of the present state of battery technology, however,

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neither electric vehicles nor electric hybrids can match the range of existing internal-combustion-engine cars. And without sufficient range, a new type of vehicle would find it difficult to gain the market acceptance necessary to compete with established vehicle designs.

An internal-combustion-engine vehicle has virtually unlimited range because of its rapid refueling capability and ready access to refueling stations. Although today's lead acid batteries cannot provide a vehicle with such unlimited range, we expect that the lithium-air batteries now under development will be able to do so by the early 1990's.¹ The question, then, becomes one of what to do now to reduce the transportation demand on petroleum and to prepare for the likely conversion from internal-combustion-engine vehicles to electric vehicles in the early 1990's.

Our study shows that it is feasible to develop a quasi-electric-drive, a lead-acid-battery electric vehicle augmented by a combustion engine for use when ranges beyond 80 km are required. (As shown by the U.S. Motor Vehicle Manufacturers Association in 1975,² 75% of all vehicle kilometres traveled consist of trips of 80 km or less.) This would serve as a transition vehicle. As batteries improve, the combustion engine's contribution can be reduced; by the early 1990's, the combustion engine might be eliminated altogether.

ELECTRIC VEHICLES

To be effective in conserving our national petroleum resources, an alternative propulsion vehicle must be able to capture a significant share of the automobile market. And to compete successfully with an existing available product in a free marketplace, an innovative product must have an equal or greater appeal to the consumer. As pointed out in the 1976 report by the Federal Task Force on Motor Vehicle Goals beyond 1980,³ there are two characteristics of a car that most buyers instinctively look for and which also have an important effect upon energy consumption:

- Vehicle size: passenger and baggage volume.
- Vehicle performance: acceleration and pulling power (top speed and cruising speed are additional factors; most cars today easily surpass the posted limit).

The Task Force's study included only heat-engine systems, so long-range vehicles were expected. With the advent of alternative propulsion systems, however, most buyers will probably consider a third factor:

- Vehicle range.

Of the three criteria, range is the important one. Electric vehicles using flywheel power boosters can be built to successfully compete with internal-combustion-engine cars in size and performance.

To determine the present and future viability of the electric vehicle, it is necessary to compare it to the internal-combustion-engine car as it exists now and as it would in the future. We know what it is now, and we calculated what it will probably be throughout the years 1977-2000.

The future combustion-engine car, if it continues to hold a large share of the market, will probably have four-, five-, and six-passenger models. For our comparison standard we will consider here only the four-passenger car described in Ref. 3. The Task Force assumed a pattern of gradual change in projecting this car into the future, gradual change resulting from a conservative application of technology and of economic and marketing principles. Analyses showed the effect on various end-use characteristics (fuel economy, for example) resulting from various combinations of basic parameters such as acceleration performance, structural design and materials, engine design, type of transmission, safety and damage-sustaining criteria, and emissions criteria. The Task Force also studied a number of scenarios assuming various times and rates of introduction of new design concepts. (No single scenario was postulated as a unique pattern of events.) From the results of this investigation, a probable future four-passenger, internal-combustion-powered automobile is described in Table 1.

Table 1. Characteristics of future internal-combustion-engine vehicles.

	1980	1985-1987	1995-2000
Fuel economy, km/litre (mpg)	10-14 (24-32)	13-16 (30-38)	16-19+ (38-45+)
Power-to-weight ratio, kW/kg (hp/lb)	0.07 (0.04)	0.05 (0.03)	0.03 (0.02)
Acceleration performance, number of seconds, 0-97 km/h (0-60 mph)	12	15	20
Basic cruise speed, km/h (mph)	89 (55)	89 (55)	89 (55)
Maximum cruise speed, km/h (mph)	129 (80)	113 (70)	105 (65)
Curb weight, kg (lb)	1134 (2500)	907 (2000)	862 (1900)
GVW, ^a kg (lb)	1452 (3200)	1225 (2700)	1182 (2600)
Range	Limited between refuelings by size of gas tank and fuel economy. Assuming that some fuel is held in reserve, 320 km (200 mi) is fairly typical. Existing infrastructure (service station network) provides quick refueling at convenient stops, resulting in essentially unlimited range.		

^aGVW, the gross vehicle weight, is curb weight plus payload weight.

To compare a future electric vehicle with our probable future combustion-engine vehicle, we must first look at the batteries the electric vehicle will use (Table 2). These batteries range from current state-of-the-art to those in an early experimental stage of development; the years indicate the time frame in which the batteries could conceivably be available to the public as electric-vehicle batteries. In all cases involving intermediate- and long-term batteries, the uncertainty of technical or economic success should be kept in mind. However, it can be seen that the specific energy and specific power of batteries is expected to increase considerably.

We next calculated the type of performance that can be expected of an electric vehicle, using our four-passenger model car with some of the batteries

listed in Table 2 instead of an internal combustion engine. Specifications of the car itself include a gross vehicle weight of 1585 kg, a power-system-to-gross-vehicle-weight ratio (α) of 0.35, and an aerodynamic drag coefficient of 0.35.

The range of this electric vehicle was evaluated over a standard prescribed driving course representative of stop-and-go residential and metropolitan environments⁴ and at a constant speed of 88 km/h. From the results, shown in Table 3, we see that in the near term, no vehicle is projected to match the range of the internal-combustion-engine vehicle over the same profile. Even though adding a flywheel will improve range,⁵ it will not be sufficient to change the overall result in the near term and make electric vehicles competitive. (The value of flywheels in the future is expected to be appreciable

Table 2. Battery characteristics.

Battery	Specific energy, W.h/kg	Specific power, ^a W/kg	Peak specific power, W/kg	Energy efficiency, %	Cycle life (full charge to 75% discharge)
Near term (1977-1982)					
Pb/PbO ₂	24	24	70	65	400
Pb/PbO ₂ improved	30	30	70	65	600
Fe/NiOOH	30-50	17	80	55	1000
Zn/NiOOH	55	20	100	65	200
Intermediate term (1982-1990)					
Pb/PbO ₂ projected	40	40	140	65	800
Fe/NiOOH projected	60	20	100	60	1500
Zn/NiOOH projected	80	20	100	65	1000
Li-Al/FeS _x advanced	150	100	200	80	1000
Zn/Cl ₂ improved	110	110	150	80	350
Long term (beyond 1990)					
Li-Al/FeS _x projected	150	100	200	80	1000
Na/S projected	100-200	280	280	80	500-1000
Li/air advanced	350	100	200	35	N/A

Note: Inconsistencies abound in the literature concerning the projected performance characteristics of batteries. These values are our best estimates.

^aSpecific energy at listed specific power.

Table 3. Calculated range of electric vehicles, $\alpha = 0.35$.

	Prescribed driving course, residential and metropolitan, km (mi)	Constant speed of 88 km/h (55 mph), km (mi)
Near-term batteries		
Pb/PbO ₂	42 (26)	39 (24)
Pb/PbO ₂ improved	63 (39)	60 (37)
Zn/NiOOH	124 (77)	122 (76)
Intermediate-term batteries		
Pb/PbO ₂ projected	97 (60)	93 (58)
Zn/NiOOH advanced	177 (110)	172 (107)
Li-Al/FeS _x advanced	348 (216)	336 (209)
Long-term batteries		
Li-Al/FeS _x projected	348 (216)	336 (209)
Na/S	372 (231)	359 (223)
Li/air	800 (497)	794 (481)

but depends on the development of advanced flywheels.)

In the intermediate term, ranges exceeding 320 km appear possible. Provided that the technically and economically successful introduction of Li-Al/FeS₂ batteries is accomplished, the competitive position of the electric vehicle will improve. However, some doubt exists that these fused-salt batteries will be available before 1990.⁶

The long-term batteries, however, are expected to provide a sufficient range to make electric vehicles attractive to consumers. This will be particularly true of the lithium-air battery, which is rapidly rechargeable. In the meantime, we can take advantage of near- and intermediate-term batteries with a transition vehicle that can both gain market acceptance and reduce transportation's use of petroleum.

TRANSITION VEHICLE

This transition vehicle is a hybrid, but it uses a hybrid concept quite different from most of the hybrid concepts of the past.⁷ Historically, the hybrid was born of the necessity to improve the performance of internal-combustion-engine vehicles.⁸ Subsequently, hybrids have been proposed as a way to reduce emissions and improve fuel economy by allowing internal combustion engines to operate at optimum conditions. Until now, hybrids have not been designed to enhance electric-vehicle performance.

Electric vehicles will begin to compete as alternatives to the heat-engine vehicle by the late 1980's or early 1990's when batteries with sufficient specific energy become available. Until then electric vehicles are unlikely to be competitive. Flywheel-battery-powered electric vehicles can be competitive in performance now. Therefore, the drawback to electric vehicles at this stage is lack of sufficient range. Since this lack of range is caused by the low specific energy of the battery, the problem is to enhance this battery characteristic. How can this be done?

In the flywheel-battery-power system the effective specific energy of the battery power system is

improved because the flywheel acts as power booster and absorbs excess power, thus: load-leveling the battery at a low power demand. Since battery capacity is greatly reduced by high power demand, low-level power demands increase the battery's effective energy capacity and thus the vehicle range. The flywheel is substituted for batteries on a pound-for-pound basis so that the power system weight remains the same.

The power-system specific energy can be further improved by the addition of a small internal combustion engine and fuel tank for an equal weight of battery removed so that again the power system weight remains the same. This is the essence of the transition vehicle.

Although this system, shown in Fig. 1, is a hybrid system, it may be more properly thought of as an electric-drive system with a combustion-engine range enhancer. Its operating principle is simple. The vehicle will be operated on its electric drive as much as possible; the combustion engine will only be used to provide energy when the battery is discharged to a preset level.

To determine the performance of this transition vehicle, we modified (through calculation) the design of a 1585-kg electric vehicle. Keeping the power-system-to-gross-vehicle-weight ratio of $\alpha = 0.35$, we added a small flywheel system for an equal weight of battery removed, as described in Ref. 5. We also substituted a small internal combustion engine and fuel tank for an additional weight of batteries removed. Thus the gross vehicle weight and α remain the same as before.

The resultant vehicle is described in Table 4. We sized the combustion engine and fuel tank to provide sufficient additional power system energy at 88 km/h on a level road so that a range of 320 km could be achieved before refueling is required. We limited battery depth of discharge to 75% to prolong battery life. When this level of discharge is reached, the power control unit would be programmed to switch on the combustion engine. At this point the vehicle would operate as a hybrid with the engine system charging and discharging the storage devices as determined by road load requirements. This

Table 4. Transition vehicle characteristics.

GVW, kg (lb)	1585 (3486)
Power systems weight, kg (lb)	555 (1220)
Battery weight (Pb/PbO ₂), kg (lb)	386 (848)
Storage system components, kg (lb)	107 (235)
Heat-engine systems (engine, fuel tank, cooling system, exhaust system, etc.), kg (lb)	62 (137)
Power system weight to GVW ratio	0.35
Frontal area, m ² (ft ²)	1.86 (20)
Aerodynamic drag coefficient	0.35

0.07 litres/km (14 km/litre) and gas is 16 cents/litre. If we further assume that the transition vehicle will run on the battery 75% of the time and on the combustion engine 25% of the time, averaged fuel cost is 0.7 cents/km. In contrast, today's internal-combustion-engine car, averaging 7.3 km/litre (17 mpg), has a fuel cost of 2.2 cents/km.

To sum up, our transition vehicle can compete with today's internal-combustion-engine vehicle in terms of performance, range, and fuel cost. As batteries improve, the combustion-engine contribution can be reduced; finally, in the 1990's the vehicle can be all electric. The transition vehicle can be the basis of an evolutionary process useful in shifting from internal-combustion-engine vehicles to all-electric vehicles and promoting electric vehicle research and development. At the same time it can begin to reduce transportation's use of our diminishing supply of petroleum.

NOTES AND REFERENCES

1. L. G. O'Connell et al., *The Lithium-Water-Air Battery: A New Concept for Automotive Propulsion*, Lawrence Livermore Laboratory, Rept. UCRL-51811 (1975).
2. *1975 Automobile Facts & Figures* (Motor Vehicle Manufacturers Association of the United States, Inc., Detroit, Michigan, 1976).
3. *The Report by the Federal Task Force on Motor Vehicle Goals Beyond 1980*, Vol. I and Vol. II, for the Energy Resources Council (1976).
4. SAE J227 Urban Driving Cycle, *SAE Handbook*, 1972 edition, Society of Automotive Engineers.
5. D. D. Davis et al., *The Battery-Flywheel Hybrid Electric Power System for Near-Term Application*, Vol. I and Vol. II, Lawrence Livermore Laboratory, Rept. UCRL-17098 (1976); see also the June 1976 *Energy & Technology Review* (UCRL-52000-76-6), p. 16.
6. E. J. Cairns and Ming-Chih Yew, *Electric Vehicles Overview*, Proceedings of the Eleventh Intersociety Energy Conversion Engineering Conference, Stateline, Nevada, September 1976, p. 356.
7. For a more detailed account of the transition vehicle, see L. G. O'Connell, J. F. Cooper, A. B. Miller, and H. W. Newkirk, *A Systematic Approach to the Evolution of High Performance Electric Vehicles*, Lawrence Livermore Laboratory, Rept. UCRL-79155 (1977).
8. C. Rosen, *Overview of Hybrid Vehicles*, Proceedings of the Second International Electric Vehicle Council, New York, New York, 1971.

Key Words: electric cars; electric vehicles; energy storage; flywheels; transportation.

SOLAR ENERGY

Wind-Energy Assessment

As part of the federal wind energy program, we are working on the island of Oahu, Hawaii, to develop general methods of assessing wind energy that will be suitable for other mountainous regions of the U.S., including the Pacific Coast, Rocky Mountain, and New England areas. We have made computer simulations and meteorological measurements to study how wind energy varies in time and from place to place. Rough, mountainous country—like Oahu—can cause enormous local variations in wind energy. However, we have identified several subareas of high wind-energy potential and are focusing our work on one that appears especially suitable for wind-power development.

The wind, one of man's oldest energy sources, has been used for thousands of years to drive ships and

for hundreds of years to raise water and thresh grain. Today we are looking at the wind as a potential large-scale energy producer.

Estimates of the available wind energy for modern uses vary significantly, but even the lowest represents a substantial potential. About 3% of the U.S. land surface, where the winds are highest, is suitable for wind-power development. Even considering the inefficiencies of energy conversion and other limiting factors, these winds could provide about 2.5 TW, roughly equal to the 1972 mean rate of energy use in the U.S. from all sources.

Present plans for capturing large amounts of wind energy focus on the use of wind turbines to generate electricity. Two examples of designs for large-scale wind-power collection are the horizontal-axis machine being developed by NASA and the vertical-axis machine being developed by Sandia Laboratories, both sponsored by ERDA.

Horizontal-axis rotors, such as the familiar farm windmills, have their axis of rotation parallel to the direction of the windstream. The NASA design

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(shown in Fig. 1) is a conventional two-bladed propeller machine scaled for power levels from 100 to 2000 kW. The rotor designed for the 100- to 200-kW range measures 37.5 m, tip to tip. Rotor and generator are mounted on a 30-m tower, with the rotor downwind of the tower. The experimental 200-kW prototype reaches full power in a 10-m/s wind. Larger machines will be necessary for economical power production. For example, at a wind speed of 14 m/s, a 61-m-diam rotor placed about 50 m above ground would produce 2 MW of power.

We can use existing technology to convert wind energy to electrical power, but the present energy cost is high, too high to risk locating an expensive generator in a dead spot. The energy in the wind goes as the cube of the speed—a 26% increase in wind speed doubles the energy—making it very important to be accurate in characterizing the winds at prospective sites. We are most interested in areas with winds around 10 m/s within about 150 m of the surface.

However, estimating the wind-energy distribution in complex terrain is very difficult. Winds flow in complicated patterns through hilly areas; in rugged coastal areas they are also influenced by the interaction of land and sea. On the other hand, it is just these coastal hills and mountain regions that often have the highest wind-power potential. This means that we must develop accurate models of the wind patterns if we are to find the best wind-power sites.

We chose the island of Oahu, Hawaii, as our initial study area because it is isolated, almost completely dependent on imported fossil fuel, and has a major city with large energy demands. Its strong, steady trade winds blowing in from the ocean and

Fig. 1. A 200-kW experimental wind turbine generator built by NASA for ERDA. The blades on this prototype are 37.5 m in diameter; the rotor and generator are mounted on a tower 30 m above the ground. For large-scale power production in high wind-speed areas (about 14 m/s), machines rated at 2 MW each would have blades almost twice this size, about 61 m in diameter.

its mountains rising from the sea provide an ideal location—a natural wind-tunnel model free from the complications of surrounding terrain—for exploring the effects of rugged terrain and developing analytical techniques for modeling wind behavior. The procedures that we develop here for assessing wind energy should be suitable for other regions as well.

FIELD MEASUREMENTS

We began our work by surveying existing wind measurement records from nine stations on the island. Such records can be misleading, however; many of these observations are from airports, for instance, and airport builders generally avoid windy areas. Also, since none of these records was originally designed for wind-energy analyses, their locations, frequency of reporting, and methods of recording were sometimes unsuitable for our studies. Some of these measurements were from stations reporting only twice a day—a meager sampling compared to the hourly readings we take.

However, these records were adequate to establish that July brought the strongest trade winds, and we selected measurements of the most frequent July wind speed and direction at each station as input for preliminary modeling. Computer calculations indicated that significant wind enhancement should occur in the northern parts of Oahu where few wind data had been reported.

We then analyzed subareas in the northern section, especially around Kahuku Point and Kaena Point, to locate sites with potentially high wind energies for our field measurements. Siting equipment to measure wind power requires much care because of the many variables that can affect the measurement, especially in rough terrain. The earth's surface offers significant wind resistance, so that wind speeds near the surface are much slower than winds aloft. Another significant effect—particularly relevant to the topography of Oahu—is that the wind's streamlines are compressed and its flow accelerated as it passes over a hill or through a narrow valley. On Oahu the wind first encounters

the steep Koolau (windward) mountain range, flows over and around it, crosses a broad valley, and finally strikes the Waianae (leeward) range. Each of these obstacles has its effect on the local wind velocity.

In August 1976 we installed conventional anemometers for recording wind speed and direction at Laie, Kahuku, Waialua, and Mokuleia, all in northern Oahu. Figure 2 is a typical set of observations from these sites: mean hourly wind speed and direction during a three-day period in August. The Laie readings, taken at sea level, show the directional steadiness typical of the trade winds. Mean hourly wind speeds at Kahuku, less than 10 km away in the hills of the windward range near a calculated wind speed maximum, were about twice those at Laie, easily exceeding throughout the three days the 10 m/s required for full-rated-capacity performance of NASA's prototype 200-kW wind turbine. The wind direction is also remarkably steady, ideal for wind-energy conversion.

At our two other measuring sites the winds were gentler and more variable. At Waialua, between the windward and leeward ranges, the wind almost died away early every morning and once even reversed direction. At Mokuleia also, on the ridge of the leeward mountain range, there were alternate periods of wind and relative calm. All these measurements point to the Kahuku area in particular as a good site for future large-scale wind-power conversion.

In addition to our conventional instruments we also used a laser anemometer that, instead of measuring wind at one point, averages wind speed across a long line of sight. This permits us to measure the average wind between hilltops or between a hilltop and sea level a few kilometres away without setting up equipment on a series of high towers.

The laser scintillation anemometer consists of a 5-mW He-Ne laser and a distant receiver. The beam, when it first leaves the laser, is coherent. As it moves through the air, however, natural variations in temperature introduce refractions—the same effect that makes stars twinkle and hot asphalt roads appear to

Fig. 7. Mean hourly wind speeds and directions at our four observation points in northern Oahu over a three-day period, starting at midnight. The winds at Kahuku are strong and steady, and have a constant heading. At Laie, on the coast, the winds are nearly as steady, but only about half as strong. Elsewhere, as at Mokuleia on the leeward ridge and at Waialua in the valley, the winds are more variable in speed and direction.

shimmer. By the time the beam reaches the receiver it contains scintillations, shifting patterns of bright spots caused by overlapping wavefronts, whose motion across the field of view correlates with the average wind speed across the line of sight. In the receiver two tiny photodetectors sample the beam. Simple electronics detects the differences between the two photodetector signals and translates them into wind speed. These laser scintillation measurements confirmed that intensified wind speeds were not merely local, but occurred over distances of 1 km or more. Such locations, where high wind speeds persist over large areas, offer the best potential for energy conversion.

WIND MODELING

The object of all these measurements is to help locate the best sites for a large number of wind-power machines. Strictly speaking, each measurement tells us only the character of the wind at a particular spot (or along a particular line) on a particular day. It is obviously impractical to cover a large area with hundreds of anemometer towers in the hope that some of them will be located in the best sites. Instead we must have some means of predicting what the winds will be all over a large region.

The tool that makes this possible is the high-speed computer, coupled with our numerical model that describes how winds behave. The model starts with a few basic assumptions:

- At high enough altitudes, the wind will blow straight and level, as if there were no mountains; conversely, near the ground, hills and valleys have large effects.
- As much air blows out of a region as blows in; no air is being generated or used up inside the region.
- Differences in air pressure from point to point throughout the region (at any given elevation) are small compared to the overall air pressure for that elevation.

To these assumptions we add a digitized map of the terrain, the locations of the anemometers, the

heights of their towers, and the observed wind speeds and directions.

The first step for the calculation is to adjust for differences in anemometer tower height. This revises the wind data to what it would have been if all measurements had been taken at the same height above the ground (as listed on the digitized map). The computer then goes over the whole map, filling in a reasonable first guess at the wind velocity at a large number of points scattered over the surface of the map and in the air above. In this process the computation is guided by the principle that intermediate points between places where different winds were measured should have intermediate wind velocities.

In the very top layer of air the wind has a uniform velocity and flows horizontally (the first assumption above). At first the model assumes that all the winds are flowing horizontally. After the first approximate velocity field is finished, the computer iterates, this time including updrafts and downdrafts to conform to the terrain and adjusting the horizontal and vertical winds accordingly to yield a self-consistent flow pattern in which air neither accumulates nor disappears (the second and third assumptions above).

SITE ANALYSIS

Once we have generated a full, three-dimensional, self-consistent map of wind flow, we can use the computer program to determine wind speeds and direction at selected points, flow lines of horizontal velocities, and isotachs (contour lines of equal horizontal wind speed). Typically, we edit these quantities at selected heights within 150 m. of the ground.

Figure 3 shows isotachs derived in this way from our recent wind measurements. The pattern of wind speeds shown represents the dominant trade wind conditions over Oahu. The areas at Kuaena Point and Kahuku Point appear especially promising for sustained wind power production, since they show consistent wind speeds of about 15 m/s.

A complete analysis of the wind energy potential in a given location must include an estimate of wind variability, since a moderate, steady wind might provide more useful power than one that is violent but gusty. We must design turbines to attain their rated output far below the maximum wind expected and to maintain this same output even when the wind blows much harder. This may mean that much of the energy in large gusts is wasted, but that is bet-

ter than having a large, expensive turbine operating below its capacity most of the time. If we know that the winds in a particular spot will be relatively steady, we can design the turbine to use more of the wind's potential because we need less allowance for slack winds.

Trade wind conditions persist over Oahu about 90% of the time, but in the remaining 10%, southerly winds, generally accompanied by storms and very

Fig. 3. A refined wind map of Oahu, showing the dominant trade wind pattern. Areas are shown where steady, high wind speeds favor wind energy conversion. This map shows isotachs of the adjusted wind speeds 120 m above the ground between 5 and 6 p.m. on August 12, 1976. This map was produced by our wind model based on our simultaneous measurements at four locations in northern Oahu (open squares) and other available data. Preexisting sources of wind speed records are shown as black squares. Mountain ridges are depicted by the chains of dots.

high wind velocities, occur. During these conditions, the wind flow direction and the distribution of high- and low-speed areas are considerably different from the trade patterns. Figure 4 shows isotachs taken in one of the storm periods in November 1976. As the wind flows from the southwest, the northwest and southeast extremes of the island strongly deflect wind flow, channeling it through the central valley. High wind speeds are shown in both the Kaena and Makapuu areas, while

low speeds occur along the northeast coast and to the southwest of the Waianae range. Kaena Point is exposed to the extremes of the storm winds while, in contrast to trade conditions, the Kahuku area is largely sheltered.

This less common wind orientation has significant implications for siting of wind machines: during the *normal* trade wind conditions, Kahuku provides a good site for steady, strong winds and during the storm season is protected from the very

Fig. 4. A refined wind map, showing the infrequent storm wind pattern over Oahu. Low wind speed areas are indicated where wind turbines would be sheltered from extreme winds. This map shows isotachs of the adjusted wind speeds 120 m above the ground between 1:00 and 2:00 a.m. on November 24, 1976. These measurements were taken during the winter storm season, when the wind flow is from the southwest. Note that although Kaena Point is exposed to strong storm winds, Kahuku Point is protected and receives only moderate wind flow.

Table 1. Calculated capacity factors at a height of 61 m for the 100-kW- and 1-MW-class wind turbines.

Location	Average velocity, m/s	Capacity factors	
		100 kW	1 MW
Kahuku	11.1	0.93	0.66
Barbers Point	7.7	0.82	0.34
Kaneohe	5.1	0.53	0.11
Wheeler	3.8	0.32	0.09
Midwestern U.S. (maximum value)	—	0.70	0.30

high winds that might unexpectedly damage equipment.

To derive additional useful information from these concepts, we convert the sum of measurements at a site into a figure of merit defined as *capacity factor*—the fraction of a turbine's rated power that it could deliver at a particular site. Sites with strong, steady winds have high capacity factors; sites with weak or variable winds have low factors. An ideal site would have a capacity factor of 1.

Table 1 contrasts the average wind velocities and the capacity factors at four sites on Oahu and for the best of midwestern U.S. sites. Of the four Hawaiian sites, one is our measuring station at Kahuku and the other three are airfields. Note the superiority of the Kahuku site, especially as a location for 1-MW turbines.

Table 1 underscores the following points:

- The Kahuku area, located by the LLL work, is even better than the best sites in the midwestern U.S.
- The airport data on Oahu show the great variation in capacity factor that occurs within a radius of only 22 km because of the complex terrain of Oahu.
- The airport data alone would not have identified the Kahuku area, and would have underestimated the energy resource.

- The airport data plus our computer model and field measurements have successfully identified the major energy resource at Kahuku.

Our wind assessment effort has produced a practical wind model of Oahu that is also applicable for wind studies in other mountainous areas. From our studies of Oahu under both trade-wind and storm conditions, we have located promising sites for large-scale wind-power production. Kahuku Point seems especially favorable since it has the advantages of a high capacity factor and a sheltered location during winter storms. We have also begun to develop the tools that enable us to predict wind-power potentials over extended regions.

As we continue to develop our wind model and assessment methods, we will be using statistical summaries to document the wind potential at specific sites and refining our model calculations to pinpoint high wind locations for further measurements. In addition we will be setting up the initial data base for the next mountainous area selected for study. By the time wind machines are ready for installation, our siting techniques will enable us to predict locations which will be best suited to meet the energy needs of different regions.

Key Words: anemometers; laser beams—effects of turbulence; numerical analysis; winds—measurement; wind power; wind turbines.

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NOTICES

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